FREQROL

MITSUBISHI
TRANSISTORIZED INVERTER

TECHNICAL NOTE

No. 24

CAPACITY SELECTION FOR CYCLIC OPERATION

MITSUBISHI

CONTENTS

CHAPTER 1 DEFINITION OF CYCLIC OPERATION AND POINTS OF CAPACITY SELECTION

1.1 Definition of Cyclic Operation

Operation patterns are largely classified by operation time are divided into constant-speed long operation and repeated short operation (cycle of start → low speed → deceleration to a stop).
The former is referred to as "continuous operation" and the latter as "cyclic operation".
Continuous operation and cyclic operation are roughly classified under the condition of the following frequency of operations (operation time):

Operation	Frequency of Starts/Stops (Operation Time)	Applicable Information
Continuous operation	Less than 10 times/hour	Technical Note No. 23
Cyclic operation	10 or more times/hour	(This manual)

<Data needed for selection> **Technical Note No. 22 "Capacity Selection: Data Part".**

1.2 Points for Capacity Selection

(1) Motor can be started.
When a motor is run by an inverter, the starting torque is smaller than when it is run from a commercial power supply. Therefore, the point is to select the motor and inverter capacities so that the motor is not unstartable.

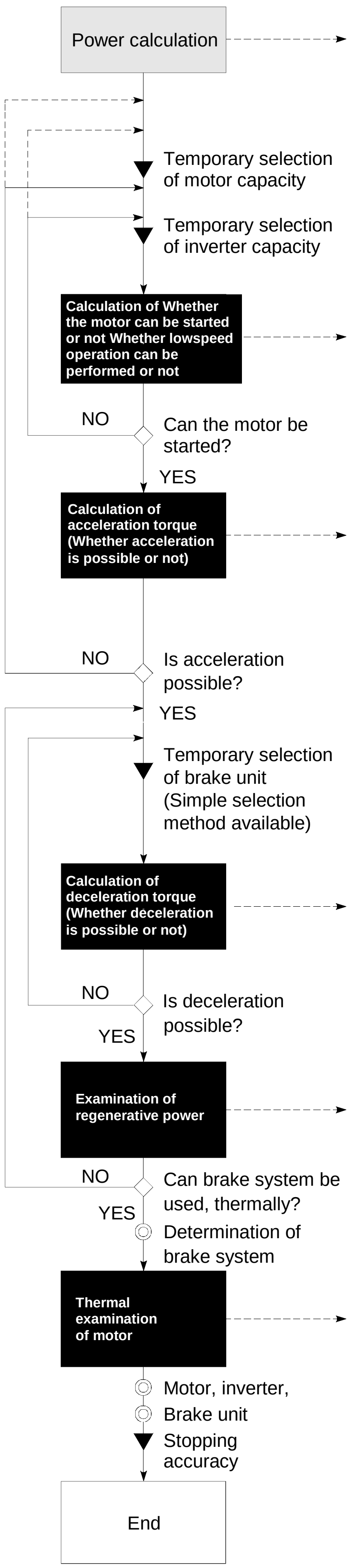
(2) Motor can be operated at low and high speeds.
The point is to select the combination of motor and inverter capacities which will make the output torque of the motor larger than the load torque during low-speed and high-speed operations.

(3) Select the inverter capacity in consideration of acceleration and deceleration capabilities.
During acceleration/deceleration, the motor current is larger than during constant speed. Hence, the inverter capacity which will endure this current must be selected. The magnitude of the current during acceleration/deceleration is determined by not only the load specifications (load torque, GD^2, speed) but also the acceleration/deceleration time in the operation pattern.
Also, since the capability of handling (consuminng) regenerative power is required for deceleration, a brake option such as a brake unit or regenerative converter may be needed.

(4) Permissible temperature of the motor should not be exceeded during operation.
Make sure that the equivalent current value of the motor is within 100% in a single-cycle operation.

CHAPTER 2 SELECTION PROCEDURE

2.1 Selection Flowchart



Selection Outline	Judgment	Refer To page
$P_L = \dfrac{\mu \times W \times V}{6120 \times \eta}$ [kW] Also calculate load torque and GD^2.	Temporarily selected motor capacity $P_M \geq P_L$	5
(1) Select the motor capacity greater than the required power.		
(1) Select the inverter corresponding to the motor capacity. (2) If necessary, increase the inverter capacity to increase acceleration torque.	Temporarily selected inverter capacity $P_{INV} \geq P_M$	
• Make sure that the starting torque and low-speed torque of the motor are larger than the load torque. δ: Motor heat coefficient	$T_{MS} > T_{LS}$ $T_M \times \alpha m \times \delta > T_{LS}$	6
• Calculation of relationship between acceleration and acceleration time • Acceleration torque $Ta = \dfrac{\Sigma GD^2 \times N\max}{38.2 \times ta}$ [N • m] 375 [kgf • m] • Calculate the torque required for acceleration. αa: Linear acceleration torque coefficient	$\alpha a > \dfrac{Ta + T_L\max}{T_M}$	7
• Deceleration torque $Td = \dfrac{\Sigma GD^2 \times N\max}{38.2 \times td}$ [N • m] 375 [kgf • m] • Calculate the torque required for deceleration. βmin: Brake torque coefficient	$\beta \min > \dfrac{Td - T_L\min}{T_M}$	9
(1) Check the short-time permissible power. (2) Check the average regenerative power. W_{INV}: Power returned to the inverter td: Deceleration time during 1 cycle tc: Time in the whole 1 cycle	$W_{INV} < W_{RS}$ $W_{INV} \times td / tc < W_{RC}$	11
Make sure that the equivalent current value does not exceed 100%. $I_{MC} = \sqrt{\dfrac{\Sigma(In^2 \times tn)}{\Sigma(Cn \times tn)}} < 100$ [%]		14
• Calculate the stopping accuracy provided by the mechanical brake.		17

Note: The unit is expressed in the SI systems of units. The half-tone screen indicates the gravitational systems of units.

2.2 Specification Symbols Related to the Load and Operation

Table 2.1 List of Specification Symbols and Units

Specifications		Symbol	SI Units	Gravitational Units
Machine side specifications	Required power	P_L	kW	kW
	Motor capacity	P_M	kW	kW
	Number of motor poles	P	——	——
	Motor speed	N	r/min	rpm
	Frequency	f	Hz	Hz
	Moving velocity	V	m/min	m/min
	Load weight (moving object weight)	W	kgf	kgf
	Machine efficiency	η	——	——
	Friction coefficient	μ	--	--
	Load torque converted into the equivalent value at the motor shaft	T_L	N·m	kgf·m
	Load torque at start converted into the equivalent value at the motor shaft	T_{LS}	N·m	kgf·m
	Load GD^2 converted into the equivalent value at the motor shaft	$GD^2{}_L$	kgf·m²	kgf·m²
	GD^2 of mechanical brake converted into the equivalent value at the motor shaft	$GD^2{}_B$	kgf·m²	kgf·m²
	Cycle time (1 cycle)	t_c	s	s
	Time in each operation zone	t_n	s	s
	Acceleration time	t_a	s	s
	Deceleration time	t_d	s	s
	Acceleration	A_{cc}	m/s²	m/s²
Specifications used for examination	Rated motor speed	N_M	r/min	rpm
	Rated motor torque	T_M	N·m	kgf·m
	Maximum motor starting torque	T_{MS}	N·m	kgf·m
	Acceleration torque	T_a	N·m	kgf·m
	Deceleration torque	T_d	N·m	kgf·m
	Load torque factor	TF	%	%
	Motor GD^2	$GD^2{}_M$	kgf·m²	kgf·m²
	Short-time maximum torque coefficient	α_m	——	——
	Maximum starting torque coefficient	α_s	——	——
	Linear acceleration torque coefficient	α_a	——	——
	Brake torque coefficient (general term)	β	——	——
	Heat coefficient	δ	——	——
	Cooling coefficient	C	——	——
	Motor current	I	%	%
Regenerative power	Motor equivalent current value	I_{MC}	%	%
	Average power absorbed by the motor	W_M	W	W
	Average power returned to the inverter	W_{INV}	W	W
	Average power returned from the machine	W_{MECH}	W	W
	Continuous permissible power of the brake unit	W_{RC}	W	W
	Short-time permissible power per one operation of the brake unit	W_{RS}	W	W
Stopping accuracy	Stopping time	tb	s	s
	Stopping distance	S	mm	mm
	Stopping accuracy	$\Delta\varepsilon$	mm	mm

Note: (1) Symbols followed by max and min (example: T_{Lmax}) indicate maximum and minimum values respectively.

(2) Symbols with subscripts $_1$, $_2$, $_3$ and n (example: I_1, I_2) indicate amounts represented by the symbols under different conditions.

CHAPTER 3 SELECTION PROCEDURE

3.1 Calculation of Load Power

(1) Required power (P_L)
Required power (P_L) is generally found by the following formulae:

SI systems of units

$$P_L = \frac{\mu \times W \times V}{6120 \times \eta} = \frac{T \times N}{9550} \quad \text{[kW]}$$

Gravitational systems of units

$$P_L = \frac{\mu \times W \times V}{6120 \times \eta} = \frac{T \times N}{974} \quad \text{[kW]}$$

W	: Load weight (moving object weight)	[kgf]
V	: Moving velocity	[m/min]
μ	: Friction coefficient	
η	: Machine efficiency	
T	: Load torque converted into the equivalent value at the motor shaft	[N•m]
	(N/9.8)	[kgf•m]
N	: Motor speed (at moving velocity V)	[r/min]

(2) Load torque converted into the equivalent value at the motor shaft (T_L)
This torque is a load condition essential to selection.
Calculate it with reference to Appendices in Technical Note No. 22.
Linear motion and rotary motion often used in cyclic operation are found by the following formulae:

SI systems of units

For linear motion ⇓ For rotary motion ⇓

Load torque converted into the equivalent value at the motor shaft

$$T_L = \frac{\mu \times 9.8 \times W \times V}{2\pi N \times \eta} = \frac{9550 \times P_L}{N} \quad \text{[N•m]}$$

Gravitational systems of units

For linear motion ⇓ For rotary motion ⇓

Load torque converted into the equivalent value at the motor shaft

$$T_L = \frac{\mu \times W \times V}{2\pi N \times \eta} = \frac{974 \times P_L}{N} \quad \text{[kgf•m]}$$

Point of minimum load torque

To ensure safety, the load torque applied when the inverter is in regenerative operation range should be calculated with the machine efficiency (η) = 1 The load torque at this time is defined as the minimum load torque ($T_L$min).

(3) Load GD^2 converted into the equivalent value at the motor shaft
Like the load torque, this value is calculated with reference to Appendices in Technical Note No. 22 .

	For linear motion ⇓ For rotary motion ⇓
Load GD^2 converted into the equivalent value at the motor shaft	$GD^2_L = 4W\left(\frac{V}{2\pi N}\right)^2 = GD^2_{LO}\left(\frac{N_{LO}}{N}\right)^2$ [kgf•m^2]

GD^2_{LO}	: GD^2 of load rotary shaft	[kgf•m^2]
N_{LO}	: Speed of load rotary shaft	[r/min]
N	: Motor speed	[r/min]

3.2 Temporary Selection of Motor and Inverter

(1) Temporary selection of motor capacity
As the motor capacity (P_M), temporarily select the value equal to or more than the required power (P_L).

> Temporarily selected motor capacity (P_M) ≥ P_L × αp [kW]
> αp: 0.5 to 2.0

When V/F control is selected or GD^2 is large, it is recommended to temporarily select the coefficient of 1.0 or more as αp. If the motor speed (N) during rated load driving is less than the rated motor speed (N_M), the motor torque cannot be utilized to the maximum and the motor capacity increases as indicated by the following expression:

> Temporarily selected motor capacity (P_M) ≥ P_L × αp × N_M/N [kW]

(2) Temporary selection of inverter capacity
Temporarily select the inverter capacity equal to or greater than the temporarily selected motor capacity.

> Temporarily selected inverter capacity (P_{INV}) ≥ temporarily selected motor capacity (P_M) [kW]

When the acceleration torque required is expected to be not less than 1.4 times of the stationary load torque, temporarily select the inverter capacity one rank higher than the motor capacity.

3.3 Examination of Whether the Motor Can Be Started or Not

To start the machine with the inverter-driven motor, the following condition must be satisfied:

> $T_{MS} > T_{LS}$

T_{MS} : Maximum starting torque of the motor [N•m] [kgf•m]
Maximum torque that may be generated within the overcurrent limit of the inverter with the motor shaft locked
Refer to Chapter 1 “How to Use this Data Section” in Technical Note No. 22 .

> $T_{MS} = T_M \times \alpha s \times \delta$

αs : Maximum starting torque coefficient
δ : Heat coefficient Refer to Technical Note No. 22 (Chapter 1 “How to Use this Data Section”).
T_{LS} : Load torque at start [N•m] [kgf•m]
Under the influence of static friction, torque for starting motion from a static state is larger than the stationary load torque. Determine this value after making full examination of the mechanical system.

3.4 Examination of Whether Low and High-Speed Operations Can Be Performed or Not

(1) Whether low-speed operation can be performed or not
It is necessary for the output torque of the motor at starting or jog operation frequency to be larger than the load torque at start.
Since starting is completed at positioning speed (creep speed), low-speed operation can be performed if the motor output torque during low-speed operation is larger than the load torque.

$$T_M \times \alpha m \times \delta > T_L max$$

$T_M \times \alpha m \times \delta$: Short-time maximum torque at low-speed running frequency (20Hz or less)
Refer to Chapter 1 "How to Use the Data Collection" in Technical Note No. 22 .

$T_L max$: Maximum load torque [N•m] [kgf•m]

For the relationship between positioning speed and stopping accuracy, refer to Section 3.9, Chapter 3 (page 16).

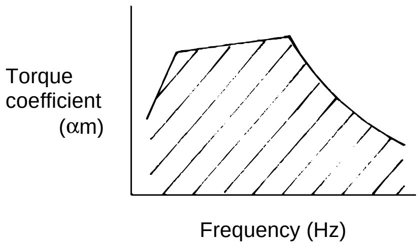
(2) Whether high-speed operation can be performed or not
High-speed operation can be performed if the motor output torque during high-speed operation is larger than the load torque. Check the motor frame size as it limits the maximum frequency.

$$T_M \times \alpha m > T_L max$$

Points about whether a motor can be started, and whether low and high-speed operation can be started or not in a short time period.

Operation can be performed if the motor output torque is larger than the load torque.
Assuming that:
Load torque coefficient = load torque/rated motor torque
operation can be performed if:
Load torque coefficient < torque coefficient αm

For example, operation can be performed if the load torque (coefficient) is within αm in the short-time maximum torque αm characteristic in Chapter 1 "How to Use the Data Collection" of Technical Note No. 22 .



3.5 Whether Acceleration is Possible or Not (Calculation of Acceleration Torque)

Fig. 3.1 shows the relationships between time, speed and torque. Examine whether acceleration can be made up to the maximum speed Nmax in the predetermined acceleration time ta is possible.

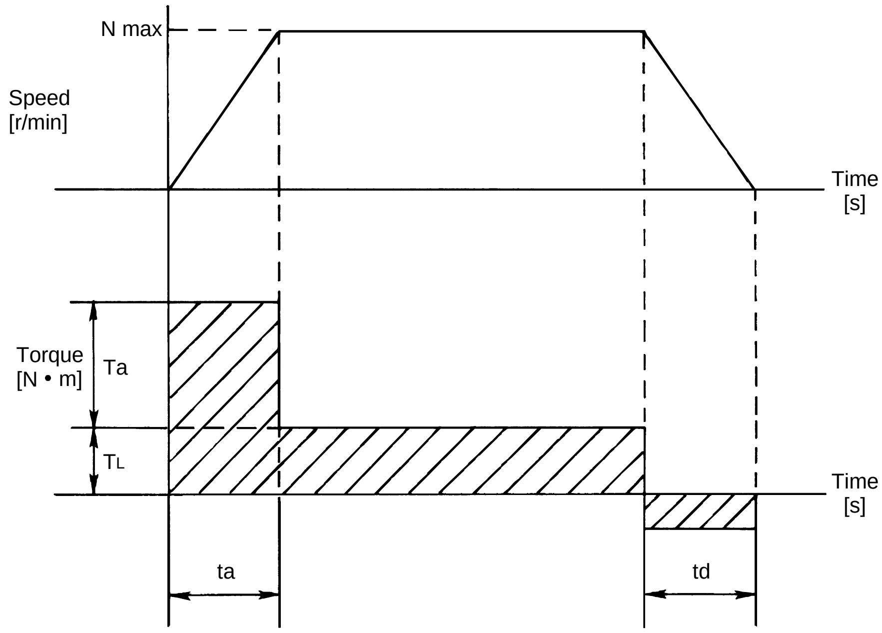


Fig. 3.1 Relationships between Acceleration Time, Speed and Torque

(1) Acceleration time (ta)

Represents a period of time required to accelerate from stop to the maximum speed (Nmax) (maximum moving velocity (Vmax)).

$$ta = \frac{Vmax}{60 \times Acc} \text{ [s]}$$

Vmax : Maximum moving velocity [m/min]

Acc : Acceleration [m/s^2]

Acceleration (Acc) [m/s^2] may sometimes be represented with reference to gravitational acceleration G.

Example : 1G is equivalent to 9.8 [m/s^2].

(2) Acceleration torque (Ta)

Acceleration torque (Ta) is found by the following formulae:

SI systems of units

$$Ta = \frac{\sum GD^2 \times Nmax}{38.2 \times ta} \text{ [N} \bullet \text{m]}$$

Gravitational systems of units

$$Ta = \frac{\sum GD^2 \times Nmax}{375 \times ta} \text{ [kgf} \bullet \text{m]}$$

$\sum GD^2$: Sum total of GD^2 converted into the equivalent value at the motor shaft

$= GD^2_M + GD^2_B + GD^2_L$

(Motor) (Brake) (Load)

(3) Whether acceleration is possible or not

To make sure that the temporarily selected motor output torque is larger than the torque required for acceleration, find the torque coefficient needed for acceleration in accordance with:

Motor output torque		Torque required for acceleration
$T_M \times \alpha a$	>	$(Ta + T_L max)$

Refer to the torque type combination lists on Chapter 2 Driving Capability Data in Technical Note No. 22 according to the temporarily selected motor-inverter combination to find the linear acceleration torque coefficient (αa). If the following formula is satisfied, acceleration is possible:

$$\text{Linear acceleration torque coefficient } (\alpha a) > \frac{Ta + T_L max}{T_M}$$

$T_L max$: Maximum value of load torque converted into the equivalent value at the motor shaft [N•m] [kg•m]

T_M : Rated motor torque [N•m] [kg•m]

αa : Linear acceleration torque coefficient

If the above condition cannot be satisfied, increase the motor output torque by the following means:

1) When V/F control is used, increase the torque boost. Alternatively, use advanced magnetic flux vector control.
2) Make the inverter capacity one rank higher than the motor capacity.
3) Make both the motor capacity and inverter capacity one rank higher.

3.6 Examination of Whether Deceleration Is Possible or Not (Calculation of Deceleration Torque)

In Fig. 3.1, examine whether deceleration can be made from the maximum speed to zero in deceleration time (td).

(1) Deceleration time (td)
Represents a period of time required to decelerate from the maximum speed to zero.

$$td = \frac{Vmax}{60 \times Acc} \text{ [s]}$$

Vmax : Maximum moving velocity [m/min]
Acc : Acceleration [m/s^2]

For deceleration to the creep speed, deceleration time is similarly represented by a period of time required to reach the creep time.

$$td' = \frac{Vmax - Vmin}{60 \times Acc} \text{ [s]}$$

(2) Deceleration torque (Td)
Deceleration torque (Td) is found by the following formulae:

SI systems of units

$$Td = \frac{\sum GD^2 \times Nmax}{38.2 \times td} \text{ [N•m]}$$

Gravitational systems of units

$$Td = \frac{\sum GD^2 \times Nmax}{375 \times td} \text{ [kgf•m]}$$

$\sum GD^2$: Sum total of GD^2 converted into the equivalent value at the motor shaft
$= GD^2_M + GD^2_B + GD^2_L$
(Motor) (Brake) (Load)

(3) Whether deceleration is possible or not
Torque required for deceleration is found by subtracting the load torque from the deceleration torque (Td). Check if the temporarily selected motor-inverter combination (built-in brake resistor or capacitor regeneration) can provide sufficient braking torque.
(Unless otherwise specified, the load torque is calculated under the worst condition, i.e. with the minimum value.)

Torque needed for deceleration ⇓ From $Td - T_Lmin$ < Brake torque of temporarily selected motor-inverter combination ⇓ $T_M \times \beta min$

$$\beta min > \frac{Td - T_Lmin}{T_M}$$

T_Lmin : Minimum value of load torque converted into the equivalent value at the motor shaft [N•m] [kg•m]
T_M : Rated motor torque [N•m] [kg•m]
βmin : Minimum value of deceleration torque coefficient
Refer to Chapter 3 Braking Capability Data in Technical Note No. 22 .

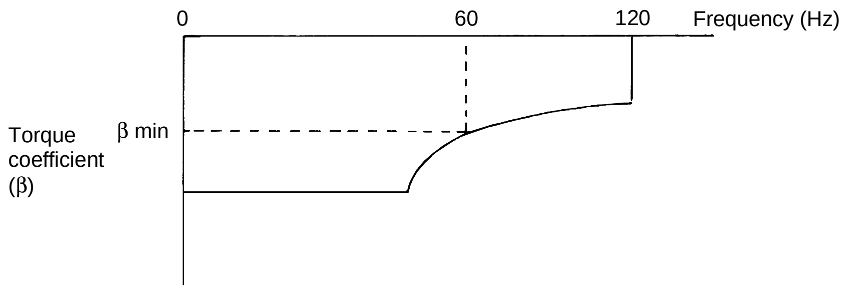
If the above condition cannot be satisfied, increase the braking torque of the motor-inverter combination by the following means. Refer to Technical Note No. 22 :

1) Use an external brake resistor or brake unit.
2) Use a power return converter.

How to find the minimum value of deceleration torque coefficient (βmin)

(1) Refer to Chapter 3 Braking Capability Data and select the inverter-braking unit combination in which the two most significant digits (representing the maximum torque value %) of the torque type is greater than the required brake torque value.

(2) Refer to the brake torque type characteristic charts on Chapter 3 Braking Capability Data and find the torque coefficient for the inverter-braking unit combination selected.



3.7 Examination of Regenerative Power (Thermal Examination of Braking Unit)

Assuming that the operation pattern is as shown in Fig. 3.2, both the short-time power and average power returned to the inverter during one cycle need to be absorbed by the brake resistor.

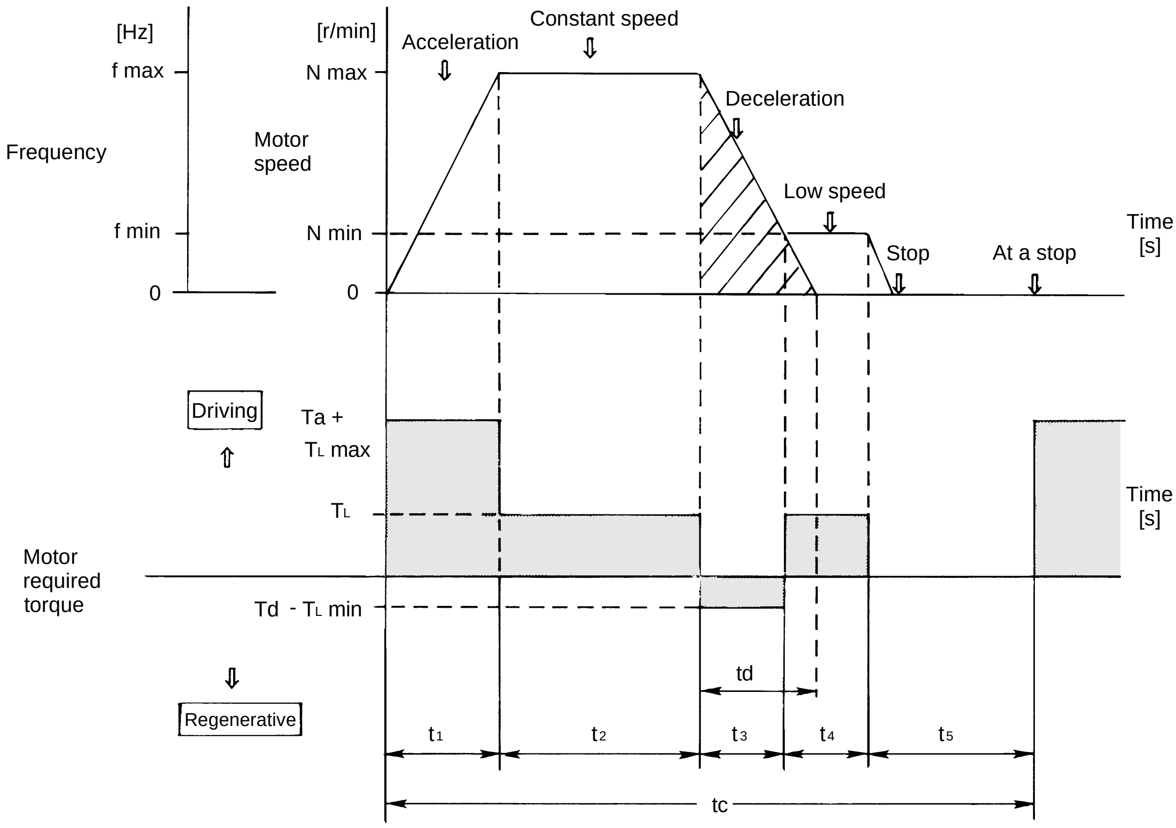


Fig. 3.2 Operation Pattern

(1) Checking the short-time permissible power

Check if the short-time permissible power per operation of the braking unit (W_{RS}) is more than the power returned to the inverter (W_{INV}).

$W_{INV} < W_{RS}$

For W_{RS}, refer to Chapter 3 Braking Capability Data in Technical Note No. 22 .

W_{INV} = (power returned from the load) - (power absorbed by the motor)

$= W_{MECH} - W_M$ [W]

Noting the hatched area in Fig. 3.2, the power returned from the load W_{MECH} is:

$$W_{MECH} = 0.1047 \times (Td - T_L min) \times \frac{Nmax + Nmin}{2} \quad [W]$$

1.027

$$W_M = (K_1 - K_2) \times P_L \quad [W]$$

P_L : Required power for the load [kW]

k_1 : Conversion coefficient at the maximum value of the running frequency (fmax)

k_2 : Conversion coefficient at the minimum value of the running frequency (fmin)

For k_1 and k_2, refer to Chapter 3 Braking Capability Data in Technical Note No. 22 .

(2) Checking the continuous average regenerative power

Check that the average regenerative power during one cycle is less than the continuous permissible power of the brake unit W_{RC}.

$$W_{INV} \times \frac{t_3}{t_c} < W_{RC}$$

For W_{RC}, refer to Technical Note No. 22 .

Comparison and features of the built-in and external brake resistors, brake unit and power return converter

(1) Brake resistor built in the inverter
Brake torque of more than 100% can be provided but the brake duty (%ED) is small (3% or less). Applied to 7.5kW or less.

(2) External brake resistor
The brake torque is identical to that of the built-in brake resistor. Use any of the following models properly according to the brake duty (%ED):

External Brake Resistor Model	%ED
MRS series	3
MYS series	6 to 8
ABR series	10

(3) Brake unit (FR-BU and FR-BR are used as a pair)
Use the brake unit which has a larger capacity than the motor capacity (also increase the inverter capacity) to increase the brake torque. The brake duty (%ED) can be 10% or more.

(4) Power return converter
As described in the brake unit. Further, the brake duty (%ED) can be 50% or more.

Simple method for selecting the brake unit or power return converter

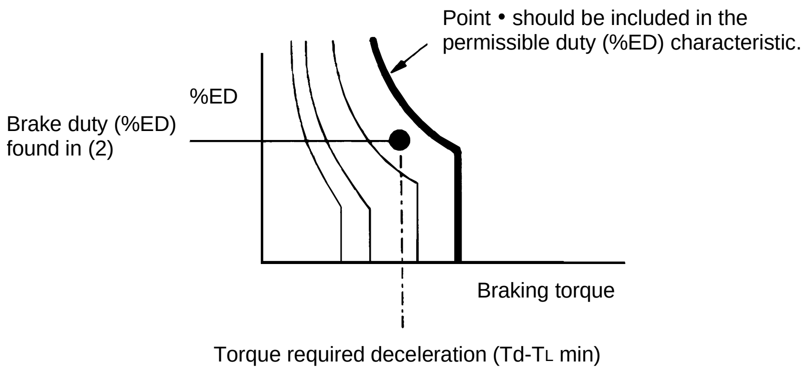
Selection can be made by simply using the permissible brake duty (%ED) characteristic chart.
(For the %ED characteristic chart, refer to Chapter 2 Driving Capability Data in Technical Note No. 22 .)

(1) Find the torque required for deceleration, refer to the braking capability data in Chapter 3 of Technical Note No. 22 , and select the unit which provides brake torque larger than the required torque.
To find the torque required for deceleration, use (Td - $T_L$min).

(2) Find the brake duty (%ED).
In Fig. 3.2,

$$\%ED = \frac{t_3}{t_C} \times 100 \ [\%]$$

(3) Then, refer to the permissible brake duty (%ED) characteristic charts on onwards in Chapter 3 Braking Capability Data of Technical Note No. 22 and make sure that the (%ED) of the unit selected satisfies the permissible brake duty (%ED).



3.8 Thermal Examination of the Motor

(1) Whether the motor can be used thermally according to the equivalent current value of the motor
Find the current in each operation zone in cycle time and make sure that the average (RMS) current, (found by root-mean-squaring all currents) is within the rated current value of the motor.

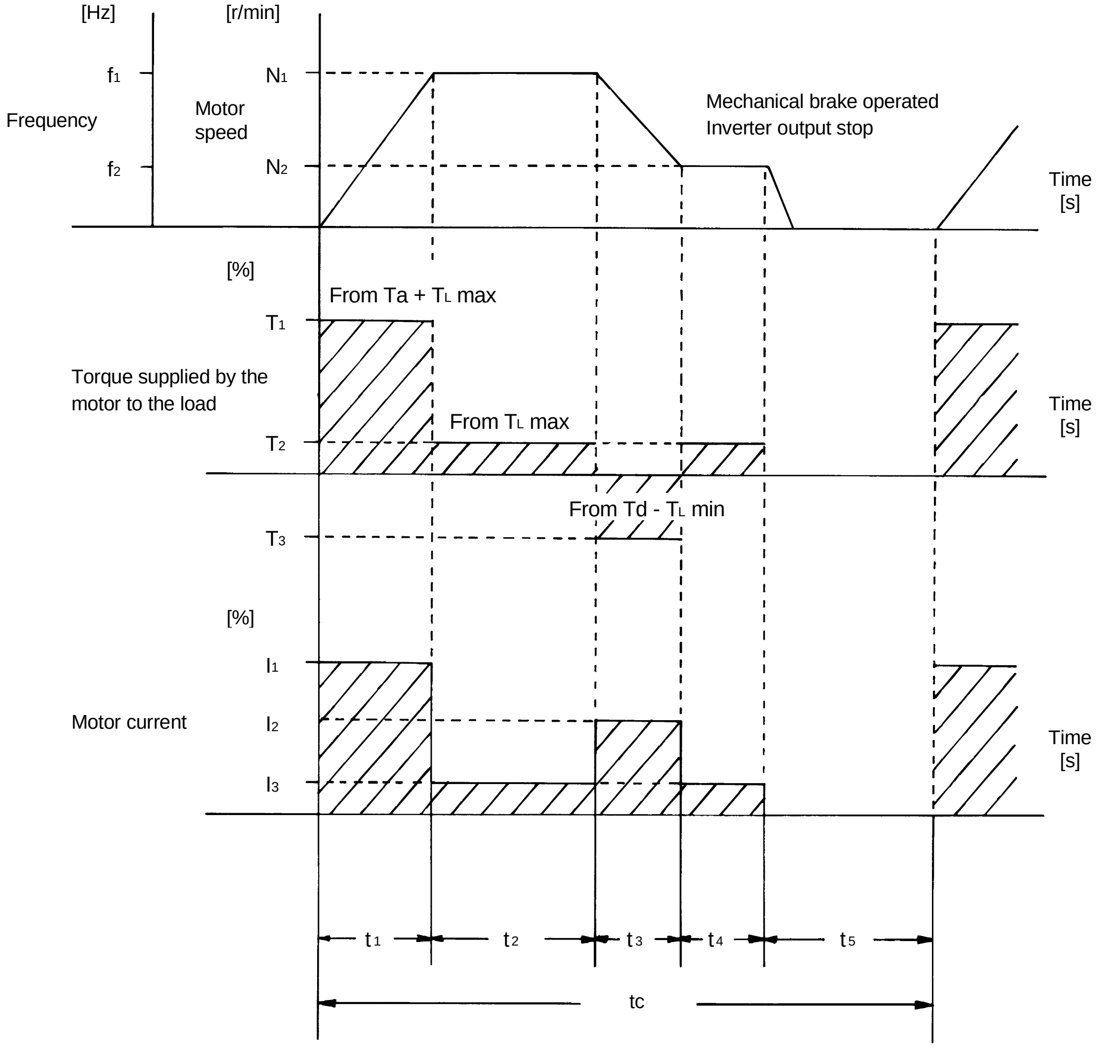


Fig. 3.3 Operation Pattern

If the following formula is satisfied, the motor can be used, thermally.

$$I_{MC} = \sqrt{\frac{I_1^2 \times t_1 + I_2^2 \times t_2 + \cdots\cdots\cdots + In^2 \times tn}{C_1 \times t_1 + C_2 \times t_2 + \cdots\cdots\cdots + Cn \times tn}} < 100\%$$

I_{MC}	: Motor equivalent current value in consideration of the cooling coefficient	[%]
I_1, I_2, ... In	: Motor currents in operation zones t_1, t_2,...tn	[%]
C_1, C_2, ... Cn	: Cooling coefficients for frequencies f_1 to fn in operation zones t_1, t_2,...tn	

(2) How to find motor currents I_1, I_2, ... In [%]
In the following procedure, find (a) torque in each operation zone, calculate (b) load torque factor, then refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22 and find the motor current [%] corresponding to the load torque factor.

(a) Refer to the following list and find the torque supplied by the motor to the load in each operation zone:

Zone Time [s]	Torque Supplied to the Load [N•m] [kgf•m]
t_1	$Ta + T_L max$
t_2	$T_L max$
t_3	$Td - T_L min$
t_4	$T_L max$
t_5	0 because of the stop zone

(b) Find the load torque factor.

$$\text{Load torque factor (TF)} = \frac{\text{torque supplied to the load}}{\text{rated torque of the motor } (T_M)} \times 100 \ [\%]$$

In the constant-output region (region higher than the base frequency, e.g. 60 to 120Hz) of the motor, the load torque factor TF is as follows:

Load torque factor at higher than the base frequency (TF)

$$= \frac{\text{torque supplied to the load}}{\text{rated torque of the motor } (T_M)} \times \frac{\text{running frequency}}{\text{base frequency}} \times 100 \ [\%]$$

(c) How to find the motor current
Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22 and find the motor current [%] corresponding to the load torque factor found in (b).
If the maximum frequency is higher than the base frequency during acceleration/deceleration, multiply the found motor current value by the current compensation coefficient (k60 or k50) (Chapter 4 Motor and Brake Characteristics in Technical Note No. 22).

Motor current [%] = (k60 or k50) × current value found in Chapter 4 Motor and Brake Characteristics in Technical Note No. 22

(3) How to find the cooling coefficients C_1, C_2, .. Cn
Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22 .

If the average current is nearly 100%

When a general-purpose motor is driven by the inverter, the motor current increases (about 1.1 times) to provide the same torque as when it is driven with the commercial power supply.
When the equivalent current value of the motor reaches 100%, that of the inverter-driven motor is about 110% therefore a general-purpose motor does not have the thermal allowance. Hence, it is necessary to fully examine the load conditions and operation duty.

3.9 Stopping Accuracy

Stopping accuracy will be explained by an example where a motor is stopped by a mechanical brake with the speed pattern as shown in Fig. 3.4.

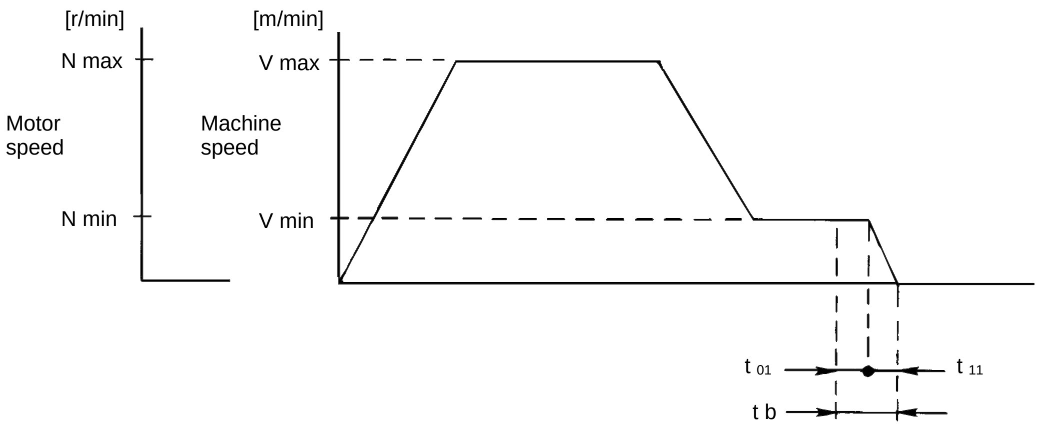


Fig. 3.4 Speed Pattern

(1) Characteristics of the mechanical brake
When the NB brake is used, refer to section 4.5 NB Brake Characteristics in Technical Note No. 22, and find the following constants (when any other brake is used, refer to the characteristic chart of the corresponding manufacturer):

Rated braking torque	: T_B	[N•m]	[kgf•m]
Delay time (independent off)	: t_{01}	[s]	
Brake GD^2	: GD^2_B	[kgf•m^2]	

(2) Stopping accuracy when the motor is running at low speed (creep speed) and is brought to a stop
Use the following formulae to find the stopping time and stopping distance and estimate the stopping accuracy:

Stopping time (tb) = delay time (t_{01}) + braking time (t_{11})

$$= t_{01} + \frac{(GD^2_L + GD^2_M + GD^2_B) \times Nmin}{38.2\,(T_B + T_L min)} \quad [s]$$

375

Stopping distance (S) = S_{01} + S_{11}

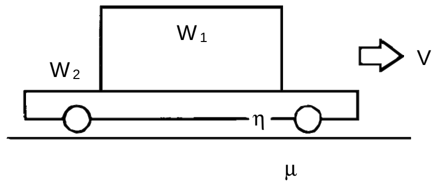
$$= \left(t_{01} \times \frac{Vmin}{60} + t_{11} \times \frac{1}{2} \times \frac{Vmin}{60}\right) \times 10^3 \quad [mm]$$

Vmin : Speed immediately before stop = corresponding to the motor speed (N min) [r/min]
Machine speed [m/min](low-speed operation speed = creep speed)

Guideline of stopping accuracy

Find using: $\Delta\varepsilon = \pm S/2$ [mm].

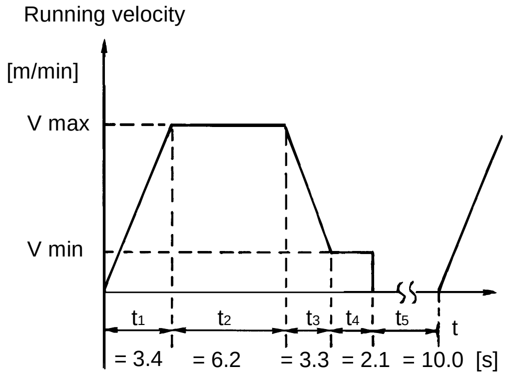
4.1 Selection Example for an Automated Guided Vehicle



(1) Calculation example of load power

<Machine specifications>

Loading weight	W_1 : 2.5 tons (2500kg)
AGV weight	W_2 : 800kg
Total weight (moving object weight)	W : 2500+800=3300kg
Running velocity	V : 100m/min
Motor speed at above velocity	N : 1500r/min
Minimum running velocity (Jog operation and creep speed)	Vmin : 3m/min
Wheel running resistance	μ : 0.05
Running resistance at start	μmax : 0.08
Machine efficiency	η : 0.75



Speed pattern

(2) Calculation of load specifications

Calculate the load specifications required for calculation from the machine specifications.

(a) Load required power

$$P_L = \frac{\mu \times W \times V}{6120 \times \eta} = \frac{0.05 \times 3300 \times 100}{6120 \times 0.75} = 3.60 \quad [\text{kW}] \tag{4.1}$$

(b) Load torque converted into the equivalent value at the motor shaft

During high-speed operation

W　　3300　　2.33 [kgf•m]

$$T_L = \frac{\mu \times 9.8 \times W \times V}{2\pi \eta N} = \frac{0.05 \times 9.8 \times 3300 \times 100}{2\pi \times 1500 \times 0.75} = 22.8 \quad [\text{N•m}] \tag{4.2}$$

At start

W　　3300　　3.73 [kgf•m]

$$T_{LS} = \frac{\mu_{max} \times 9.8 \times W \times V}{2\pi N \eta} = \frac{0.08 \times 9.8 \times 3300 \times 100}{2\pi \times 1500 \times 0.75} = 36.6 \quad [\text{N•m}] \tag{4.3}$$

(c) Load GD^2 converted into the equivalent value at the motor shaft

$$GD^2_L = 4W\left(\frac{V}{2\pi N}\right)^2 \tag{4.4}$$

$$= 4 \times 3300\ (100/(2\pi \times 1500))^2 = 1.49 \quad [\text{kgf•m}^2]$$

(3) Temporary selection of motor capacity

Temporarily selected motor capacity ≥ $P_L \times \alpha p$ = 3.60 × 1.5 = 5.4 [kW]　1.5 temporarily selected as αp.

Hence, 5.5[kW] 4P is selected temporarily.

Rated torque of the temporarily selected motor

$T_M = 9550 P_M / N_M$

974

(For 60Hz rating basis)

=9550 × 5.5/1800 = 29.2 [N•m]

974　　2.98 [kgf•m]

GD^2 of the temporarily selected motor

GD^2_M = 0.11 [kgf•m²]

From Table 4.2 Totally Enclosed, Fan Cooled Type Characteristic Chart in Chapter 4 Motor and Brake Characteristics in Technical Note No. 22

(4) Temporary selection of inverter capacity

Temporarily select the inverter capacity identical to the temporarily selected motor capacity.
Assume that the FR-A520-5.5K has been selected.
Since the variable speed range is relatively large, V: 100m/min to Vmin: 3m/min = 33.3:1, suppose that operation is performed under advanced magnetic flux vector control.

Note

1. Variable speed range of the motor
   Due to its structure (cooling, bearings, reduction gear, etc.), there are restrictions on the variable speed range of the motor driven by the inverter. Refer to the Appendices in Technical Note No. 22.

2. The load required power is not identical to the motor capacity!
   For constant-torque loads such as conveyors, when the motor speed at running velocity (machine moving velocity) is not more than the rated motor speed, the motor capacity has the following relationship:

$$\text{Motor capacity} = \text{load required power} \times \frac{\text{rated speed of motor } (N_0)}{\text{motor speed at running velocity (machine moving velocity) (N)}}$$

   (where $N_0 \geq N$)
   If $N_0 \leq N$, the motor capacity is basically equal to the load required power because the constant-output region of the motor is used.

3. Variable speed range and machine reduction ratio
   The variable speed range of the general-purpose motor varies with the motor capacity and the number of poles. Refer to the Appendices in Technical Note No. 22. Increasing the reduction ratio to increase the inverter frequency reduces the load torque and load GD^2 at the motor shaft and gives the following advantages:
   1. The motor can be started easily.
   2. The motor can be used continuously down to low speed.
   3. The variable speed range can be expanded.

(5) Whether the motor can be started or not

(a) Required starting frequency
The operating frequency range is found with the following procedure:
The motor speed is 1500r/min at V of 100m/min.
According to N = 120f/P, f = NP/120 = 1500 × 4/120 = 50Hz
At the lowest velocity 3m/min, 50/33.3 = 1.5Hz

(b) Motor starting torque (T_{MS})
Refer to Section 2.1.2 Short-time maximum torque coefficient (Chapter 2 Driving Capability Data) in Technical Note No. 22 .

1) As the motor capacity is 5.5kW, advanced magnetic flux vector control is used, and the inverter is FR-A520, select "torque type 15A1".
2) Refer to 1) Short-time maximum torque (αm) on the reference page (Chapter 2 Driving Capability Data) for "15A1".
   As the short-time maximum torque (αm) = 1.5 corresponds to the 1.5Hz frequency at the lowest velocity;

$$T_{MS} = T_M \times \alpha_m \times \sigma$$
$$= 29.2 \times 15 \times 0.85 = 37.2 \quad [\text{N•m}]$$

2.98 ... 3.80 [kgf•m] (4.5)

(c) Load torque at start
According to Section 4.1 (2)(b) on page 17,
$T_{LS} = 36.6$ [N•m]
3.73 [kgf•m]

(d) Analysis of whether the motor can be started or not
As T_{MS} = 37.2 > T_{LS} = 36.6, the motor can be started.
3.80 3.73

(6) Examination of whether low and high-speed operations can be performed or not

(a) Whether low-speed operation (jog, creep speed) can be performed or not

Load torque during low-speed operation: According to formulas (4.2, 4.3),

Continuous operation load torque $T_L = 22.8$ [N•m]

2.33 [kgf•m]

Load torque at start $T_{LS} = 36.6$ [N•m]

3.73 [kgf•m]

According to formula (4.5), the motor starting torque (at 1.5Hz) is: $T_{MS} = 37.2$ [N•m]

3.80 [kgf•m]

As $T_L < T_{LS} < T_{MS}$, low-speed operation can be performed.

(b) Whether high-speed operation can be performed or not

Since the temporarily selected motor 5.5kW 4P has the frame number 132 (according to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22), the motor can be run at up to the maximum operating frequency. Refer to Appendices in Technical Note No. 22 .

Since the motor output torque is larger than the load torque as indicated in the following calculation, the motor can be run at 50Hz.

$T_M \times \alpha m = 29.2 \times 15 = 43.8 > T_L = 22.8$ [N•m]

2.98 4.47 2.33 [kgf•m]

αm: Torque coefficient at high-speed operation (50Hz)

Refer to "torque type 15A1" (Chapter 2 Driving Capability Data) in Technical Note No. 22.

(c) Guideline of stopping accuracy

Assuming that the delay time for a stop is 0.3 seconds, creep speed Vmin = 3m/min. Hence,

$$\text{Delay distance } s = \frac{V\min \times 10^3 \times t}{2 \times 60} = \frac{3 \times 10^3 \times 0.3}{2 \times 60} = 7.5\text{mm}$$

Therefore, the guideline of stopping accuracy is $\Delta\varepsilon = \pm s/2 = \pm 3.75$mm

(7) Examination of whether acceleration is possible or not (calculation of acceleration torque)

(a) Acceleration time (ta)

(b) As acceleration Acc = 0.5 [m/s^2], acceleration time (ta) is:

$$Ta = \frac{V\max}{60 \times Acc} = \frac{100}{60 \times 0.5} = 3.33 \rightarrow 3.4 \text{ [s]},$$

(b) Acceleration torque (Ta)

$$Ta = \frac{\Sigma GD^2 \times N\max}{38.2 \times ta} = \frac{(GD^2{}_L + GD^2{}_M)\, N}{38.2 \times ta}$$

375 375

$$= \frac{(14.9 + 0.11) \times 1500}{38.2 \times 3.4} = 18.5 \text{ [N•m]}$$

375 1.88 [kgf•m]

(c) Torque required for acceleration

$Ta + T_{L\max} = 18.5 + 22.8 = 41.3$ [N•m]

$1.88 + 2.33 = 4.21$ [kgf•m]

(d) Motor output torque

$T_M \times \alpha a = 29.2 \times 14 = 40.9$ [N•m]

$2.98 \times 14 = 4.17$ [kgf•m]

Here, T_M = 29.2 [N•m]............ according to Section 4.1 (3) (page 17)

2.98 [kgf•m]

αa = 1.4........................ According to 3) in Chapter 2 Driving Capability Data "torque type 15A1" in Technical Note No. 22

(e) Whether acceleration is possible or not

$$\text{Torque coefficient required for acceleration } (\alpha) = \frac{Ta+T_{Lmax}}{T_M} = \frac{41.3}{29.2}\left(\frac{4.21}{2.98}\right) = \underline{1.41 > \alpha a = 1.4}$$

Namely, since:

Torque needed for acceleration		Motor output torque
$Ta + T_{Lmax}$ = 41.3 [N•m]	>	$T_M \times \alpha a$ = 40.9 [N•m]
4.21 [kgf•m]		4.17 [kgf•m]

the motor cannot be accelerated, therefore make the inverter capacity one rank higher.
The following examination assumes that the inverter used is the one one rank higher (FR-A520-7.5K).

(f) Linear acceleration torque coefficient for an inverter one rank higher (FR-A520-7.5K)
Refer to the torque type combination list in Chapter 2 Driving Capability Data in Technical Note No. 22 .
As the motor is 5.5kW and the inverter is the FR-A520-7.5K, "select torque type 16U1" (Technical Note No. 22, Chapter 2 Driving Capability Data). The linear acceleration torque coefficient is αa=1.5.

(g) Whether acceleration is possible or not for the inverter one rank higher (FR-A520-7.5K)
As the torque coefficient needed for acceleration α = 1.41 < α a = 1.5, acceleration is possible.

When the motor output torque is compared with the torque needed for acceleration

Motor output torque		Torque needed for acceleration
$T_M \times \alpha a = 29.2 \times 1.5 = 43.8$ [N•m]	>	$Ta + T_{Lmax}$ = 41.3 [N•m]
$2.98 \times 1.5 = 4.47$ [kgf•m]		4.21 [kgf•m]

and therefore torque comparison also indicates that acceleration is possible.

(8) Examination of whether deceleration is possible or not (calculation of deceleration torque)

(a) Deceleration time td

$$td = \frac{Vmax}{60 \times Acc} = \frac{100}{60 \times 0.5} = 3.33 \rightarrow 3.4 \text{ [s]}$$

(b) Deceleration torque td

$$\frac{\Sigma GD^2 \times Nmax}{38.2 \times td \; (375)} = \frac{(GD^2_L + GD^2_M)N}{38.2 \times td \; (375)}$$

$$= \frac{(14.9 + 0.11) \times 1500}{38.2 \times 3.4 \; (375)} = 18.5 \text{ [N•m]} \quad (1.88 \text{ [kgf•m]})$$

(c) Torque required for deceleration and deceleration torque coefficient

1) Torque required for deceleration
$Td + T_{Lmin}$ = 18.5 – 17.1 = 1.4 [N•m]
1.88 – 1.75 = 0.13 [kgf•m]

Information on T_{Lmin}

Here, in consideration of safety, the minimum value of the load torque has been calculated with machine efficiency η = 1.

$$T_{L\,min} = \mu \times 9.8 \times W \times V / (2\pi N) = 0.05 \times 9.8 \times 3300 \times 100 / (2\pi \times 1500) = 17.1 \text{ [N•m]}$$
(3300) (1.75 [kgf•m])

2) Deceleration torque coefficient

$$\beta = \frac{Td - T_{Lmin}}{T_M} = \frac{1.4}{29.2}\left(\frac{0.13}{2.98}\right) = 0.05$$

(When B<0, driving mode deceleration is made and the required maximum torque is calculated by the judgment of whether acceleration is possible or not. Therefore, it need not be judged here.)

(d) Temporary selection of braking unit
As deceleration torque coefficient (β) = 0.05, refer to Chapter 3 Braking Capability Data in Technical Note No. 22 and select the built-in brake resistor as the braking unit and torque type of 12B for the combination of the motor 5.5kW and the inverter 7.5K.

(e) Minimum value of brake torque coefficient (βmin) and whether deceleration is possible or not
Referring to Torque type 12B, 1) 60Hz torque basis in Chapter 3 Braking Capability Data in Technical Note No. 22, the minimum value of the deceleration torque coefficient (β) in the operating frequency range (fmax to fmin = 50 to 1.5Hz) is found as follows:

$\beta min = 1.2$

Hence, the deceleration torque coefficient

$\beta = 0.05 < \beta min = 1.2$

and deceleration is possible.

Comparison of deceleration torque

Minimum value of deceleration torque generated by the motor $T_M \times \beta min = 29.2 \times 1.2 = 35.0$ [N•m]

$2.98 \times 1.2 = 3.58$ [kgf•m]

Torque needed for deceleration $Td - T_{L\,min} = 18.5 - 17.1 = 1.4$ [N•m]

$1.88 - 1.75 = 0.13$ [kgf•m]

As $Td - T_{Lmin} < T_M \times \beta min$, deceleration is possible.

(9) Examination of regenerative power

(a) Power returned from the load

$$W_{MECH} = 0.1047 \times (T_d - T_{L\,min}) \times \frac{Nmax + Nmin}{2} \quad [W]$$

1.027

$$= 0.1047 \times (18.5 - 17.1) \times \frac{1500 + 45}{2} = 113 \quad [W]$$

1.027 1.88–1.75

(b) Power absorbed by the motor
The results of finding k_1 and k_2 from the figure in Chapter 3 Braking Capability Data in Technical Note No. 22 are as follows:
k_1 : 84 when fmax = 50Hz and the reference frequency is 60Hz
k_2 : 2 when fmin = 1.5Hz and the reference frequency is 60Hz
Hence,
$W_M = (k_1 - k_2) \times P_L$
$= (84 - 2) \times 3.6$
$= 295$ [W]

(c) Power returned to the inverter
$W_{INV} = W_{MECH} - W_M = 113 - 295 = -182$ [W]

(d) Comparison between the power returned to the inverter and the short-time permissible power per one operation of the brake unit
According to 120W40 in the characteristic chart for the MRS resistor in Chapter 3 Braking Capability Data in Technical Note No. 22,
When deceleration time (operating time) (t_3) = 3.3 seconds, W_{RS} = 860 [W]
$W_{INV} = -182$ [W] $< W_{RS} = 860$ [W]
As the short-time permissible power is larger than the power returned to the inverter, the inverter can be used.
Note that since the power returned to the inverter is negative (i.e. driving operation state), the regenerative state does not occur. Therefore, as $W_{INV} \leq 0$, regenerative power is all consumed by the motor and is not returned to the inverter. Accordingly, the following items related to the regenerative brake will not be examined. For your reference, however, calculations will be made in the predetermined procedure.

(e) Checking the average regenerative power

$$\text{Average regenerative power} \quad W_{INV} \times \frac{t_3}{tc} = -182 \times \frac{3.3}{25} = -24.0 \quad [W]$$

(f) Comparison between the average regenerative power and the continuous permissible power (W_{RC})
According to Section 4.1 Permissible Power List in Chapter 3 Braking Capability Data in Technical Note No. 22,
W_{RC} of the MRS type 120W40 built-in resistor of the 5.5K inverter is 80 [W].
Average regenerative power = –24.0 [W] < continuous permissible power (W_{RC}) = 80 [W]
Hence, the inverter can be used.

Simple method for selecting the brake unit

(1) Brake duty

$$\%ED = \frac{t_3}{tc} \times 100 = \frac{3.3}{25} \times 100 = 13.2 \quad [\%]$$

(2) Torque needed for deceleration $Td - T_{Lmin} = 1.4$ [N•m]
0.13 [kgf•m]

Deceleration torque coefficient (β) = 0.05 → As brake torque is 5%, the duty %ED of 40% or higher can be found according to the graph for 5.5K and 7.5K in (2) MRS brake resistor in Chapter 3 Braking Capability Data in Technical Note No. 22.
Therefore, %ED = 13.2[%] < duty %ED 40% or higher and the inverter 7.5K can be used.

(10) Examination of whether the motor can be used thermally

(a) Motor torque and motor current value in each operation zone
For zones t_1 to t_5 in the operation pattern, find the corresponding load torque factors with the following formula and find the current characteristic [%] in accordance with Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

$$\text{Load torque factor TF} = \frac{\text{torque supplied to the load}}{\text{rated motor torque } T_M} \times 100 \quad [\%]$$

(T_M = 29.2)
2.98

Then, find the cooling coefficients according to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22 and list them as given below:

Required Time [s]	Torque supplied to the load	Load torque factor	Current characteristic (%)	Cooling coefficient
t_1 = 3.4	Ta + $T_L$max = 41.3 4.21	TF = 141	I_1 = 138	C_1 = 0.75
t_2 = 6.2	$T_L$max = 22.8 2.33	TF = 78	I_2 = 84	C_2 = 1.00
t_3 = 3.3	–Td + $T_L$min = –1.4 –0.13	TF = –5	I_3 = 50	C_3 = 0.75
t_4 = 2.1	$T_L$max = 22.8 2.33	TF = 78	I_4 = 84	C_4 = 0.4
t_5 = 10.0	Due to the stop zone = 0	TF = 0	I_5 = 0	C_5 = 0.4

(b) Motor equivalent current value and judgment of whether the motor can be used thermally
Motor equivalent current value

$$I_{MC} = \sqrt{\frac{I_1^2 \times t_1 + I_2^2 \times t_2 + I_3^2 \times t_3 + I_4^2 \times t_4 + I_5^2 \times t_5}{C_1 \times t_1 + C_2 \times t_2 + C_3 \times t_3 + C_4 \times t_4 + C_5 \times t_5}}$$

$$= \sqrt{\frac{138^2 \times 3.4 + 84^2 \times 6.2 + 50^2 \times 3.3 + 84^2 \times 2.1 + 0^2 \times 10}{0.75 \times 3.4 + 1.00 \times 6.2 + 0.75 \times 3.3 + 0.4 \times 2.1 + 0.4 + 10}}$$

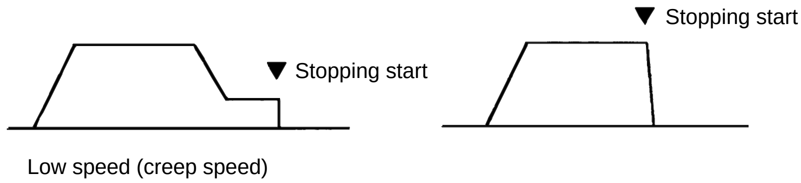
$$= \sqrt{\frac{131564.4}{16.065}} = 90.5 < 100\%$$

Since the motor equivalent current value is within the rating, the motor can be used thermally.
(Note that if $I_{MC} \geq 100\%$, the motor does not have thermal allowance and its equivalent current value will exceed the rating. In this case, the operation pattern must be changed or the motor capacity increased.)

(11) Examination of stopping accuracy

Differences in stopping accuracy between the following two stopping methods will be examined.

When the motor running at low speed (creep speed) is brought to a stop	When the motor running at high speed is stopped by the NB brake



(a) Characteristics of the NB brake

According to (2) Brake characteristics in Chapter 4 Motor and Brake Characteristics in Technical Note No. 22, the NB-7.5C is selected.

NB-7.5C	Rated braking torque	: T_B	= 73.5	[N•m]
			7.5	[kgf•m]
	Delay time (independent off)	: t_{01}	= 0.036	[s]
	Brake GD^2	: $GD^2{}_B$	= 0.062	[kgf•m^2]

(b) Stopping accuracy when the motor is running at low speed (creep speed) and is brought to a stop

Stopping time $\quad tb = t_{01} + t_{11}$

$$= t_{01} + \frac{(GD^2{}_L + GD^2{}_M + GD^2{}_B) \times N\min}{38.2\,(T_B + T_L\min)}$$

375

$$= 0.036 + \frac{(1.49 + 0.12 + 0.062) \times 45}{38.2\,(73.5 + 17.1)}$$

375 7.5 1.75

$$= 0.036 + 0.022 = 0.058 \quad [s]$$

Stopping distance $\quad S = S_{01} + S_{11} \quad$ (creep speed $V\min = 3\text{m / min}$)

$$= (t_{01} \times \frac{V\min}{60} + t_{11} \times \frac{1}{2} \times \frac{V\min}{60}) \times 10^3$$

$$= (0.036 \times \frac{3}{60} + 0.022 \times \frac{1}{2} \times \frac{3}{60}) \times 10^3$$

$$= 0.00235 \times 10^3 = 2.35 \quad [mm]$$

Guideline of stopping accuracy

$$\Delta\varepsilon = \pm S / 2 = \pm 2.35 / 2 = \pm 1.18 \quad [mm]$$

(c) Stopping accuracy when the motor is running at high speed and is stopped suddenly by the NB brake

Stopping time $\quad tb = t_{01} + t_{11}$

$$= t_{01} + \frac{(GD^2{}_L + GD^2{}_M + GD^2{}_B) \times N\max}{38.2\,(T_B + T_L\min)}$$

375

$$= 0.036 + \frac{(1.49 + 0.12 + 0.062) \times 1500}{38.2\,(73.5 + 17.1)}$$

375 7.5 1.75

$= 0.036 + 0.723 = 0.759$ [s]

Stopping distance $\quad S = S_{01} + S_{11}$ (high speed $V\max = 100\text{m} / \text{min}$)

$$= (t_{01} \times \frac{V\max}{60} + t_{11} \times \frac{1}{2} \times \frac{V\max}{60}) \times 10^3$$

$$= (0.036 \times \frac{100}{60} + 0.723 \times \frac{1}{2} \times \frac{100}{60}) \times 10^3$$

$$= 0.663 \times 10^3 = 663 \quad \text{[mm]}$$

Guideline of stopping accuracy

$$\Delta\varepsilon = \pm S / 2 = \pm 663 / 2 = \pm 332 \quad \text{[mm]}$$

Stopping accuracy is greatly improved by decelerating the motor to a slow speed (creep speed) and then stopping it by a mechanical brake (such as the NB brake) than by suddenly stopping the motor running at high speed by a mechanical brake.

4.2 Calculation Examples Using Calculation Sheets

Calculation Sheets <For Gravitational Systems of Units>

1. Machine Conditions Required for Examination

1.1 Voltage and frequency of the power supply: 220 [V] 60 [Hz]

1.2 Machine specifications

Understand the conditions of either the linear motion or rotary motion.

[Linear motion]

(1)	Full weight of the moving part	W	1500	[kgf]
(2)	Velocity of linear motion	V	60	[m/min]
	Corresponding motor speed	N	1800	[rpm]
(3)	Minimum velocity of linear motion	Vmin	5	[m/min]
	Corresponding motor speed	Nmin	180	[rpm]
(4)	Running resistance	μ	0.03	
	Maximum running resistance value	μmax	0.04	
(5)	Machine efficiency	η	0.75	

1.3 Number of poles of the planned motor: 4 [poles]

1.4 Planned mechanical brake: Type NB brake

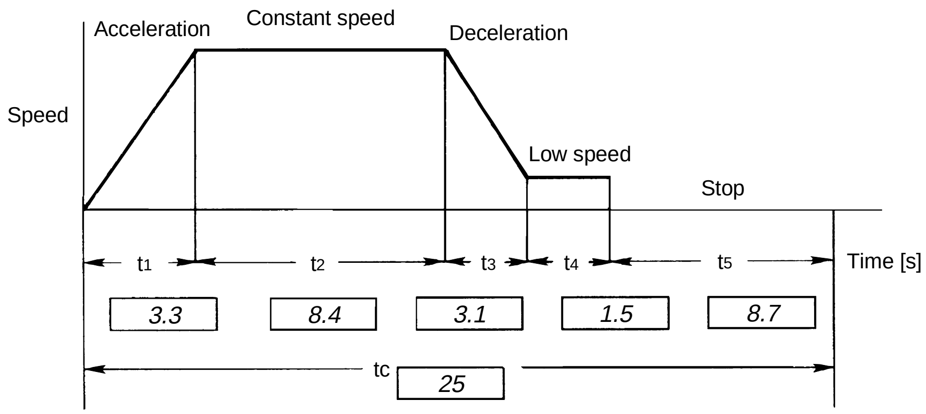
1.5 Between stop and maximum speed

Acceleration time	ta	Acceleration time	3.3	[seconds]		
Deceleration time	td	Deceleration time	3.3	[seconds]		
or Acceleration		Acceleration		[G] or	0.5	[m/s²]

1.6 Repetition time (time of 1 cycle): tc 25 [seconds]

1.7 Stop time during 1 cycle: t_5 8.8 [seconds]

1.8 Operation pattern



2. Calculation of Load Specifications Required for Calculation

(1) Load required power

For linear motion ⇓ For rotary motion ⇓

$$P_L = \frac{\mu \times W \times V}{6120 \times \eta} \left(= \frac{T_{LO} \times N_{LO}}{974} \right)$$

$$= \frac{0.03 \times 1500 \times 60}{6120 \times 0.75} = 0.59 \text{ [kW]}$$

(2) Load torque converted into the equivalent value at the motor shaft

For linear motion ⇓ For rotary motion ⇓

$$T_L = \frac{\mu \times W \times V}{2\pi N \times \eta} \left(= \frac{974\, P_L}{N} \right)$$

$$= \frac{0.03 \times 1500 \times 60}{2\pi \times 1800 \times 0.75} = 0.318 \text{ [kgf•m]}$$

Note 1: When there is maximum running resistance, such as static friction, at start, replace μ with μmax to find the load torque (T_L):

Load torque at start (T_{LS}) = 0.424 [kgf•m]

Note 2: Calculate the deceleration characteristic with machine efficiency (η) = 1 to provide some allowance.
The torque load in this case is defined as $T_L min$.

Minimum load torque ($T_L min$) = 0.239 [kgf•m]

(3) Load GD^2 converted into the equivalent value at the motor shaft

For linear motion ⇓ For rotary motion ⇓

$$GD^2{}_L = 4W \left(\frac{V}{2\pi N}\right)^2 \left(= GD^2{}_{LO} \left(\frac{N_{LO}}{N}\right)^2 \right)$$

$$= 4 \times 1500 \times \left(\frac{60}{2\pi \times 1800}\right)^2 = 0.169 \text{ [kgf • m}^2\text{]}$$

3. Temporary Selection of Motor and Inverter Capacities

(1) Temporary selection of motor capacity ≥ $P_L \times \alpha p$ = 0.59 × 1.5 = 0.89 [kW]

αp: 0.5 to 2.0

Note 3: When rated motor speed (N_M) > motor speed (N) during rated load drive
Temporarily selected motor capacity ≥ $P_L \times \alpha p \times N_M/N$

(2) Capacity of the temporarily selected motor

P_M 1.5 [kW] Number of poles 4 [poles]

(3) Rated torque of the temporarily selected motor (60Hz rating basis)

$$T_M = \frac{974 \times P_M}{N_M} = \frac{974 \times 1.5}{1800} = 0.81 \text{ [kgf•m]}$$

(4) GD^2 of the temporarily selected motor
Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

$GD^2{}_M$ 0.027 [kgf•m^2]

(5) When the mechanical brake is included in the temporarily selected motor
Brake type NB-1.5C

Braking torque (T_B) 1.5 [kgf•m] $GD^2{}_B$ 0.0034 [kgf•m^2]

(6) Temporary selection of inverter capacity
(As identical to the motor capacity) select *FR-A520-1.5K*

(7) Torque type of the temporarily selected motor and inverter *15A0*
Torque basis frequency (60Hz or 50Hz) *60* [Hz]
Refer to the description on page 1-1 and the torque type combination list on pages 2-2 and 3 in Technical Note No. 22.

(8) Operating frequency range of the temporarily selected inverter
According to f = (motor speed × number of motor poles)/120
Frequency corresponding to the maximum speed (f)

$$= \frac{N \times p}{120} = \frac{1800 \times 4}{120} = 60 \text{ [Hz]}$$

Frequency corresponding to the minimum speed (fmin)

$$= \frac{N\min \times p}{120} = \frac{180 \times 4}{120} = 6 \text{ [Hz]}$$

4. Whether the Motor Can Be Started and Run at Low Speed or Not

(1) Motor starting torque $T_{MS} = T_M \times \alpha s \times \sigma =$ *0.81× 0.8 × 0.85* = *0.551* [kgf•m]

Refer to the torque coefficient in Chapter 2 Driving Capability Data and the heat coefficient in Chapter 1 How to Use the Data Collection in Technical Note No. 22.

According to Section 2. (2)

Analysis of whether the motor can be started or not

T_{LS} = *0.424* < T_{MS} OK

(2) Short-time maximum torque at fmin $T_{M1} = T_M \times \alpha_m \times \sigma =$ *0.81× 0.8 × 0.85* = *0.551* [kgf•m]

Refer to the torque coefficient in Chapter 2 Driving Capability Data and the heat coefficient in Chapter 1 How to Use the Data Collection in Technical Note No. 22.

Analysis of whether low-speed operation can be performed or not

T_L = *0.318* < T_{M1} OK

5. Whether Acceleration Is Possible or Not

(1) Acceleration torque (Ta) $= \frac{(GD^2_L + GD^2_M + GD^2_B) N}{375 \times ta}$

$$= \frac{(0.169 + 0.027 + 0.0034) \times 1800}{375 \times 3.3} = 0.290 \text{ [kgf•m]}$$

(2) Torque coefficient required for acceleration $(\alpha) = \frac{Ta + T_L max}{T_M} = \frac{0.290 + 0.318}{0.81} = 0.75$

Analysis of whether acceleration is possible or not

Linear acceleration torque coefficient (αa) = *0.8* > α

Refer to the torque coefficient in Chapter 2 Driving Capability Data in Technical Note No. 22. OK

6. Whether Deceleration Is Possible or Not

(1) Deceleration torque (Td) $= \dfrac{(GD^2{}_L + GD^2{}_M + GD^2{}_B)\,N}{375 \times td}$

$$= \frac{(0.169 + 0.027 + 0.0034) \times 1800}{375 \times 3.3} = 0.290 \text{ [kgf•m]}$$

(2) Torque coefficient required for deceleration (β) $= \dfrac{Td - T_L min}{T_M} = \dfrac{0.290 - 0.239}{0.81} = 0.063$

(3) Temporary selection of the brake unit

Refer to the braking capability data in Chapter 3 Braking Capability Data in Technical Note No. 22.

Torque type: *Built-in 15B*

Refer to the brake torque data in Chapter 3 Braking Capability Data in Technical Note No. 22.

Analysis of whether deceleration is possible or not

Minimum value of brake torque coefficient (βmin) = *1.5* > β

OK

7. Examination of Regenerative Power

(1) Power returned from the load

$$W_{MECH} = 1027\,(Td - T_L\,min) \times \frac{N max + N min}{2}$$

$$= 1.027\,(0.290 - 0.239) \times \frac{1800 + 180}{2} = 52 \text{ [W]}$$

(2) Power absorbed by the motor

According to the data on Chapter 3 Braking Capability Data in Technical Note No. 22

$$W_M = (k_1 - k_2) \times P_L$$

$$= (100 - 10) \times 0.59 = 53 \text{ [W]}$$

(3) Power returned to the inverter

$$W_{INV} = W_{MECH} - W_M = 52 - 53 = -1 \text{ [W]}$$

(4) Short-time permissible power per one operation of the brake unit

According to the data in Chapter 3 Braking Capability Data in Technical Note No. 22.

W_{RS} = *660* [W]

Analysis of short-time permissible power

$W_{RS} > W_{INV}$ *OK*

(5) Checking the continuous average regenerative power

$$W_{INV} \times \frac{t_3}{tc} = -1 \times \frac{3.0}{25} = -0.12 \text{ [W]}$$

(6) Continuous permissible power

According to Permissible power list in Chapter 3 Braking Capability Data in Technical Note No. 22

W_{RC} = *55* [W]

Analysis of continuous permissible power

$W_{RC} > W_{INV} \times \dfrac{t_3}{tc}$ *OK*

8. Whether the Motor Can Be Used Thermally

(1) Motor torque and motor current value in each operation zone

(2) Load torque factor (TF) = $\dfrac{\text{torque supplied to the load}}{\text{rated motor torque } (T_M)} \times 100$ [%]

(T_M = 0.81 [kgf•m])

Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

Zone Time [s]	Torque Supplied to the Load [kgf•m]	Load Torque factor [%]	Current Characteristic [%]	Cooling Coefficient
t_1 = *3.3*	Ta + $T_L$max = *0.608*	TF = *75*	I_1 = *83*	C_1 = *0.75*
t_2 = *8.4*	$T_L$max = *0.318*	TF = *39*	I_2 = *65*	C_2 = *1.0*
t_3 = *3.0*	–Td + $T_L$min = *–0.051*	TF = *6*	I_3 = *56*	C_3 = *0.8*
t_4 = *1.5*	Td + $T_L$max = *0.318*	TF = *39*	I_4 = *65*	C_4 = *0.4*
t_5 = *8.8*	Because of stop zone, T = *0*	TF = *0*	I_5 = *0*	C_5 = *0.4*

(2) Motor equivalent current value and analysis of whether the motor can be used thermally

Motor equivalent current value

$$I_{MC} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2 + I_3^2 t_3 + I_4^2 t_4 + I_5^2 t_5}{C_1 t_1 + C_2 t_2 + C_3 t_3 + C_4 t_4 + C_5 t_5}}$$

$$= \sqrt{\frac{83^2 \times 3.3 + 65^2 \times 8.4 + 56^2 \times 3.0 + 65^2 \times 1.5 + 0^2 \times 8.8}{0.75 \times 3.3 + 1.0 \times 8.4 + 0.8 \times 3.0 + 0.4 \times 1.5 + 0.4 \times 8.8}}$$

Analysis

$$= \sqrt{\frac{73969}{17.4}} = 65.2 < 100 \ [\%]$$

9. Stopping Accuracy

(1) Characteristics of the mechanical brake

(When the NB brake is used, refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.)

(When any other brake is used, refer to the characteristic chart of the corresponding manufacturer)

Rated braking torque	:	T_B =	*1.5*	[kgf•m]
Delay time (independent off)	:	t_{01} =	*0.026*	[s]
Brake GD^2	:	GD^2_B =	*0.0034*	[kgf•m²]

(2) Stopping accuracy when the motor is running at low speed (creep speed) and is brought to a stop

Stopping time $tb = t_{01} + t_{11}$

$$= t_{01} + \frac{(GD^2_L + GD^2_M + GD^2_B) \times N\min}{375 \times (T_B + T_L\min)}$$

$$= 0.026 + \frac{(0.169 + 0.027 + 0.0034) \times 180}{375 \times (1.5 + 0.239)}$$

$$= 0.026 + 0.0550 = 0.0810 \text{ [s]}$$

Stopping distance $S = S_{01} + S_{11}$ (Creep speed Vmin = *6* [m/min])

$$= (t_{01} \times \frac{V\min}{60} + t_{11} \times \frac{1}{2} \times \frac{V\min}{60}) \times 10^3$$

$$= (0.026 \times \frac{6}{60} + 0.0550 \times \frac{1}{2} \times \frac{6}{60}) \times 10^3$$

$$= 0.00535 \times 10^3 = 5.35 \text{ [mm]}$$

Guideline of stopping accuracy

$$\Delta\varepsilon = \pm S/2 = \pm 5.35 /2 = \pm 2.68 \text{ [mm]}$$

10. Selection Result

According to the above calculations, select the equipment.

Motor	*SF-JR 1.5kW4P with NB brake*
Inverter	*FR-A520-1.5K for 1.5kW*
Braking unit	*Not required (the brake resistor built in the above inverter is used)*

1) Calculation Sheets <For SI Systems of Units>

1. Machine Conditions Required for Examination

1.1 Voltage and frequency of the power supply ______ [V] ______ [Hz]

1.2 Machine specifications
Understand the conditions of either the linear motion or rotary motion.

[Linear motion]

(1)	Full weight of the moving part	W		[kg]
(2)	Velocity of linear motion	V		[m/min]
	Corresponding motor speed	N		[r/min]
(3)	Minimum velocity of linear motion	Vmin		[m/min]
	Corresponding motor speed	Nmin		[r/min]
(4)	Running resistance	μ		
	Maximum running resistance value	μmax		
(5)	Machine efficiency	η		

[Rotary motion]

(1)	Full weight on the load rotary shaft	W		[kg]
(2)	Load torque on the load rotary shaft	T_{LO}		[N•m]
(3)	Load GD^2 on the load rotary shaft	GD^2_{LO}		[kgf•m^2]
(4)	Speed of the load rotary shaft	N_{LO}		
	Motor speed at the speed indicated on the left	N		[r/min]

1.3 Number of poles of the planned motor ______ [poles]

1.4 Planned mechanical brake Type ______

1.5 Between stop and maximum speed

Acceleration time ta Acceleration time ______ [seconds]

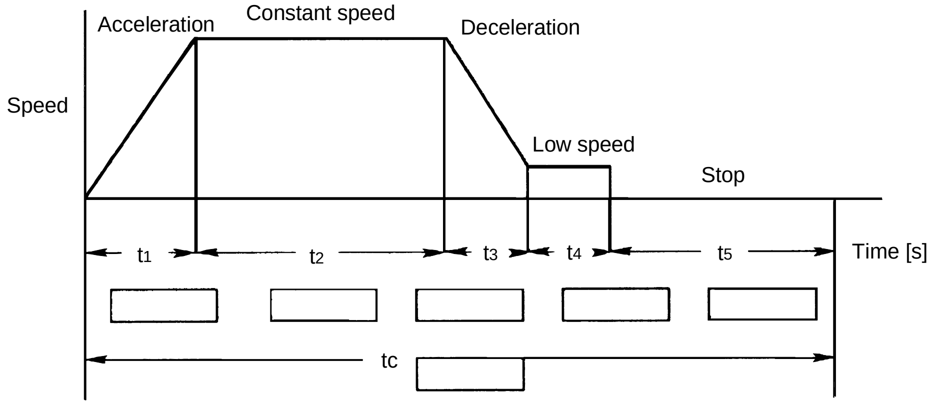
Deceleration time td Deceleration time ______ [seconds]

or Acceleration Acceleration ______ [G] or ______ [m/s^2]

1.6 Repetition time (time of 1 cycle) tc ______ [seconds]

1.7 Stop time during 1 cycle t_5 ______ [seconds]

1.8 Operation pattern



2. Calculation of Load Specifications Required for Calculation

(1) Load required power

For linear motion ⇓ For rotary motion ⇓

$$P_L = \frac{\mu \times W \times V}{6120 \times \eta} \left(= \frac{T_{LO} \times N_{LO}}{9550} \right)$$

$$= \frac{\quad}{\quad} = \boxed{\quad} \text{ [kW]}$$

(2) Load torque converted into the equivalent value at the motor shaft

For linear motion ⇓ For rotary motion ⇓

$$T_L = \frac{\mu \times 9.8 \times W \times V}{2\pi N \times \eta} \left(= \frac{9550 \times P_L}{N} \right)$$

$$= \frac{\quad}{\quad} = \boxed{\quad} \text{ [N•m]}$$

Note 1: When there is maximum running resistance, such as static friction, at start, replace μ with μmax to find the load torque (T_L):

Load torque at start (T_{LS}) = ☐ [N•m]

Note 2: Calculate the deceleration characteristic with machine efficiency (η) = 1 to provide some allowance.

The torque load in this case is defined as $T_L min$.

Minimum load torque ($T_L min$) = ☐ [N•m]

(3) Load GD^2 converted into the equivalent value at the motor shaft

For linear motion ⇓ For rotary motion ⇓

$$GD^2_L = 4W \left(\frac{V}{2\pi N}\right)^2 \left(= GD^2_{LO} \left(\frac{N_{LO}}{N}\right)^2 \right)$$

$$= \boxed{\quad \times \left(\frac{\quad}{\quad}\right)^2} = \boxed{\quad} \text{ [kgf • m}^2\text{]}$$

3. Temporary Selection of Motor and Inverter Capacities

(1) Temporary selection of motor capacity ≥ $P_L \times \alpha p$ = ☐ × ☐ = ☐ [kW]

αp: 0.5 to 2.0

Note 3: When rated motor speed (N_M) > motor speed (N) during rated load drive

Temporarily selected motor capacity ≥ $P_L \times \alpha p \times N_M/N$

(2) Capacity of the temporarily selected motor

P_M ☐ [kW] Number of poles ☐ [poles]

(3) Rated torque of the temporarily selected motor (60Hz rating basis)

$$T_M = \frac{9550 \times P_M}{N_M} = \boxed{\frac{9550 \times}{\quad}} = \boxed{\quad} \text{ [N•m]}$$

(4) GD^2 of the temporarily selected motor

Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

GD^2_M ☐ [kgf•m²]

(5) When the mechanical brake is included in the temporarily selected motor

Brake type ______________________

Braking torque (T_B) ☐ [N•m] GD^2_B ☐ [kgf•m²]

(6) Temporary selection of inverter capacity

(As identical to the motor capacity) select [*FR-*]

(7) Torque type of the temporarily selected motor and inverter [ ]

Torque basis frequency (60Hz or 50Hz) [ ] [Hz]

Refer to the description in Chapter 1 How to Use this Data Section and the torque type combination list in Chapter 2 Driving Capability Data and Chapter 3 in Technical Note No. 22 (Data Section).

(8) Operating frequency range of the temporarily selected inverter

According to f = (motor speed × number of motor poles)/120

Frequency corresponding to the maximum speed (f)

$$= \frac{N \times p}{120} = \frac{\quad \times \quad}{120} = \square \text{ [Hz]}$$

Frequency corresponding to the minimum speed fmin

$$= \frac{N_{min} \times p}{120} = \frac{\quad \times \quad}{120} = \square \text{ [Hz]}$$

4. Whether the Motor Can Be Started and Run at Low Speed or Not

(1) Motor starting torque $T_{MS} = T_M \times \alpha s \times \sigma =$ [ ]

Refer to the torque coefficient in Chapter 2 Driving Capability Data (→ αs)

and the heat coefficient in Chapter 1 How to Use this Data Section in Technical Note No. 22. (→ σ)

= [ ] [N•m]

According to Section 2. (2)

Judgment of whether the motor can be started or not

$T_{LS} =$ [ ] $< T_{MS}$ ← OK

(2) Short-time maximum torque at fmin $T_{M1} = T_M \times \alpha m \times \sigma =$ [ ]

Refer to the torque coefficient in Chapter 2 Driving Capability Data (→ αm)

and the heat coefficient in Chapter 1 How to Use this Data Section in Technical Note No. 22. (→ σ)

= [ ] [N•m]

Analysis of whether low-speed operation can be performed or not

$T_L =$ [ ] $< T_{M1}$ ←

$T_{LS} =$ [ ] $< T_{MS}$ ←

5. Whether Acceleration is Possible or Not

(1) Acceleration torque (Ta) $= \dfrac{(GD^2_L + GD^2_M + GD^2_B)\,N}{38.2 \times ta}$

$$= \frac{(\qquad\qquad) \times}{38.2 \times} = \square \text{ [N•m]}$$

(2) Torque coefficient required for acceleration $\alpha = \dfrac{Ta + T_L max}{T_M} = \dfrac{\quad + \quad}{\quad} =$ [ ]

Analysis of whether acceleration is possible or not

Linear acceleration torque coefficient (αa) = [ ] $> \alpha$ ←

↑ Refer to the torque coefficient in Chapter 2 Driving Capability Data in Technical Note No. 22.

6. Whether Deceleration is Possible or Not

(1) Deceleration torque $Td = \dfrac{(GD^2{}_L + GD^2{}_M + GD^2{}_B)\,N}{38.2 \times td}$

$$= \frac{(\qquad\qquad)}{38.2 \times \qquad} = \boxed{}\ [N \bullet m]$$

(2) Torque coefficient required for deceleration (β) $= \dfrac{Td - T_L min}{T_M} = \dfrac{\quad - \quad}{\qquad} = \boxed{}$

(3) Temporary selection of the brake unit
Refer to the braking capability data in Chapter 3 Braking Capability Data in Technical Note No. 22.

Torque type $\boxed{}$

Refer to the brake torque data in Chapter 3 Braking Capability Data in Technical Note No. 22.

Analysis of whether deceleration is possible or not

Minimum value of brake torque coefficient (βmin) = $\boxed{}$ > β

7. Examination of Regenerative Power

(1) Power returned from the load

$$W_{MECH} = 0.1047\,(Td - T_L min) \times \frac{N max + N min}{2}$$

$$= 0.1047\,(\qquad) \times \frac{\quad + \quad}{2} = \boxed{}\ [W]$$

(2) Power absorbed by the motor
According to the data in Chapter 3 Braking Capability Data in Technical Note No. 22.

$$W_M = (k_1 - k_2) \times P_L$$

$$= (\quad - \quad) \times \qquad = \boxed{}\ [W]$$

(3) Power returned to the inverter

$$W_{INV} = W_{MECH} - W_M = \quad - \quad = \boxed{}\ [W]$$

(4) Short-time permissible power per one operation of the brake unit

W_{RS} = $\boxed{}$ [W]

According to the data in Chapter 3 Braking Capability Data in Technical Note No. 22.

Analysis of short-time permissible power

$W_{RS} > W_{INV}$

(5) Checking the continuous average regenerative power

$$W_{INV} \times \frac{t_3}{tc} = \quad \times \frac{\quad}{\quad} = \boxed{}\ [W]$$

(6) Continuous permissible power

W_{RC} = $\boxed{}$ [W]

According to Table 4-1 in Chapter 3 Braking Capability Data in Technical Note No. 22.

Analysis of continuous permissible power

$$W_{RC} > W_{INV} \times \frac{t_3}{tc}$$

8. Whether the Motor Can Be Used Thermally

(1) Motor torque and motor current value in each operation zone

$$\text{Load torque factor (TF)} = \frac{\text{torque supplied to the load}}{\text{rated motor torque } (T_M)} \times 100 \ \ [\%]$$

(T_M = [ ] [N•m])

Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

Zone Time [s]	Torque Supplied to the Load [N•m]	Load Torque factor [%]	Current Characteristic [%]	Cooling Coefficient
t_1 =	Ta + $T_L$max =	TF =	I_1 =	C_1 =
t_2 =	$T_L$max =	TF =	I_2 =	C_2 =
t_3 =	–Td + $T_L$min =	TF =	I_3 =	C_3 =
t_4 =	$T_L$max =	TF =	I_4 =	C_4 =
t_5 =	Because of stop zone, T = 0	TF = 0	I_5 = 0	C_5 = 0.4

(2) Motor equivalent current value and analysis of whether the motor can be used thermally

Motor equivalent current value

$$I_{MC} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2 + I_3^2 t_3 + I_4^2 t_4 + I_5^2 t_5}{C_1 t_1 + C_2 t_2 + C_3 t_3 + C_4 t_4 + C_5 t_5}}$$

$$= \sqrt{\frac{\quad + \quad + \quad + \quad + \quad}{\quad + \quad + \quad + \quad + \quad}}$$

Judgment

$$= \sqrt{\frac{\quad}{\quad}} = \boxed{\quad} < 100 \ \ [\%]$$

9. Stopping Accuracy

(1) Characteristics of the mechanical brake

(When the NB brake is used, refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.)

(When any other brake is used, refer to the characteristic chart of the corresponding manufacturer)

Rated braking torque	:	T_B =		[N•m]
(Note :	1 [kgf•m]	=	*9.80665*	[N•m]
Delay time (independent off)	:	t_{01} =		[s]
Brake GD^2	:	GD^2_B =		[kgf•m^2]

(2) Stopping accuracy when the motor is running at low speed (creep speed) and is brought to a stop

Stopping time $tb = t_{01} + t_{11}$

$$= t_{01} + \frac{(GD^2_L + GD^2_M + GD^2_B) \times N\min}{38.2 \times (T_B + T_L\min)}$$

$$= \boxed{\quad + \frac{(\qquad\qquad) \times}{38.2 \times (\qquad)}}$$

$$= \boxed{\qquad + \qquad} = \boxed{\qquad} \text{ [s]}$$

Stopping distance $S = S_{01} + S_{11}$ (Creep speed Vmin = [ ] [m/min])

$$= (t_{01} \times \frac{V\min}{60} + t_{11} \times \frac{1}{2} \times \frac{V\min}{60}) \times 10^3$$

$$= (\boxed{\quad \times \frac{\quad}{60}} + \boxed{\quad \times \frac{1}{2} \times \frac{\quad}{60}}) \times 10^3$$

$$= \boxed{\qquad} \times 10^3 = \boxed{\qquad} \text{ [mm]}$$

Guideline of stopping accuracy

$\Delta\varepsilon = \pm S/2 = \pm$ [ ] /2 = ± [ ] [mm]

10. Selection Result

According to the above calculations, select the equipment.

Motor	*kW* *P*
Inverter	
Braking unit	

2) Calculation Sheets <For Gravitational Systems of Units>

1. Machine Conditions Required for Examination

1.1 Voltage and frequency of the power supply [V] [Hz]

1.2 Machine specifications

Grasp the conditions of either the linear motion or rotary motion.

[Linear motion]

(1)	Full weight of the moving part	W		[kgf]
(2)	Velocity of linear motion	V		[m/min]
	Corresponding motor speed	N		[rpm]
(3)	Minimum velocity of linear motion	Vmin		[m/min]
	Corresponding motor speed	Nmin		[rpm]
(4)	Running resistance	μ		
	Maximum running resistance value	μmax		
(5)	Machine efficiency	η		

[Rotary motion]

(1)	Full weight on the load rotary shaft	W		[kgf]
(2)	Load torque on the load rotary shaft	T_{LO}		[kgf•m]
(3)	Load GD^2 on the load rotary shaft	GD^2_{LO}		[kgf•m^2]
(4)	Speed of the load rotary shaft	N_{LO}		
	Motor speed at the speed indicated on the left	N		[rpm]

1.3 Number of poles of the planned motor [poles]

1.4 Planned mechanical brake Type

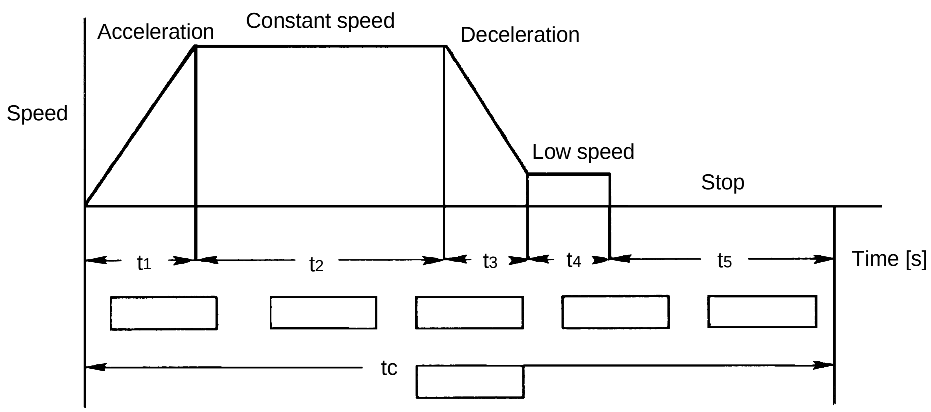
1.5 Between stop and maximum speed

Acceleration time	ta	Acceleration time		[seconds]		
Deceleration time	td	Deceleration time		[seconds]		
or Acceleration		Acceleration		[G] or		[m/s^2]

1.6 Repetition time (time of 1 cycle) tc [seconds]

1.7 Stop time during 1 cycle t_5 [seconds]

1.8 Operation pattern



2. Calculation of Load Specifications Required for Calculation

(1) Load required power

For linear motion ⇓ For rotary motion ⇓

$$P_L = \frac{\mu \times W \times V}{6120 \times \eta} \left(= \frac{T_{LO} \times N_{LO}}{974} \right)$$

$$= \boxed{\frac{\quad}{\quad}} = \boxed{\quad} \text{ [kW]}$$

(2) Load torque converted into the equivalent value at the motor shaft

For linear motion ⇓ For rotary motion ⇓

$$T_L = \frac{\mu \times W \times V}{2\pi N \times \eta} = \frac{974 \times P_L}{N}$$

$$= \boxed{\frac{\quad}{\quad}} = \boxed{\quad} \text{ [kgf•m]}$$

Note 1: When there is maximum running resistance, such as static friction, at start, replace μ with μmax to find the load torque (T_L):

Load torque at start (T_{LS}) = ☐ [kgf•m]

Note 2: Calculate the deceleration characteristic with machine efficiency η = 1 to provide some allowance.
The torque load in this case is defined as T_Lmin.

Minimum load torque (T_Lmin) = ☐ [kgf•m]

(3) Load GD^2 converted into the equivalent value at the motor shaft

For linear motion ⇓ For rotary motion ⇓

$$GD^2{}_L = 4W \left(\frac{V}{2\pi N}\right)^2 = GD^2{}_{LO} \left(\frac{N_{LO}}{N}\right)^2$$

$$= \boxed{\quad \times \left(\frac{\quad}{\quad}\right)^2} = \boxed{\quad} \text{ [kgf • m}^2\text{]}$$

3. Temporary Selection of Motor and Inverter Capacities

(1) Temporary selection of motor capacity ≥ $P_L \times \alpha p$ = ☐ × ☐ = ☐ [kW]

αp: 0.5 to 2.0

Note 3: When rated motor speed (N_M) > motor speed (N) during rated load drive
Temporarily selected motor capacity ≥ $P_L \times \alpha p \times N_M/N$

(2) Capacity of the temporarily selected motor

P_M ☐ [kW] Number of poles ☐ [poles]

(3) Rated torque of the temporarily selected motor (60Hz rating basis)

$$T_M = \frac{974 \times P_M}{N_M} = \boxed{\frac{974 \times \quad}{\quad}} = \boxed{\quad} \text{ [kgf•m]}$$

(4) GD^2 of the temporarily selected motor
Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

$GD^2{}_M$ ☐ [kgf•m^2]

(5) When the mechanical brake is included in the temporarily selected motor
Brake type ______________________

Braking torque (T_B) ☐ [kgf•m] $GD^2{}_B$ ☐ [kgf•m^2]

(6) Temporary selection of inverter capacity

(As identical to the motor capacity) select [FR-]

(7) Torque type of the temporarily selected motor and inverter [ ]

Torque basis frequency (60Hz or 50Hz) [ ] [Hz]

Refer to the description in Chapter 1 How to Use this Data Section and the torque type combination list in Chapter 2 Driving Capability Data in Technical Note No. 22.

(8) Operating frequency range of the temporarily selected inverter

According to f = (motor speed × number of motor poles)/120

Frequency corresponding to the maximum speed (f)

$$= \frac{N \times p}{120} = \frac{\quad \times \quad}{120} = \boxed{\quad} \text{ [Hz]}$$

Frequency corresponding to the minimum speed (fmin)

$$= \frac{N_{min} \times p}{120} = \frac{\quad \times \quad}{120} = \boxed{\quad} \text{ [Hz]}$$

4. Whether the Motor Can Be Started and Run at Low Speed or Not

(1) Motor starting torque $T_{MS} = T_M \times \alpha s \times \sigma = \boxed{\quad}$

Refer to the torque coefficient in Chapter 2 Driving Capability Data (→ αs)

and the heat coefficient in Chapter 1 How to Use this Data Section in Technical Note No. 22. (→ σ)

= [ ] [kgf•m]

According to Section 2. (2)

Analysis of whether the motor can be started or not

T_{LS} = [ ] < T_{MS}

(2) Short-time maximum torque at fmin $T_{M1} = T_M \times \alpha m \times \sigma = \boxed{\quad}$

Refer to the torque coefficient in Chapter 2 Driving Capability Data (→ αm)

and the heat coefficient in Chapter 1 How to Use this Data Section in Technical Note No. 22. (→ σ)

= [ ] [kgf•m]

Analysis of whether low-speed operation can be performed or not

T_L = [ ] < T_{M1}

5. Whether Acceleration is Possible or Not

(1) Acceleration torque (Ta)

$$= \frac{(GD^2_L + GD^2_M + GD^2_B)\,N}{375 \times ta}$$

$$= \frac{(\qquad\qquad) \times}{375 \times} = \boxed{\quad} \text{ [kgf•m]}$$

(2) Torque coefficient required for acceleration (α) $= \frac{Ta + T_L max}{T_M} = \frac{\quad + \quad}{\quad} = \boxed{\quad}$

Analysis of whether acceleration is possible or not

Linear acceleration torque coefficient (αa) = [ ] > α

Refer to the torque coefficient in Chapter 2 Driving Capability Data in Technical Note No. 22.

6. Whether Deceleration is Possible or Not

(1) Deceleration torque (Td) $= \dfrac{(GD^2_L + GD^2_M + GD^2_B)\,N}{375 \times td}$

$= \dfrac{(\qquad)}{375 \times} = \underline{\qquad}$ [kgf•m]

(2) Torque coefficient required for deceleration (β) $= \dfrac{Td + T_L min}{T_M} = \dfrac{\quad - \quad}{\qquad} = \underline{\qquad}$

(3) Temporary selection of the brake unit

Refer to the braking capability data in Chapter 3 Braking Capability Data in Technical Note No. 22.

Torque type

Refer to the brake torque data in Chapter 3 Braking Capability Data in Technical Note No. 22.

Analysis of whether deceleration is possible or not

Minimum value of brake torque coefficient (βmin) = $\underline{\qquad}$ > β

7. Examination of Regenerative Power

(1) Power returned from the load

$W_{MECH} = 1027\,(Td - T_L min) \times \dfrac{N max + N min}{2}$

$= 1.027\,(\qquad) \times \dfrac{\quad + \quad}{2} = \underline{\qquad}$ [W]

(2) Power absorbed by the motor

According to the data in Chapter 3 Braking Capability Data in Technical Note No. 22.

$W_M = (k_1 - k_2) \times P_L$

$= (\quad - \quad) \times \qquad = \underline{\qquad}$ [W]

(3) Power returned to the inverter

$W_{INV} = W_{MECH} - W_M = \quad - \quad = \underline{\qquad}$ [W]

(4) Short-time permissible power per one operation of the brake unit

$W_{RS} = \underline{\qquad}$ [W]

According to the data in Chapter 3 Braking Capability Data in Technical Note No. 22.

Analysis of short-time permissible power

$W_{RS} > W_{INV}$

(5) Checking the continuous average regenerative power

$W_{INV} \times \dfrac{t_3}{tc} = \quad \times \dfrac{\quad}{\quad} = \underline{\qquad}$ [W]

(6) Continuous permissible power

$W_{RC} = \underline{\qquad}$ [W]

According to Table 4-1 in Chapter 3 Braking Capability Data in Technical Note No. 22.

Analysis of continuous permissible power

$W_{RC} > W_{INV} \times \dfrac{t_3}{tc}$

8. Whether the Motor Can Be Used Thermally

(1) Motor torque and motor current value in each operation zone

(2) Load torque factor (TF) $= \dfrac{\text{torque supplied to the load}}{\text{rated motor torque } (T_M)} \times 100$ [%]

(T_M = ☐ [kgf•m])

Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

Refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

Zone Time [s]	Torque Supplied to the Load [kgf•m]	Load Torque factor [%]	Current Characteristic [%]	Cooling Coefficient
t_1 =	Ta + $T_L$max =	TF =	I_1 =	C_1 =
t_2 =	$T_L$max =	TF =	I_2 =	C_2 =
t_3 =	–Td + $T_L$min =	TF =	I_3 =	C_3 =
t_4 =	$T_L$max =	TF =	I_4 =	C_4 =
t_5 =	Because of stop zone, T =	TF = 0	I_5 = 0	C_5 = 0.4

(2) Motor equivalent current value and judgment of whether the motor can be used thermally

Motor equivalent current value

$$I_{MC} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2 + I_3^2 t_3 + I_4^2 t_4 + I_5^2 t_5}{C_1 t_1 + C_2 t_2 + C_3 t_3 + C_4 t_4 + C_5 t_5}}$$

$$= \sqrt{\frac{\quad + \quad + \quad + \quad + \quad}{\quad + \quad + \quad + \quad + \quad}}$$

Analysis

$$= \sqrt{\frac{\square}{\square}} = \square < 100 \ [\%]$$

9. Stopping Accuracy

(1) Characteristics of the mechanical brake

When the NB brake is used, refer to Chapter 4 Motor and Brake Characteristics in Technical Note No. 22.

When any other brake is used, refer to the characteristic chart of the corresponding manufacturer

Rated braking torque	:	T_B =		[kgf•m]
Delay time (independent off)	:	t_{01} =		[s]
Brake GD^2	:	GD^2_B =		[kgf•m^2]

(2) Stopping accuracy when the motor is running at low speed (creep speed) and is brought to a stop

Stopping time $tb = t_{01} + t_{11}$

$$= t_{01} + \frac{(GD^2_L + GD^2_M + GD^2_B) \times N\min}{375 \times (T_B + T_L\min)}$$

$$= \boxed{\quad + \frac{(\qquad\qquad) \times}{375 \times (\qquad\qquad)}}$$

$$= \boxed{\qquad + \qquad} = \boxed{\qquad} \text{ [s]}$$

Stopping distance $S = S_{01} + S_{11}$ (Creep speed Vmin = $\boxed{\qquad}$ [m/min])

$$= (t_{01} \times \frac{V\min}{60} + t_{11} \times \frac{1}{2} \times \frac{V\min}{60}) \times 10^3$$

$$= (\boxed{\quad \times \frac{\quad}{60}} + \boxed{\quad \times \frac{1}{2} \times \frac{\quad}{60}}) \times 10^3$$

$$= \boxed{\qquad} \times 10^3 = \boxed{\qquad} \text{ [mm]}$$

Guideline of stopping accuracy

$$\Delta\varepsilon = \pm S/2 = \pm \boxed{\qquad} /2 = \pm \boxed{\qquad} \text{ [mm]}$$

10. Selection Result

According to the above calculations, select the equipment.

Motor	kW P
Inverter	
Braking unit	