MITSUBISHI ELECTRIC

INVERTER

TECHNICAL NOTE

No. 31

CAPACITY SELECTION II
[CALCULATION PROCEDURE]

(CONTINUOUS OPERATION)
(CYCLIC OPERATION)
(LIFT OPERATION)

CONTENTS

Technical Notes No.23 to No.25 were integrated as this document. This Technical Note targets the 500 series inverters. For the earlier models, refer to Technical Notes No.23 to No.25.

CHAPTER 1 DEFINITION OF OPERATION PATTERNS AND FUNDAMENTAL CONCEPTS FOR CAPACITY SELECTION

1.1 Definition of operation patterns

Operations patterns are categorized into the following two patterns based on their operation time: the long-duration operation at constant speed is called "Continuous operation," and the repeated short-duration operation is called "Cyclic operation" (repetition of start ⇨ constant-speed operation ⇨ deceleration to stop). Lift operation is a part of Cyclic operation. The main characteristic of Lift operation is that it has different loads according to the rotation direction. Two loads, the positive load (normally when ascending) and the negative load (normally when descending), exist. When ascending/descending, the regenerative power for the negative load requires special attention.

Operation patterns are categorized by the following operation conditions :

Operation pattern	Number of starts/stops (operation period)	Load condition
Continuous operation	Less than 10 times/h	Positive load
Cyclic operation	10 times/h or more	Positive load
Lift operation	10 times/h or more	Positive load and negative load

《Necessary documents for the selection》

Please prepare TECHNICAL NOTE No.30 CAPACITY SELECTION [DATA]

1.2 Fundamental concepts for capacity selection

(1) The machine can start

The starting torque during inverter operation should be smaller than the torque during commercial power supply operation. Select appropriate capacities for the motor and inverter so that the motor can start with the small torque available during inverter operation. Especially in Lift operation, select the motor and inverter capacities that provide enough starting torque because the object may drop due to a starting torque shortage. An inverter with Advanced magnetic flux vector control or vector control, which enables torque increase at low speed, is the optimum choice.

(2) The machine can run at low speed and at high speed

Select appropriate motor and inverter capacities so that the motor's output torque is higher than the load torque at low and high constant-speed operation.

(3) The machine can accelerate/decelerate within the specified acceleration/deceleration time

The motor current during acceleration/deceleration should be higher than the current during constant-speed operation. Select an inverter capacity that tolerates the increased current. In addition to the load characteristics (load torque, moment of inertia, speed), the acceleration/deceleration time in the operation pattern affects the amount of current flow during acceleration/deceleration.

(4) The regenerative power can be consumed

During deceleration, the regenerative power must be consumed. Braking options such as a brake unit or a regenerative converter may be required. For Lift operation, negative load is applied even during constant-speed operation. Consider using a brake unit or a regenerative converter.

(5) The operating temperature cannot exceed the permissible temperature of the motor

Check that the equivalent current of the motor torque is 100% or less and the electronic thermal relay and the transistor thermal protection are not activated.

(6) Mechanical safety brake must be used for lifting equipment

Always use a mechanical safety brake for lifting equipment to keep the stop status of the lifted object.

1.3 Applicable inverter and motor series

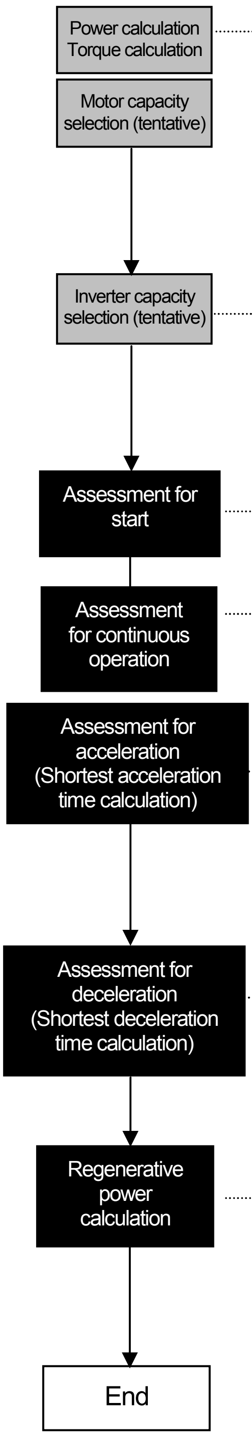
Applicable inverter series
FR-A500
FR-F500
FR-E500
FR-S500
FR-V500

Applicable motor series	
Standard motor	SF-JR, SF-HR
Constant torque motor	SF-HRCA
Geared motor	GM-D, GM-S
Vector motor	SF-V5R
Standard motor with encoder	SF-JR

CHAPTER 2 SELECTION PROCEDURE

2.1 Selection flowchart

(1) Continuous operation



Selection outline	Assessment	Refer to page
Calculate the required power and the load torque, and select a motor capacity that can be driven by the required power or higher. When selecting, also check that the rated motor torque is equal to or higher than the load torque. Required power : $P_{LR} = \dfrac{\mu \times W \times V_{max}}{6120 \times \eta}$ [kW] Load torque : $T_{LR} = \dfrac{9550 \times P_{LR}}{N_{max}}$ [N·m]	Selected motor capacity (tentative) : P_M Selected rated motor torque (tentative) : T_M $P_M \geq P_{LR}$ $T_M \geq T_{LR}$	7
Select the inverter capacity that is equivalent to the motor capacity. If higher acceleration torque is required, select the inverter capacity, which is higher than the motor capacity.	Selected inverter capacity (tentative) : P_{INV} $P_{INV} \geq P_M$	8
Check that the starting torque of the motor is larger than the load torque at start. Maximum starting torque of the motor : $T_{MS} = T_M \times \alpha_s \times \delta$ α_s : Starting torque coefficient δ : Hot motor coefficient Load torque at start : T_{LS}	$T_{MS} > T_{LS}$	10
Check that the load torque is within the continuous operation torque range of the motor. Continuous operation torque of the motor: $T_{MC} = T_M \times \alpha_c$ α_c : Continuous operation torque coefficient	$T_{MC} = T_M \times \alpha_c > T_{LR}$	11
Calculate the shortest acceleration time. Check that the value satisfies the desired acceleration time. Shortest acceleration time : $t_{as} = \dfrac{\sum J \times N_{max}}{9.55(T_M \times \alpha_a - T_{LRmax})}$ [s] Linear acceleration torque coefficient : α_a	Desired acceleration time : t_a $t_{as} < t_a$	14
Calculate the shortest deceleration time. Check that the value satisfies the desired deceleration time. Shortest deceleration time : $t_{ds} = \dfrac{\sum J \times N_{max}}{9.55(T_M \times \beta + T_{LRmin})}$ [s] Deceleration torque coefficient : β	Desired deceleration time : t_d $t_{ds} < t_d$	15
(1) Check how much regenerative power can be consumed during deceleration. (2) Check how much regenerative power can be consumed during continuous regenerative operation. Power to be regenerated to the inverter : W_{INV} Short-time permissible power : W_{RS}	$W_{RS} > W_{INV}$	17

(2) Cyclic operation

Flow	Selection outline	Assessment	Refer to page
Power calculation Torque calculation ↓ Motor capacity selection (tentative)	Calculate the required power and the load torque, and select a motor capacity that can be driven by the required power or higher. When selecting, also check that the rated motor torque is equal to or higher than the load torque. Required power : $P_{LR} = \dfrac{\mu \times W \times Vmax}{6120 \times \eta}$ [kW] Load torque : $T_{LR} = \dfrac{9550 \times P_{LR}}{Nmax}$ [N·m]	Selected motor capacity (tentative) : P_M Selected rated motor torque (tentative) : T_M $P_M \geq P_{LR}$ $T_M \geq T_{LR}$	19
Inverter capacity selection (tentative)	Select the inverter capacity that is equivalent to the motor capacity. If higher acceleration torque is required, select the inverter capacity, which is higher than the motor capacity.	Selected inverter capacity (tentative) : P_{INV} $P_{INV} \geq P_M$	20
Assessment for start	Check that the starting torque of the motor is larger than the load torque at start. Maximum starting torque of the motor : $T_{MS} = T_M \times \alpha s \times \delta$ αs : Starting torque coefficient δ : Hot motor coefficient Load torque at start : T_{LS}	$T_{MS} > T_{LS}$	22
Assessment for low-speed operation Assessment for high-speed operation	Check that the output torque of the motor during low-speed and high-speed operation is larger than the load torque. Torque during low-speed operation : $T_M \times \alpha m \times \delta$ Torque during high-speed operation : $T_M \times \alpha m$ αm : Maximum short-time torque coefficient	During low-speed operation $T_M \times \alpha m \times \delta > T_{LR}$ During high-speed operation $T_M \times \alpha m > T_{LR}$	23
Assessment for acceleration (Acceleration torque calculation)	Check that the output torque of the motor during acceleration is larger than the total torque during acceleration. Acceleration torque : $Ta = \dfrac{\sum J \times Nmax}{9.55 \times ta}$ [N·m] Total acceleration torque : $Tat = Ta + T_{LR}max$ Output torque of the motor during acceleration : $T_M \times \alpha a$ αa : Linear acceleration torque coefficient	$T_M \times \alpha a > Tat = Ta + T_{LR}max$	24
Assessment for deceleration (Deceleration torque calculation)	Check that the output torque of the motor during deceleration is larger than the total torque during deceleration. Deceleration torque : $Td = \dfrac{\sum J \times Nmax}{9.55 \times td}$ [N·m] Total deceleration torque : $Tdt = -Td + T_{LR}min$ Output torque of the motor during deceleration : $T_M \times \beta$ β : Brake torque coefficient	$T_M \times \beta > Tdt = \lvert -Td + T_{LR}min \rvert$	27
Regenerative power calculation	(1) Check the short-time permissible power (2) Check the average regenerative power W_{INV} : Power to be regenerated to the inverter td : Deceleration time of one cycle tc : Total time of one cycle	$W_{RS} > W_{INV}$ $W_{RC} > W_{INV} \times \dfrac{td}{tc}$	29
Motor temperature calculation	(1) Check that the equivalent current of the motor torque is less than 100%. $I_{MC} = \sqrt{\dfrac{\sum (In^2 \times tn)}{\sum (Cn \times tn)}} < 100$ [%] (2) Check that the electronic thermal relay does not get activated. (3) Check that the transistor protection thermal does not get activated.		32
End	· Calculate the stop accuracy by the mechanical brake.	—	36

(3) Lift operation

Step	Selection outline	Assessment	Refer to page
Power calculation Torque calculation ↓ Motor capacity selection (tentative)	Calculate the required power and the load torque, and select a motor capacity that can be driven by the required power or higher. When selecting, also check that the rated motor torque is equal to or higher than the load torque. Required power : $P_{LR} = \dfrac{W \times V_{max}}{6120 \times \eta}$ [kW] Load torque : $T_{LR} = \dfrac{9550 \times P_{LR}}{N_{max}}$ [N·m]	Selected motor capacity (tentative) : P_M Selected rated motor torque (tentative) : T_M $P_M \geq P_{LR}$ $T_M \geq T_{LR}$	37
Inverter capacity selection (tentative)	Select the inverter capacity that is equivalent to the motor capacity. If higher acceleration torque is required, select the inverter capacity, which is higher than the motor capacity.	Selected inverter capacity (tentative) : P_{INV} $P_{INV} \geq P_M$	38
Assessment for start	Check that the load torque of the motor is larger than the load torque at start. Maximum starting torque of the motor : $T_{MS} = T_M \times \alpha s \times \delta$ αs : Starting torque coefficient δ: Hot motor coefficient Load torque : T_{LR}	$T_{MS} > T_{LR}$	39
Assessment for low-speed operation Assessment for high-speed operation	Check that the output torque of the motor is larger than the load torque (during power driving and regenerative driving). αm : Maximum short-time torque coefficient	During low-speed and high-speed operations During power driving : $T_M \times \alpha m \times \delta > T_{LU}$ During regenerative driving : $T_M \times \beta \times \delta > T_{Lf}$	40
Assessment for acceleration (Acceleration torque calculation)	Check that the output torque of the motor during acceleration is larger than the total torque during acceleration. Acceleration torque : $Ta = \dfrac{\Sigma J \times N_{max}}{9.55 \times ta}$ [N·m] Total acceleration torque : $Tat = Ta + T_{LU}$ Output torque of the motor during acceleration : $T_M \times \alpha a$ Linear acceleration torque coefficient : αa	$T_M \times \alpha a > Tat$	42
Assessment for deceleration (Deceleration torque calculation)	Check that the output torque of the motor during deceleration is larger than the total torque during deceleration. Deceleration torque : $Td = \dfrac{\Sigma J \times N_{max}}{9.55 \times td}$ [N·m] Total deceleration torque : $Tdt = -Td + T_{Lf}$ Output torque of the motor during deceleration : $T_M \times \beta$ Brake torque coefficient : β	$T_M \times \beta > \lvert Tdt \rvert$	42
Regenerative power calculation	(1) Check the short-time permissible power (2) Check the regenerative power generated in the continuous regenerative operation range (3) Check the average regenerative power W_{nc} : Average power in the continuous regenerative operation range W_{INV} : Power to be regenerated to the inverter	$W_{RS} > \lvert W_n \rvert \times 0.9$ $W_{RS} > W_{nc}$ $W_{RC} > W_{INV}$	46
Motor temperature calculation	(1) Check that the equivalent current of the motor torque is 100% or less. $I_{MC} = \sqrt{\dfrac{\sum (In^2 \times tn)}{\sum (Cn \times tn)}} < 100$ [%] (2) Check that the electronic thermal relay does not get activated. (3) Check that the transistor protection thermal does not get activated.		50
End	· Calculate the stop accuracy by the mechanical brake.	—	55

2.2 Symbols of the loads/operations required for the capacity selection

Table 2.1 Symbols and units of characteristics

Characteristic		Symbol	SI units	Converted value
Machine-side characteristic	Required power	P_{LR}	kW	
	Motor capacity	P_M	kW	
	Number of motor poles	P	——	
	Motor speed	N	r/min	
	Frequency	f	Hz	
	Travel speed	V	m/min	
	Load mass (moving mass)	W	kg	
	Machine efficiency	η	——	
	Friction coefficient (driving resistance)	μ	——	
	Load torque at motor shaft (constant-speed)	$T_{L\square}$ (Note 3)	N·m	1 kgf·m= 9.8 N·m
	Load moment of inertia at motor shaft	J_L	$kg \cdot m^2$	$J = \frac{GD^2}{4}$
	Mechanical brake moment of inertia at motor shaft	J_B	$kg \cdot m^2$	$J = \frac{GD^2}{4}$
	Cycle time (one cycle)	t_c	s	
	Time in each operation block	t_n	s	
	Acceleration time	t_a	s	
	Deceleration time	t_d	s	
	Acceleration speed	A_{CC}	m/s^2	
	Rated motor speed	N_M(Note 1)	r/min	
Considered characteristic	Rated motor torque	$T_{M\square}$(Note 3)	N·m	1 kgf·m= 9.8 N·m
	Acceleration torque	$T_{a\square}$(Note 3)	N·m	1 kgf·m= 9.8 N·m
	Deceleration torque	$T_{d\square}$(Note 3)	N·m	1 kgf·m= 9.8 N·m
	Rated brake torque	T_B	N·m	1 kgf·m= 9.8 N·m
	Load torque ratio	TF	%	
	Motor moment of inertia	J_M	$kg \cdot m^2$	$J = \frac{GD^2}{4}$
	Margin coefficient for tentative motor selection	k_P	——	
	Maximum short-time torque coefficient	αm	——	
	Maximum starting torque coefficient	αs	——	
	Linear acceleration torque coefficient	αa	——	
	Continuous operation torque coefficient	αc	——	
	Brake torque coefficient (generic name)	β	——	
	Brake duty	%ED (Loaded time ratio)	%	ED : Abbreviation of "Einschalt-Dauer"
	Motor-consuming power conversion coefficient	k	——	
	Hot coefficient	δ	——	
	Cooling coefficient	C	——	
	Motor current	I	%	
	Equivalent current of motor torque	I_{MC}	%	
	Electronic thermal relay operation time	t_{THn}	s	
Regenerative power	Regenerative power consumed by motor	W_M	W	
	Power regenerated to inverter	W_{INV}	W	
	Power regenerated from machine	W_{MECH}	W	
	Average power in the continuous regenerative operation range	W_{nc}	W	
	Continuous operation permissible power of a braking option	W_{RC}	W	
	Short-time permissible power of a braking option activation	W_{RS}	W	
Stop accuracy	Time to stop	t_b	s	
	Distance to stop	S	mm	
	Stop accuracy	$\Delta\varepsilon$	mm	

Note (1) "max" on symbols indicates the maximum value. "min" indicates the minimum value. (Example: T_{LRmax})

(2) The numbers such as 1, 2, 3 ... n, which follows the symbols, indicate different conditions of the characteristic represented by the symbol. (Example: I_1, I_2)

(3) The following characteristics are indicated in the □ part : S, at start; R, at constant-speed; t, total; U, ascending (power driving); f, descending (regenerative driving); C, continuous.

CHAPTER 3 CONTINUOUS OPERATION

3.1 Calculation of load-driving power and load torque

Load characteristics (power, operation pattern, etc.) are required for the calculation. (Refer to Table 2.1.) Especially if the power value is unclear, correct assessment cannot be performed. Use the following procedure for the calculation.

(1) Required power P_{LR}

Size of a load differs by the machine (load type), but it can be roughly categorized into the following : "constant-torque load" represented by a conveyor, "variable-torque load" such as a fan and pump, and "constant-output load" such as a winding machine.
For the details of required power calculation, refer to TECHNICAL NOTE No.30 (Appendix)

1) When the load torque is known

$$P_{LR} = \frac{T_{LR} \times N_{max}}{9550} \quad [kW] \quad \cdots (3.1\text{-}1)$$

T_{LR} : Load torque at motor shaft [N·m]
N_{max} : Maximum motor speed [r/min]

2) When calculating the value from the characteristics at machine side

Example: Conveyor

$$P_{LR} = \frac{\mu \times W \times V_{max}}{6120 \times \eta} \quad [kW] \quad \cdots (3.1\text{-}2)$$

μ : Friction coefficient
W : Load mass [kg]
V_{max} : Maximum travel speed [m/min]
η : Machine efficiency

3) When calculating the value from the motor current (when operating the pre-installed machine with the commercial power supply)
The required power can be calculated with the measured current size of the motor.
It can be calculated based on the test report of the connected motor.

(2) Load torque at motor shaft T_{LR}

When the load torque is unknown, the value can be calculated with the required power P_{LR} in the following formula.

$$T_{LR} = \frac{9550 \times P_{LR}}{N_{max}} \quad [N \cdot m] \quad \cdots (3.1\text{-}3)$$

(Note) The motor speed N_{max} is the speed at the required power P_{LR} (travel speed is V_{max}).
(It is not the rated motor speed.)

(Information) When calculating the value from the characteristics at machine side

$$T_{LR} = \frac{\mu \times 9.8 \times W \times V_{max}}{2\pi N_{max} \times \eta} \quad [N \cdot m] \quad \cdots (3.1\text{-}4)$$

Points for the minimum load torque

In some cases, the load torque in the regenerative-drive area is calculated with the machine efficiency $\eta=1$ considering the safety, and the obtained torque from this calculation is used as the minimum load torque T_{LRmin}.

CONTINUOUS OPERATION

(3) Load moment of inertia at motor shaft

Calculate this value in the same manner as for the load torque by referring to TECHNICAL NOTE No.30 (Appendix).

1) When calculating the value from the characteristics at machine side

$$J_L = W \times \left(\frac{V_{max}}{2\pi N_{max}} \right)^2 \quad [kg \cdot m^2] \quad \cdots (3.1\text{-}5)$$

2) When the moment of inertia at the load shaft is known

$$J_L = J_{LO} \times \left(\frac{N_{LO}}{N_{max}} \right)^2 \quad [kg \cdot m^2] \quad \cdots (3.1\text{-}6)$$

J_{LO} : Moment of inertia at the load-driving shaft [$kg \cdot m^2$]
N_{LO} : Speed at the load-driving shaft [r/min]
N_{max} : Maximum motor speed [r/min]
(Speed at V_{max})

3.2 Selection of motor and inverter capacities (tentative)

(1) Selection of the motor capacity (tentative)

Select a motor capacity (tentative) based on the required power obtained in the last section. Select a motor capacity that is equal to or higher than the required power in typical operations.

$$\text{Motor capacity } P_M \geq \text{Required power } P_{LR} \text{ [kW]} \quad \cdots (3.2\text{-}1)$$

Example: When the required power P_{LR}=2.8kW, tentatively select the motor capacity 3.7kW, which is the closest to the required power.

Check if the tentatively selected motor capacity satisfies the following condition.
Check if the load torque is within the rated motor torque.
If the value does not satisfy the formula, try a larger-capacity motor, and re-evaluate.

$$T_M = \frac{9550 \times P_M}{N_M} \geq T_{LR} \quad [N \cdot m] \quad \cdots (3.2\text{-}2)$$

T_M : Rated motor torque [N・m]
P_M : Rated motor output [kW]
N_M : Rated motor speed [r/min]
(Use the synchronous speed for the calculation.)

Points for motor capacity selection

Example: Different motor speeds (1600r/min and 1200r/min) produce different load torques although the required power (2.8kW) is the same. Because of this, different motor capacity must be selected.

When the motor capacity 3.7kW is selected according to the required power 2.8kW :

$$\text{Rated motor torque } T_M = \frac{9550 \times 3.7}{1800} = 19.6 \quad [\text{N·m}]$$

- When the required torque is 2.8kW, and the motor speed is 1200r/min :

$$\text{Load torque } T_{LR} = \frac{9550 \times 2.8}{1200} = 22.3 \quad [\text{N·m}]$$

$T_M=19.6<T_{LR}=22.3$

Even though the load torque T_{LR} is larger than the rated motor torque T_M and the required power is 2.8kW, the 3.7kW motor cannot be used. In this case, select a 5.5kW motor.

- When the required torque is 2.8kW, and the motor speed is 1600r/min :

$$\text{Load torque } T_{LR} = \frac{9550 \times 2.8}{1600} = 16.7 \quad [\text{N·m}]$$

$T_M=19.6>T_{LR}=16.7$

Because the load torque T_{LR} is within the rated motor torque T_M, a 3.7kW motor can be used.

(2) Selection of the inverter capacity (tentative)

Select the inverter capacity (tentative) based on the motor capacity (tentative) obtained in the last section. When using a motor with six poles or more, check that the rated inverter current is equal to or higher than the rated motor current.

Selected inverter capacity (tentative) $P_{INV} \geq$ Rated motor output P_M [kW] ··· (3.2-3)

Points for inverter capacity selection

Choice of an inverter model (series) affects the generated torque, the continuous operation range, and the braking efficiency of the motor. Consider this when selecting an inverter model.

- Generated torque of the motor (maximum short-time torque and starting torque)
  The generated torque under (Advanced) magnetic flux vector control is larger than the torque under conventional V/F control.
- Continuous operation range (the running frequency range where the 100% torque is generated)
  The continuous operation range widens when using a 1.5kW motor or less under (Advanced) magnetic flux vector control.
- Braking efficiency (built-in brake resistor)
  The inverter with a built-in brake resistor is suitable for outputting a brake torque and consuming the regenerative power during deceleration.

3.3 Assessment for the start

To start driving a machine (load), the starting torque of the motor must be larger than the starting torque of the load.
Find out the starting torque of the motor to determine if the machine can be started. The following conditions must be satisfied.

(1) Starting torque of the motor

The starting torque of the motor during inverter operation is smaller than the torque during commercial power supply operation.
The starting torque of the motor is affected by the following conditions.

- Inverter capacity
  The starting torque is larger when a larger-capacity inverter is connected to the motor.
  However, there is a limit to the connectable inverter capacity.
- Control method of the inverter
  The starting torque under (Advanced) magnetic flux vector control is larger than the torque under V/F control.
- Torque boost
  Under V/F control, the higher the torque boost setting is, the larger the starting torque becomes.
  (Starting torque……high torque boost setting>standard torque boost setting)

The maximum starting torque of the motor can be calculated by the following formula.

$$T_{MS} = T_M \times \alpha_S \times \delta \quad [N\cdot m] \quad \cdots (3.3\text{-}1)$$

T_{MS} : Starting torque [N・m]
α_S : Maximum starting torque coefficient…Select according to TECHNICAL NOTE No.30
δ : Hot coefficient…Select according to TECHNICAL NOTE No.30

The load torque at start can be calculated by the following formula.

$$T_{LS} = \frac{\mu_S \times 9.8 \times W \times V_{max}}{2\pi N_{max} \times \eta} \quad [N\cdot m] \quad \cdots (3.3\text{-}2)$$

T_{LS} : Load torque at start [N·m]
W : Load mass [kg]
μ_S : Friction coefficient at start
V_{max} : Maximum travel speed [m/min]
N_{max} : Maximum motor speed [r/min]
η : Machine efficiency

(2) Assessment for the start

The machine can be started if the following condition is satisfied.

$$\text{Maximum starting torque of motor } T_{MS} > \text{Load torque at start } T_{LS} \quad \cdots (3.3\text{-}3)$$

Example :
- Load torque at start T_{LS}=11 [N·m]
- Motor capacity of 3.7kW 4P (T_M = 19.6 [N·m])
- FR-A520-3.7K inverter (V/F control with standard torque boost setting)

Starting torque of the motor $T_{MS} = T_M \times \alpha_S \times \delta$
$=19.6 \times 0.8 \times 0.85 = 13.3 > T_{LS} = 11$ ⇨The machine can be started

α_S : Maximum starting torque coefficient 0.8 (Power driving performance data in TECHNICAL NOTE No.30)
δ : Hot coefficient 0.85 (Outline of Technical Note No.30 [DATA] in TECHNICAL NOTE No.30)

(Note) The output frequency (starting frequency) is determined for the starting torque coefficient of the motor α_S. When the desired minimum operation frequency is within the starting frequency, certain limits are applied to the operation range.
Operation may not be performed at the frequency equal to or lower than the starting frequency.

(3) Countermeasures to take when the start is unavailable

1) Change V/F control ⇒ (Advanced) magnetic flux vector control.
2) Use a larger-capacity inverter.
3) Use a larger-capacity inverter and a larger-capacity motor.

3.4 Assessment for the continuous operation

When the load torque T_{LR} is within the maximum short-time torque of the motor, the motor can rotate. However, in order to operate continuously, the maximum temperature of the motor must not be exceeded.
Permissible temperature of the motor differs by the running frequency. Decide whether a continuous operation can be performed based on the "continuous operation torque characteristic."

(1) Motor temperature characteristic during continuous operation

Cooling efficiency of a motor reduces as the output frequency decreases. Because of this, the permissible temperature of the motor also decreases in most cases.

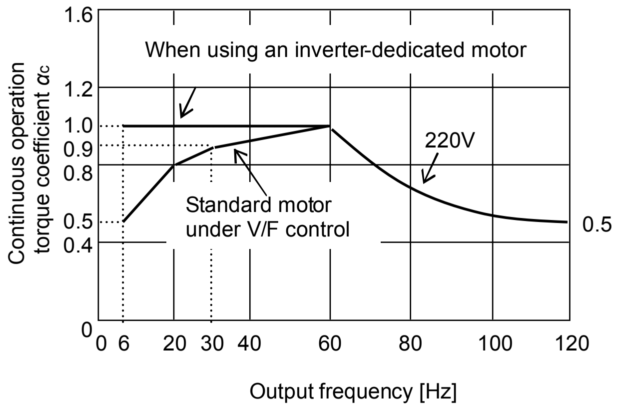


Figure 3.1 Torque characteristic during continuous operation of the motor

(Note) 1. Under V/F control, the continuous operation range differs by the torque boost setting. If the torque boost setting is maximum, a continuous operation cannot be performed at 15Hz or less.
2. The continuous operation torque coefficient does not increase by only increasing the inverter capacity.
3. For the continuous operation torque characteristic of each motor and control, refer to TECHNICAL NOTE No.30 [DATA].

"Reference torque" and motor characteristic

To fabricate a machine, design by using the generated motor torque (rated torque) as a reference.
The rated motor torque can be calculated from the rated speed at 50Hz or 60Hz. However, the rated torque is 1.2 times larger at 50Hz compared with the torque at 60Hz, and the current is also larger by the same rate.
For this reason, the permissible value for a continuous operation (torque coefficient) of the motor differs, so the two data values, one for "reference torque of 50Hz" and another for "reference torque of 60Hz", are available.

- When designing a machine, select appropriate data values according to the reference torque (regardless of the power supply frequency)
  For the maximum starting torque coefficient and the acceleration/deceleration torque coefficient, also select appropriate data values in the same manner.
- Take caution when driving a pre-installed machine (designed for the commercial power supply) with an inverter.

(2) Assessment for the continuous operation

If the load torque exceeds the continuous operation torque range of the motor, a continuous operation cannot be performed.

Continuous operation torque of the motor $T_{MC} = T_M \times \alpha_C >$ Load torque T_{LR} ··· (3.4-1)

T_M : Rated motor torque [N· m]

OR

Continuous operation torque coefficient of the motor $\alpha_C >$ Load torque ratio $TF = \frac{T_{LR}}{T_M}$ ··· (3.4-2)

In the desired operation range (running frequency range) as shown in the figure below, a continuous operation cannot be performed in the area where the load torque ratio exceeds the continuous operation torque coefficient (shaded area).

Continuous operation torque characteristic is determined by the "continuous operation torque coefficient" in TECHNICAL NOTE No.30.

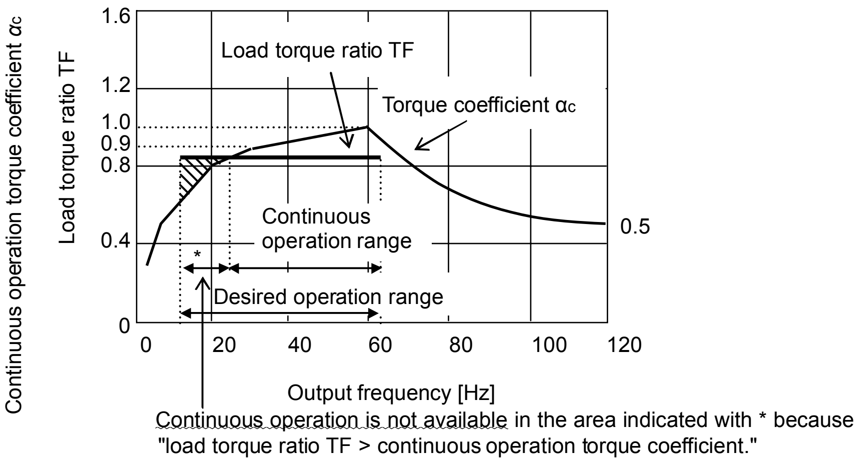


Figure 3.2 Assessment for the continuous operation range

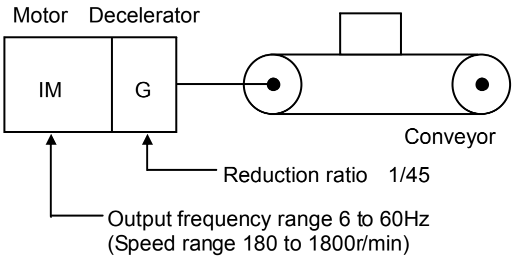
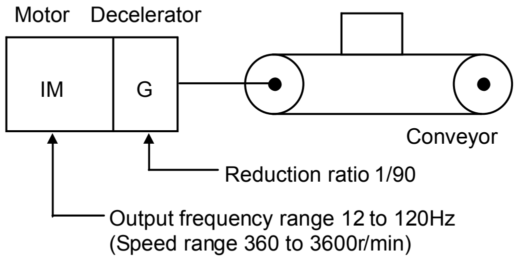
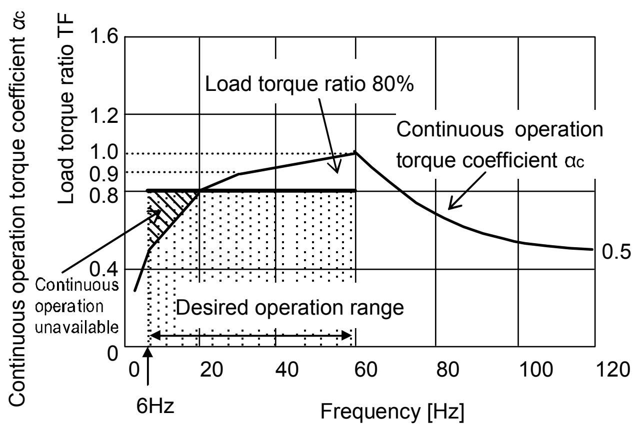
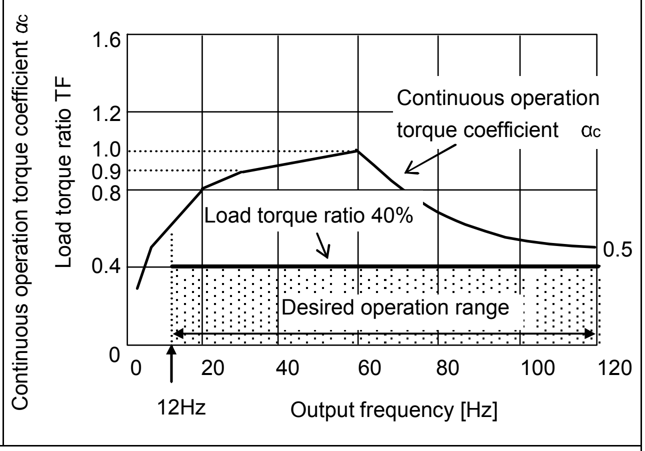
(3) Countermeasures to take when a continuous operation is unavailable

1) Use a larger-capacity inverter and a larger-capacity motor.
   Temperature characteristic of the motor can be improved by using a larger-capacity motor.
2) Temperature characteristic during low-speed operation may be improved by using (Advanced) magnetic flux vector control (or General-purpose magnetic flux control). Refer to the continuous operation torque coefficient in TECHNICAL NOTE No.30 [DATA].
3) Use an inverter-dedicated motor.
   The temperature characteristic during low-speed operation is better with a dedicated motor than with a standard motor.
4) Set a higher reduction ratio.
   Also consider the following countermeasure when a continuous operation is unavailable in certain operation range.
   This method is useful when a larger-capacity motor cannot be used.
   The load torque must be within the continuous operation torque range. The load torque at the motor shaft can be reduced by changing the deceleration mechanism (reduction ratio) mechanically.

《Example of changing the reduction gear of the machine as a countermeasure》

Load/operation specification

- Machine name: conveyor
- Conveyor speed: 30[m/min]
- Transmission ratio: 1 : 10
- Power supply: 220V 60Hz

Design A	Design B
	
● Load torque T_{LR} (at motor shaft) 80% of the rated motor torque ● Maximum speed 1800[r/min]	● Load torque T_{LR} (at motor shaft) Because the reduction ratio of Design A is doubled : Load torque = 80%÷2 = 40% ● Maximum speed 3600[r/min]
	

By halving the reduction ratio of Design A, the load torque at motor shaft becomes half in Design B. The non-operative range (6 to 20Hz) of Design A can be operated in Design B.

Remarks ● Operation at 120Hz may not be available depending on the motor capacity, the number of motor poles and the decelerator type. Check at which frequency the motor can operate in advance.

3.5 Assessment for the acceleration

Calculate the shortest acceleration time that is required to accelerate to the specified frequency.
Shortest acceleration time is the acceleration time exhibited with the maximum acceleration capability without activating the inverter protection circuit.

(1) Limit for the acceleration time

1) When no operational limit exists for the acceleration time
For an actual operation, set the acceleration time longer than the shortest acceleration time by taking a margin. The longer the acceleration time is, the less stress is applied to the motor and inverter.

2) When a limit exists for the acceleration time
When the desired operation cannot be performed with the obtained value, even shorter acceleration time is required. Take the following measures.

Assessment for the acceleration

- Change V/F control ⇒ (Advanced) magnetic vector flux control.
  Generated torque of the motor (short-time torque) increases, and the acceleration torque also increases.
- Use a larger-capacity inverter.
  The acceleration torque increases like the above method.
- Use a larger-capacity inverter and a larger-capacity motor.
  The acceleration torque increases most by this method.

(2) Calculation of the shortest acceleration time

$$\text{Shortest acceleration time } t_{as} = \frac{(J_L + J_M + J_B) \times N_{max}}{9.55\,(T_M \times \alpha_a - T_{LRmax})} \quad [s] \qquad \cdots (3.5\text{-}1)$$

J_L	: Load moment of inertia (at motor shaft) [kg·m^2]
J_M	: Motor moment of inertia [kg·m^2]
J_B	: Brake moment of inertia (at motor shaft) [kg·m^2]
N_{max}	: Maximum motor speed [r/min]
T_M	: Rated motor torque [N·m]
α_a	: Linear acceleration torque coefficient
T_{LRmax}	: Maximum load torque [N·m]

(Note) For the linear acceleration torque coefficient α_a, refer to maximum short-time torque/torque type data in TECHNICAL NOTE No.30.

(3) Assessment for the acceleration

Acceleration is available if the desired acceleration time t_a is longer than the shortest acceleration time t_{as}.

$$t_{as} < t_a \qquad \cdots (3.5\text{-}2)$$

(4) Consideration for the shortest acceleration time

If the current, which activates the inverter's stall prevention function (150% of the rated inverter current), flows for a long time during acceleration, the motor and inverter temperatures exceed the permissible value.

$$\text{Load torque ratio during acceleration } T_{Fa} = \frac{\dfrac{(J_L + J_M + J_B) \times N_{max}}{9.55 \times t_a} + T_{LRmax}}{T_M} \quad [\%] \qquad \cdots (3.5\text{-}3)$$

1) When the shortest acceleration time is within 60s and the load ratio during acceleration T_{Fa} is within 150% (within 120% for FR-F500)
The motor and inverter temperatures are within the permissible value, so the acceleration is available.

2) When the shortest acceleration time exceeds 60s or the load ratio during acceleration T_{Fa} is 150% or higher (120% or higher for FR-F500)
The motor and inverter temperatures may exceed the permissible value.
Refer to the temperature calculations of the motor and inverter in Chapter 4.8 (Cyclic operation), and consider a heat treatment for the acceleration.

3.6 Assessment for the deceleration

Calculate the shortest deceleration time that is required to stop from the specified frequency.
Shortest deceleration time is the deceleration time exhibited with the maximum deceleration capability without activating the inverter protection circuit.

(1) Limit for the deceleration time

1) When no operational limit exists for the deceleration time
For an actual operation, set the deceleration time longer than the shortest deceleration time by taking a margin. The longer the deceleration time is, the less stress is applied to the motor and inverter.

2) When a limit exists for the deceleration time
When the desired operation cannot be performed with the obtained value, even shorter deceleration time is required. Take the following measures.

Assessment for the deceleration

- Use a larger-capacity inverter.
  If an inverter with a built-in brake resistor is being used, using a larger-capacity inverter increases the deceleration torque.
  If an inverter without a built-in brake resistor is been used, using a larger-capacity inverter does not increase the deceleration capability.
- Use a larger-capacity inverter and a larger-capacity motor.
- Use a braking option (brake resistor or brake unit) or a power regeneration converter.

(2) Calculation of the shortest deceleration time

The shortest deceleration time can be calculated by the following formula.

Shortest deceleration time $$t_{ds} = \frac{(J_L + J_M + J_B) \times N_{max}}{9.55\,(T_M \times \beta + T_{LRmin})}$$ [s] ··· (3.6-1)

J_L : Load moment of inertia (at motor shaft) [kg·m^2]
J_M : Motor moment of inertia [kg·m^2]
J_B : Brake moment of inertia (at motor shaft) [kg·m^2]
N_{max} : Maximum motor speed [r/min]
T_M : Rated motor torque [N·m]
β : Deceleration torque coefficient
T_{LRmin} : Maximum load torque [N·m]

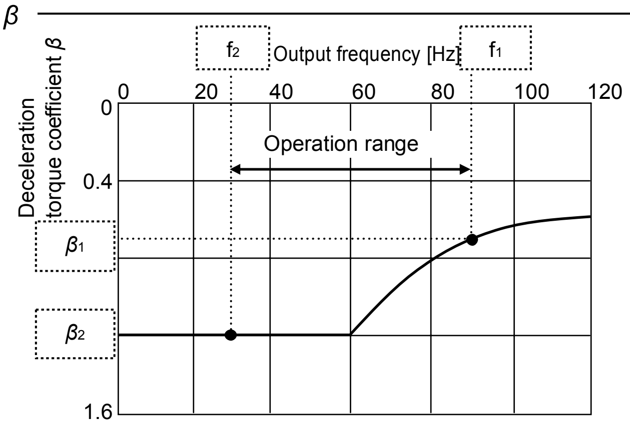
(Note) For the deceleration torque coefficient β, refer to Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30.

How to obtain the deceleration torque coefficient β

To calculate the shortest deceleration time using the deceleration torque characteristic (see the right figure), use the lowest deceleration torque coefficient within the output frequency range for the operation.

For the deceleration torque coefficient β for the calculation, use β 1 because it is smaller than β 2 in the right figure.

(Note) The output torque of the motor during deceleration can be calculated by the following formula :
"output torque of the motor T_M × β"



(3) Assessment for the deceleration

Deceleration is available if the desired deceleration time t_d is longer than the shortest deceleration time t_{ds}.

$$t_{ds} < t_d \qquad \cdots (3.6\text{-}2)$$

Points for the deceleration torque

To perform operation, set the deceleration time longer than the shortest deceleration time described in the former section.

The following formula shows the relationship between the deceleration time and the deceleration torque. As the deceleration time increases, the required torque for the deceleration decreases.

$$\text{Deceleration torque} \quad T_d = \frac{(J_L + J_M + J_B) \times N_{max}}{9.55 \times t_d} \quad [\text{N·m}] \qquad \cdots (3.6\text{-}3)$$

t_d: Deceleration time [s]

3.7 Regenerative power calculation

CONTINUOUS OPERATION

Regenerative power is generated during deceleration and an operation with a negative load. If the regenerative power to the inverter is not consumed enough, the protection circuit of the inverter is activated. Calculate how much regenerative power can be consumed by the inverter based on the regenerative power amount.
The following assessment is not required if the deceleration is confirmed to be available by the capacitor regeneration.

(1) Regenerative power amount

1) Power regenerated from the machine

- During deceleration

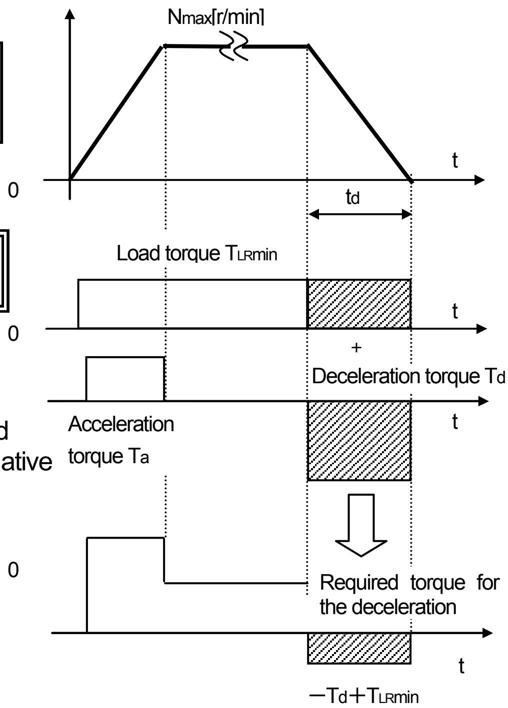
$$W_{MECH}=0.1047\times(-T_d+T_{LRmin})\times\frac{N_{max}}{2}\ [W] \qquad \cdots(3.7\text{-}1)$$

- During constant-speed operation (with negative load)

$$W_{MECH}=0.1047\times T_{LR}\times N_{max} \qquad [W] \qquad \cdots(3.7\text{-}2)$$

T_{LR} : Load torque [N·m]

The power regenerated from the machine can be calculated from the above formulas. When the obtained value is a negative value, it is a regenerative power.



When : $W_{MECH}<0$ (Regenerative driving)

$$W_{MECH}=\left|W_{MECH}\right| \qquad \cdots(3.7\text{-}3)$$

When : $W_{MECH}\geq 0$ (Power driving)
The following calculations are not required.

Example: Deceleration from 1800r/min to stop with the deceleration torque T_d=20 [N·m] and the minimum load torque T_{LRmin}=4 [N·m]

$$W_{MECH} = 0.1047\times(-20+4)\times\frac{1800}{2} \quad [W]$$
$$= -1508 \quad [W]$$

$W_{MECH}<0$, so it is the regenerative driving. Use the following formula for the following calculations.

$$W_{MECH}=\left|W_{MECH}\right|$$
$$=\left|-1508\right|=1508 \quad [W]$$

2) Motor consumed power

$$W_M = k\times P_{LR} \qquad [W] \quad \cdots(3.7\text{-}4)$$

k : Conversion coefficient (calculate from the diagram in 3.6 Power consumed by the motor (Chapter 3 Regeneration performance data) in TECHNICAL NOTE No.30)
P_{LR} : Required power [kW]

3) Power regenerated to the inverter

$$W_{INV} = W_{MECH}-W_M \qquad [W] \quad \cdots(3.7\text{-}5)$$

(2) Assessment for the consumable regenerative power

1) When the regenerative power W_{INV} is a negative value, the operation is performed in power driving like in acceleration (not in regenerative driving), so this assessment is not required.

2) Select a braking option (like a brake resistor), which has higher permissible power than the power regenerated to the inverter W_{INV}.

● During deceleration

$W_{RS} > W_{INV}$ ··· (3.7-6) W_{RS} : Short-time permissible power of a braking option [W]

● During continuous operation (continuous operation with a negative load such as an unwinding operation of a winding machine)

$W_{RC} > W_{INV}$ ··· (3.7-7) W_{RC} : Continuous operation permissible power of a braking option [W]

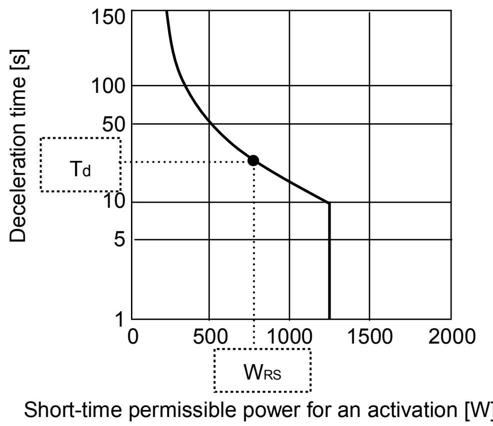
(Note) For the continuous operation permissible power of a braking option, refer to Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30.

How to obtain the short-time permissible power W_{RS} and the continuous operation permissible power W_{RC}

● Short-time permissible power W_{RS}

Selection procedure

1. Calculate the short-time permissible power of the braking option by referring to "Connectable braking option" (Chapter 3 Regeneration performance data) in TECHNICAL NOTE No.30.
2. Calculate the short-time permissible power of the braking option by referring to "Permissible power" (Chapter 3 Regeneration performance data) in TECHNICAL NOTE No.30.
   Calculate the short-time permissible power from the cross point between the deceleration time t_d (used time t_d) line and the characteristic line.



● Continuous operation permissible power W_{RC}

Selection procedure

1. Select a braking option by referring to "Connectable braking option" (Chapter 3 Regeneration performance data) in TECHNICAL NOTE No.30.
2. Calculate the continuous operation permissible power of the braking option by referring to "Permissible power" (Chapter 3 Regeneration performance data) in TECHNICAL NOTE No.30.

CHAPTER 4 CYCLIC OPERATION

4.1 Calculation of load-operating power and load torque

Load characteristics (power, operation pattern, etc.) are required for the calculation. (Refer to Table 2.1.) Especially if the power value is unclear, correct assessment cannot be performed. Follow the following procedure for the calculation.

(1) Required power P_{LR}

Size of a load differs by the machine (load type), but it can be roughly categorized into the following: "constant-torque load" represented by a conveyor, "variable-torque load" such as a fan and pump, and "constant-output load" such as a winding machine.
For the details of required power calculation, refer to TECHNICAL NOTE No.30 (Appendix)

1) When the load torque is known

$$P_{LR} = \frac{T_{LR} \times N_{max}}{9550} \quad [kW] \quad \cdots (4.1\text{-}1)$$

T_{LR} : Load torque at motor shaft [N·m]
N_{max} : Maximum motor speed [r/min]

2) When calculating the value from the characteristics at machine side

Example: Conveyor

$$P_{LR} = \frac{\mu \times W \times V_{max}}{6120 \times \eta} \quad [kW] \quad \cdots (4.1\text{-}2)$$

μ : Friction coefficient
W : Load mass [kg]
V_{max} : Maximum travel speed [m/min]
η : Machine efficiency

3) When calculating the value from the motor current (when operating the pre-installed machine with the commercial power supply)

The required power can be calculated with the measured current size of the motor.
It can be calculated based on the test report of the connected motor.

(2) Load torque at motor shaft T_{LR}

When the load torque is unknown, the value can be calculated with the required power P_{LR} in the following formula.

$$T_{LR} = \frac{9550 \times P_{LR}}{N_{max}} \quad [N \cdot m] \quad \cdots (4.1\text{-}3)$$

(Note) The motor speed N_{max} is the speed at the required power P_{LR} (travel speed is V_{max}).
(It is not the rated motor speed.)

(Information) To calculate the value from the characteristics at machine side

$$T_{LR} = \frac{\mu \times 9.8 \times W \times V_{max}}{2\pi N_{max} \times \eta} \quad [N \cdot m] \quad \cdots (4.1\text{-}4)$$

Points for the minimum load torque

In some cases, the load torque in the regenerative-drive area is calculated with the machine efficiency $\eta = 1$ considering the safety, and the obtained torque from this calculation is used as the minimum load torque T_{LRmin}.

(3) Load moment of inertia at motor shaft

Calculate this value in the same way as the load torque by referring to TECHNICAL NOTE No.30 (Appendix).

1) When calculating the value from the characteristics at machine side

$$J_L = W \times \left(\frac{V_{max}}{2\pi N_{max}}\right)^2 \quad [kg \cdot m^2] \quad \cdots (4.1\text{-}5)$$

2) When the moment at inertia of the load shaft is known

$$J_L = J_{LO} \times \left(\frac{N_{LO}}{N_{max}}\right)^2 \quad [kg \cdot m^2] \quad \cdots (4.1\text{-}6)$$

J_{LO} : Moment of inertia at the load-driving shaft $[kg \cdot m^2]$

N_{LO} : Speed at the load-driving shaft [r/min]

N_{max} : Maximum motor speed [r/min] (Speed at V_{max})

4.2 Selection of motor and inverter capacities (tentative)

(1) Selection of the motor capacity (tentative)

Select a motor capacity (tentative) based on the required power obtained in the last section. Select a motor capacity that is equal to or higher than the required power in typical operations.

$$\text{Motor capacity } P_M \geq \text{Required power } P_{LR} \times k_P \quad [kW] \quad \cdots (4.2\text{-}1)$$

k_P : Margin coefficient for tentative motor selection 1.0 to 2.0

Example: When the required power P_{LR}=2.8 [kW] and k_p=1.0
Tentatively select the motor capacity 3.7kW, which is the closest to the required power.

Check if the tentatively selected motor capacity satisfies the following condition.
Check if the load torque is within the rated motor torque.
If the value does not satisfy the formula, try a larger-capacity motor, and re-evaluate.

$$T_M = \frac{9550 \times P_M}{N_M} \geq T_{LR} \quad [N \cdot m] \quad \cdots (4.2\text{-}2)$$

T_M : Rated motor torque $[N \cdot m]$

P_M : Rated motor output [kW]

N_M : Rated motor speed [r/min] (Use the synchronous speed for the calculation.)

Points for motor capacity selection

Example: Different motor speeds (1600r/min and 1200r/min) produce different load torques although the required power (2.8kW) is the same. Because of this, different motor capacity must be selected.

When the motor capacity 3.7kW is selected according to the required power 2.8kW:

$$\text{Rated motor torque } T_M = \frac{9550 \times 3.7}{1800} = 19.6 \quad [\text{N·m}]$$

- When the required torque is 2.8kW, and the motor speed is 1200r/min:

$$\text{Load torque } T_{LR} = \frac{9550 \times 2.8}{1200} = 22.3 \quad [\text{N·m}]$$

$T_M=19.6<T_{LR}=22.3$

Even though the load torque T_{LR} is larger than the rated motor torque T_M and the required power is 2.8kW, the 3.7kW motor cannot be used. In this case, select a 5.5kW motor.

- When the required torque is 2.8kW, and the motor speed is 1600r/min:

$$\text{Load torque } T_{LR} = \frac{9550 \times 2.8}{1600} = 16.7 \quad [\text{N·m}]$$

$T_M=19.6>T_{LR}=16.7$

Because the load torque T_{LR} is within the rated motor torque T_M, a 3.7kW motor can be used.

(2) Selection of the inverter capacity (tentative)

Select the inverter capacity (tentative) based on the motor capacity (tentative) obtained in the last section. When using a motor with six poles or more, check that the rated inverter current is equal to or higher than the rated motor current.

$$\text{Selected inverter capacity (tentative) } P_{INV} \geq \text{Rated motor output } P_M \quad [\text{kW}] \qquad \cdots (4.3\text{-}3)$$

If the acceleration torque is required to be 1.4 times or more of the standard load torque, tentatively select the inverter capacity that is one rank higher than the motor capacity.

Points for inverter capacity selection

Choice of an inverter model (series) affects the generated torque, the continuous operation range, and the braking efficiency of the motor. Consider this point when selecting an inverter model.

- Generated torque of the motor (maximum short-time torque and starting torque)
  The generated torque under (Advanced) magnetic flux vector control is larger than the torque under conventional V/F control.
- Continuous operation range (the running frequency range where the 100% torque is generated)
  The continuous operation range widens when using a 1.5kW motor or less under (Advanced) magnetic flux vector control.
- Braking efficiency (built-in brake resistor)
  The inverter with a built-in brake resistor is suitable for outputting a brake torque and consuming the regenerative power during deceleration.

4.3 Assessment for the start

To start running a machine (load), the starting torque of the motor must be higher than the starting torque of the load.
Find out the starting torque of the motor to determine if the machine can be started. The following conditions must be satisfied.

(1) Starting torque of the motor

The starting torque of the motor during inverter operation is smaller than the torque during commercial power supply operation.
The starting torque of the motor is affected by the following conditions.

- Inverter capacity
  The starting torque is larger when a larger-capacity inverter is connected to the motor.
  However, there is a limit to the connectable inverter capacity.
- Control method of the inverter
  The starting torque under (Advanced) magnetic flux vector control is larger than the torque under V/F control.
- Torque boost
  Under V/F control, the higher the torque boost setting is, the larger the starting torque becomes.
  (Starting torque……high torque boost setting>standard torque boost setting)

The maximum starting torque of the motor can be calculated by the following formula.

$$T_{MS} = T_M \times \alpha_s \times \delta \quad [N\cdot m] \quad \cdots (4.3\text{-}1)$$

T_{MS} : Starting torque [N·m]
α_s : Maximum starting torque coefficient…Select according to TECHNICAL NOTE No.30
δ : Hot coefficient…Select according to TECHNICAL NOTE No.30

The load torque at start can be calculated by the following formula.

$$T_{LS} = \frac{\mu_s \times 9.8 \times W \times V_{max}}{2\pi N_{max} \times \eta} \quad [N\cdot m] \quad \cdots (4.3\text{-}2)$$

T_{LS} : Load torque at start [N·m]
W : Load mass [kg]
μ_s : Maximum friction coefficient
V_{max} : Maximum travel speed [m/min]
N_{max} : Maximum motor speed [r/min]
η : Machine efficiency

(2) Assessment for the start

The machine can be started when the following condition is satisfied.

Maximum starting torque of motor T_{MS} > Load torque at start T_{LS} ··· (4.3-3)

Example :
- Load torque at start T_{LS} = 11 [N·m]
- Motor capacity of 3.7kW 4P(T_M=19.6 [N·m])
- FR-A520-3.7K inverter (V/F control with standard torque boost setting)

Starting torque of the motor $T_{MS} = T_M \times \alpha_s \times \delta$
$= 19.6 \times 0.8 \times 0.85 = 13.3 > T_{LS} = 11 \Rightarrow$ The machine can be started
α_s : Maximum starting torque coefficient 0.8 (Power driving performance data in TECHNICAL NOTE No.30)
δ: Hot coefficient 0.85 (Outline of Technical Note No.30 [DATA] in TECHNICAL NOTE No.30)

(Note) The output frequency (starting frequency) is determined for the starting torque coefficient of motor α_s.
When the desired minimum operation frequency is within the starting frequency, some limits are applied to the operation range.
Operation may not be performed at the frequency equal to or lower than the starting frequency.

(3) Countermeasures to take when the start is unavailable

1) Change V/F control ⇒ (Advanced) magnetic flux vector control.
2) Use a larger-capacity inverter.
3) Use a larger-capacity inverter and a larger-capacity motor.

4. 4 Assessment for the low-speed and high-speed operations

(1) Assessment for the low-speed operation

The low-speed operation is available when the output torque of the motor (maximum short-time torque) is larger than the load torque during the low-speed operation of less than 20Hz.

$$T_M \times \alpha_m \times \delta > T_{LRmax} \quad \cdots (4.4\text{-}1)$$

α_m : Maximum short-time torque coefficient…Select according to TECHNICAL NOTE No.30.
δ : Hot coefficient…Select according to TECHNICAL NOTE No.30.
T_{LRmax} : Maximum load torque [N･m]

(2) Assessment for the high-speed operation

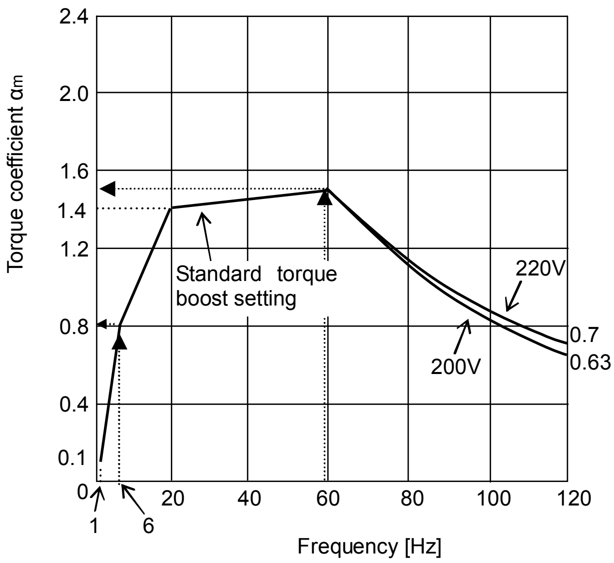
The high-speed operation is available when the output torque of the motor (maximum short-time torque) is larger than the load torque during the high-speed operation of 20Hz or higher.
Maximum frequency is limited in some motor capacities (frame number). Check TECHNICAL NOTE No.30 [DATA].

$$T_M \times \alpha_m > T_{LRmax} \quad \cdots (4.4\text{-}2)$$

How to obtain the maximum short-time torque coefficient α_m

Obtain the maximum short-time torque coefficient α_m by referring to the maximum short-time torque characteristic (shown right) in Chapter 2 Power driving performance data in TECHNICAL NOTE No.30.

Maximum short-time torque α_m changes as shown in the figure on the right.
When a low-speed operation is performed at 6Hz, α_m=0.8
When a high-speed operation is performed at 60Hz, α_m=1.5



4.5 Assessment for the acceleration (calculation of the total acceleration torque)

Figure 4.1 shows the relationship among time, speed and torque. Assess if the acceleration to the maximum speed N_{max} can be performed within the specified acceleration time t_a.

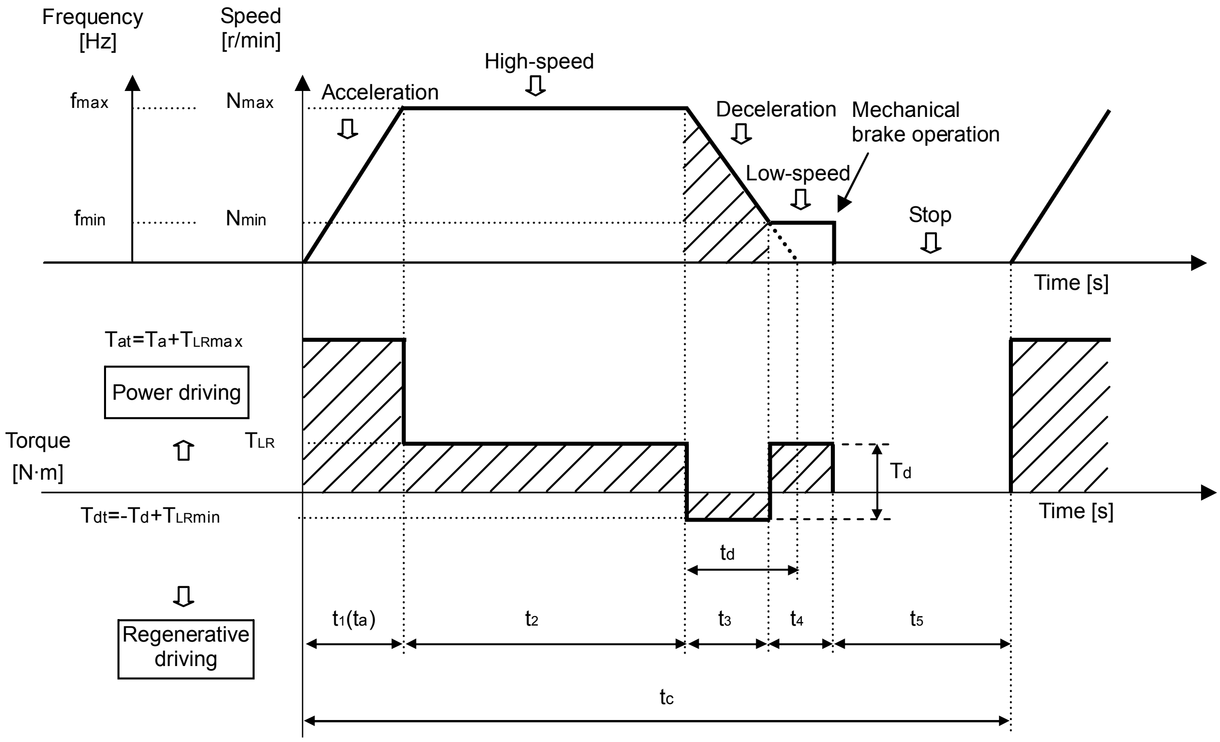


Figure 4.1 Relationship among acceleration time, speed and torque

(1) Acceleration torque T_a

Calculate the acceleration torque T_a in the following formula.

$$T_a = \frac{\sum J \times N_{max}}{9.55 \times t_a} \quad [\text{N·m}] \quad \cdots (4.5\text{-}1)$$

$\sum J$: Total moment of inertia at motor shaft

$= J_M$ (motor) $+ J_B$ (brake) $+ J_L$ (load)

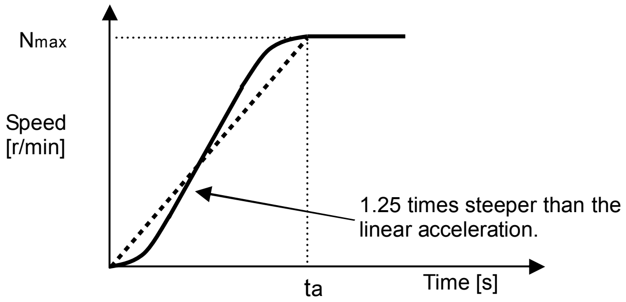
t_a : Acceleration time [s]

N_{max} : Maximum motor speed [r/min]

T_{LRmax} : Maximum load torque [N·m]

Acceleration/deceleration torque during S-pattern acceleration/deceleration (Pr.29=2)

When the S-pattern acceleration/deceleration is selected (Pr.29=2), the slope during S-pattern acceleration/ deceleration is steeper than the slope during linear acceleration/deceleration in some area. Use the steepest area for the calculation.



(Example)

Acceleration speed during linear acceleration = N_{max}/t_a

Maximum acceleration speed during S-pattern acceleration (Pr.29=2) = $1.25 \times N_{max}/t_a$

In this S-pattern acceleration/deceleration (Pr.29=2), calculate the acceleration torque in the following formula.

$$T_a = \frac{\Sigma J \times 1.25 \times N_{max}}{9.55 \times t_a} \quad [N \cdot m]$$

(Information)

When the time between the stop status and the maximum speed N_{max} (maximum travel speed V_{max}) is indicated by the acceleration speed A_{cc}, the A_{cc} value can be converted to the acceleration time t_a by the following formula.

$$t_a = \frac{V_{max}}{60 \times A_{cc}} \quad [s]$$

V_{max} : Maximum travel speed [m/min]

A_{cc} : Acceleration speed [m/s^2]

Acceleration speed is sometimes expressed in gravitational acceleration G.

In that case, refer to the following equation.

(Example) 1G = 9.8 [m/s^2]

(2) Total acceleration torque T_{at}

Total of the acceleration torque T_a and the load torque T_{LR} is required for the acceleration. This value is called the total acceleration torque T_{at}.

To assess cautiously, use the maximum load torque T_{LRmax} as the load torque for the calculation.

$$T_{at} = T_a + T_{LRmax} \qquad [N \cdot m] \qquad \cdots(4.5\text{-}2)$$

T_{at} : Total acceleration torque [N·m]

T_{LRmax} : Maximum load torque at motor shaft [N·m]

(3) Assessment for the acceleration

Acceleration is available when the output torque of the tentatively selected motor is larger than the total acceleration torque T_{at}.

Output torque of the motor		Required torque for the acceleration
$T_M \times \alpha_a$	>	$T_{at} (= T_a + T_{LRmax})$ ···(4.5-3)

α_a : Linear acceleration torque coefficient…Select according to TECHNICAL NOTE No.30.

If the above condition is not satisfied, take the following measures to output larger torque from the motor.

1) If V/F control has been used, set the torque boost setting higher. Alternatively, use (Advanced) magnetic flux vector control.
2) Use an inverter capacity that is one rank higher than the motor capacity.
3) Use one-rank-higher motor and inverter capacities.

4.6 Assessment for the deceleration (calculation of the deceleration torque)

By referring to Figure 4.1, assess if the deceleration from the maximum speed to "0" can be performed within the deceleration time t_d.

(1) Deceleration torque T_d

Calculate the deceleration torque T_d in the following formula.

$$T_d = \frac{\Sigma J \times N_{max}}{9.55 \times t_d} = \frac{\Sigma J \times (N_{max} - N_{min})}{9.55 \times t_3} \quad [N\cdot m] \cdots (4.6\text{-}1)$$

ΣJ : Total moment of inertia at motor shaft
= J_M (motor) + J_B (brake) + J_L (load)

t_d : Deceleration time [s]

N_{max} : Maximum motor speed [r/min]

N_{min} : Minimum motor speed [r/min]

(Information)

When the time between the maximum speed N_{max} (maximum travel speed V_{max}) and the stop is indicated by the acceleration speed A_{cc}, the A_{cc} value can be converted to deceleration time t_d by the following formula.

$$t_d = \frac{V_{max}}{60 \times A_{cc}} \quad [s]$$

V_{max} : Maximum travel speed [m/min]

A_{cc} : Acceleration speed [m/s^2]
Acceleration speed is sometimes expressed in gravitational acceleration G.
In that case, refer to the following equation.
(Example) 1G = 9.8 [m/s^2]

(2) Total deceleration torque T_{dt}

The difference between the deceleration torque t_d and the load torque T_{LR} is required for the deceleration. This value is called the total deceleration torque T_{dt}.
To assess cautiously, use the minimum load torque T_{LRmin} as the load torque for the calculation. To assess the worst case, use T_{LRmin} =0.

$T_{dt} = -T_d + T_{LRmin}$ [N·m] ···(4.6-2)
·When $T_{dt}<0$ → Assess for the deceleration (4.6-3) by assuming $T_{dt}=|T_{dt}|$.
·When $T_{dt}\geq 0$ → Assessment for the deceleration and calculation of regenerative power are not required.

T_{dt} : Total deceleration torque [N·m]

T_{LRmin} : Maximum load torque at motor shaft [N·m]

(3) Assessment for the deceleration

Deceleration is available when the output torque of the tentatively selected motor is larger than the total deceleration torque T_{dt}.

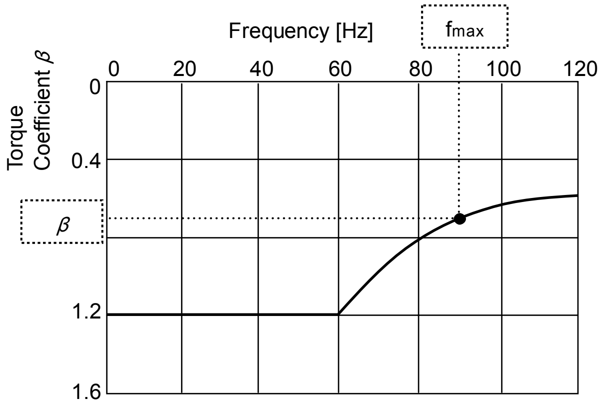
Output torque of the motor		Required torque for the deceleration	
$T_M \times \beta$	>	$T_{dt}(= -T_d + T_{LRmin})$	···(4.6-3)

β :Deceleration torque coefficient…Select according to TECHNICAL NOTE No.30.

If the above condition is not satisfied, take the following measures to output larger torque from the motor.
1) Use an external brake resistor or a brake unit in combination.
2) Use a power regeneration converter.

How to obtain the deceleration torque coefficient *β*

(1) Refer to Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30. Select a braking option to be additionally used that satisfies the following condition: The value in first two digits of torque type (indicating the maximum torque %) is equal to or higher than the required brake torque.
(2) Calculate the torque coefficient when using a braking option, which has been selected according to the brake torque data in Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30, in combination.



4.7 Regenerative power calculation (temperature calculation of the braking option)

Assume the operation pattern of Figure 4.2. The power regenerated to the inverter must be consumed by the braking option during short-time operation and throughout the operation. The following assessment is not required if $-T_d + T_{LRmin} > 0$. The following assessment is also not required if the deceleration is confirmed to be available by the capacitor regeneration.

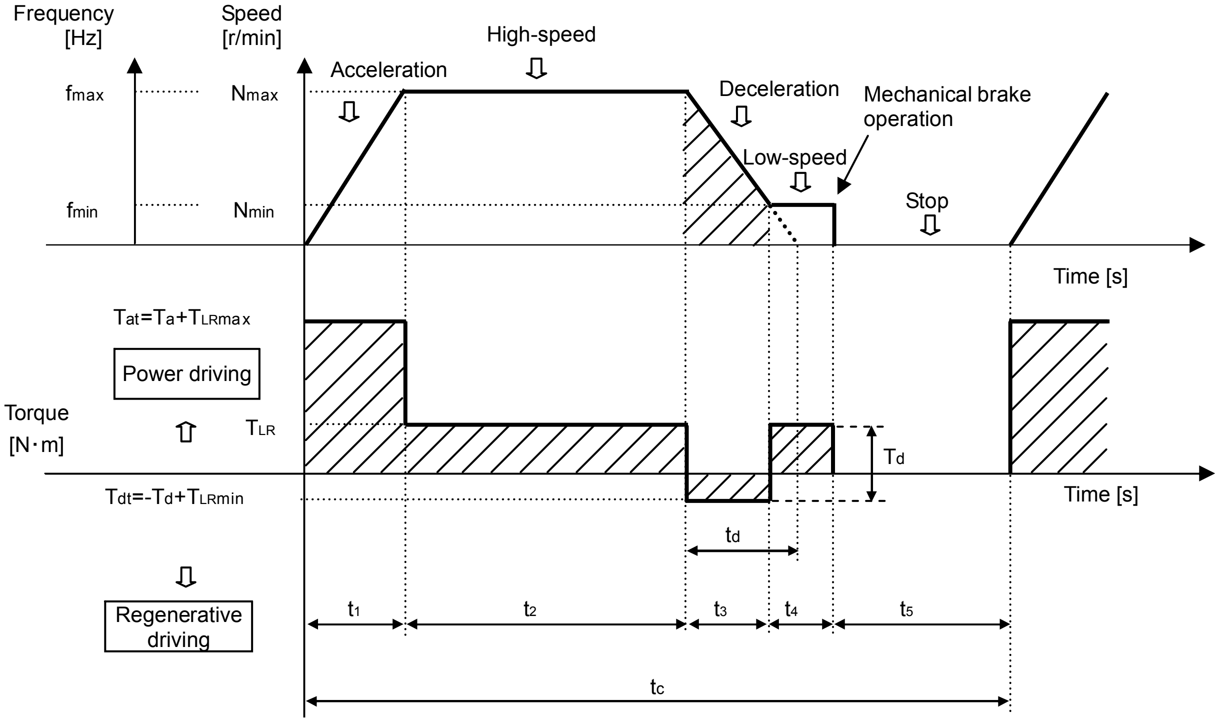


Figure 4.2 Operation pattern

(1) Check for the short-time permissible power

Calculate the power regenerated from the load W_{MECH}. Focus on the deceleration part in Figure 4.2. The power regenerated from the machine W_{MECH} can be calculated by the following formula.

$$W_{MECH} = 0.1047 \times (-T_d + T_{LRmin}) \times \frac{N_{max} + N_{min}}{2} \quad [W] \quad \cdots(4.7\text{-}1)$$

The power regenerated from the machine can be calculated from the above formula. When the obtained value is a negative value, it is a regenerative power.

When $W_{MECH}<0$ (Regenerative driving)
$W_{MECH}=|W_{MECH}|$
When $W_{MECH}\geq 0$ (Power driving)
The following calculations are not required.

Some of this regenerative power is consumed by the motor. The following formula shows how much power is consumed by the motor (W_M).

$$W_M = (k_1 - k_2) \times P_{LR} \quad [W] \quad \cdots(4.7\text{-}2)$$

P_{LR} : Required power for the load
k_1 : Conversion coefficient at the maximum running frequency f_{max}
k_2 : Conversion coefficient at the minimum running frequency f_{min}

For k_1 and k_2, refer to Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30.

The following formula shows how much power is regenerated to the inverter (W_{INV}).

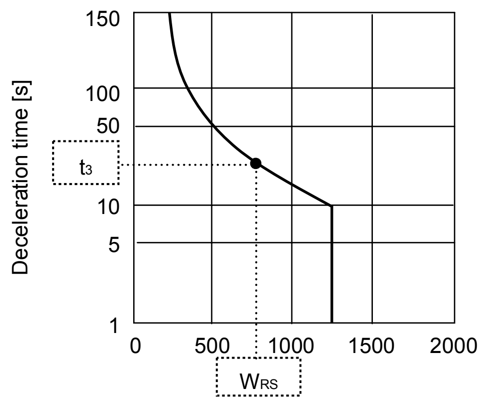
$$W_{INV} = (\text{Power consumed from the load}) - (\text{Power consumed by the motor}) = W_{MECH} - W_M \quad [W] \quad \cdots(4.7\text{-}3)$$

Check if the short-time permissible power of the braking option (W_{RS}) is equal to or larger than the power regenerated to the inverter (W_{INV}).

$$W_{RS} > W_{INV} \qquad \cdots(4.7\text{-}4)$$

How to obtain the short-time permissible power of a regenerative power unit activation W_{RS}

Select the short-time permissible power of the braking option by referring to Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30.
Calculate the permissible power for an operation based on the deceleration time.



(2) Check for the average continuous regenerative power

Check that the average regenerative power is within the continuous operation permissible power of the braking option throughout a cycle (W_{RS}).

$$W_{RC} > W_{INV} \times \frac{t_3}{t_C} \qquad \cdots(4.7\text{-}5)$$

For W_{RC}, refer to TECHNICAL NOTE No.30.

Characteristic and comparison of the built-in/external brake resistor, brake unit, and power regeneration converter

(1) Inverter built-in brake resistor
100% or higher brake torque can be obtained, but the brake duty (%ED) is low (3% or less).
This is available for 7.5kW or less.

(2) External brake resistor
Same size of brake torque can be obtained as the built-in brake resistor. Choose one according to the required brake duty (%ED).

External brake resistor model	%ED
MRS series	3
MYS series	6
ABR series	10

(3) Brake unit (FR-BU type and FR-BR type used in combination)
Obtain larger brake torque by using the brake unit capacity (and the inverter capacity), which is higher than the motor capacity. 10% or higher brake duty (%ED) is available.

(4) Power regeneration common converter (FR-CV type)
Same as for the brake unit. Continuous operation with 100% torque is also available.

Simple selection of a brake unit or a power regeneration converter

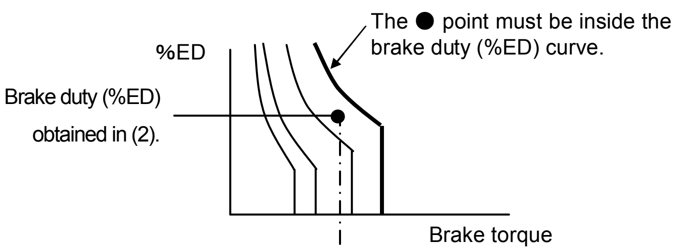
Simple selection can be made by referring to the characteristic diagram of the permissible brake duty (%ED). (For the %ED characteristic diagram, refer to Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30.)

(1) Calculate the required torque for the deceleration. Select the braking option, which has larger brake torque than the calculated required torque by referring to Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30.
Calculate the required torque for the deceleration by $-T_d + T_{LRmin}$.

(2) Calculate the brake duty (%ED).
In Figure 4.2

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

(3) Check that the brake duty is within the permissible brake duty (%ED), which is selected earlier, by referring to the characteristic diagram (%ED) in Chapter 3.5 Permissible brake duty (%ED)(Chapter 3 Regeneration performance data) in TECHNICAL NOTE No.30.



Required torque for the deceleration $\frac{|-T_d + T_{LRmin}|}{T_M} \times 100\%$

4.8 Temperature calculation of the motor and inverter

CYCLIC OPERATION

(1) Temperature assessment by the equivalent current of the motor torque

Calculate the current in each operation block of one cycle. Check that the root mean square of the currents, which is the average current throughout the cycle, is within the rated current of the motor.

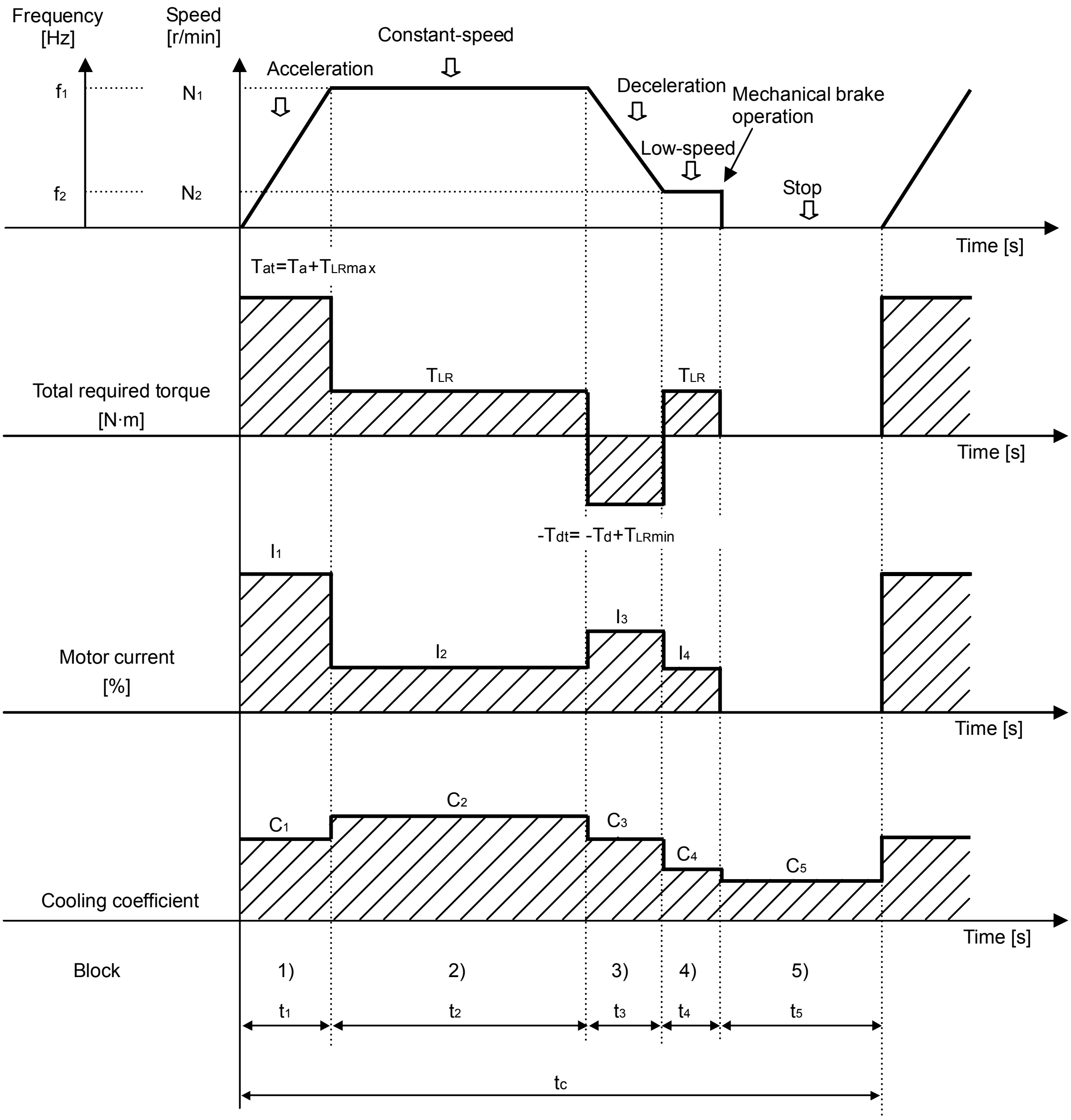


Figure 4.3. Operation pattern

(2) How to calculate the motor current $I_1, I_2 ... I_n$ [%] and the cooling coefficient $C_1, C_2 ... C_n$

Calculate the total torque in each operation block by the following procedure. After calculating the load torque ratio, calculate the ratio of the motor current (%) to the load torque ratio by referring to Chapter 4 Motor and brake characteristics in TECHNICAL NOTE No.30.

1) Calculate the total torque in each operation block by referring to the table below

Operation block	Time period in the block [s]	Total torque in the operation block [N·m]
1)	t_1	$T_1 = Ta + T_{LRmax}$
2)	t_2	$T_2 = T_{LR}$
3)	t_3	$T_3 = -Td + T_{LRmin}$
4)	t_4	$T_4 = T_{LR}$
5)	t_5	$T_5 = 0$ (Block for stop status)

2) Calculate the load torque ratio

$$\text{Load torque ratio } TF_n = \frac{\text{Total torque in each operation block } T_n}{\text{Rated motor torque } T_M} \times 100 \quad (n=1, 2, 3...) \quad [\%] \cdots (4.8\text{-}1)$$

The following formula shows how the current-equivalent load torque ratio TF_I is calculated within the rated output range of the motor (the range equal to or higher than the base frequency) (example : 60 to 120Hz).

Current-equivalent load torque ratio in the range equal to or higher than the base frequency

$$TF_I = \frac{\text{Total torque in each operation block } T_n}{\text{Rated motor torque } T_M} \times \frac{\text{Running frequency}}{\text{Base frequency}} \times 100 \quad [\%] \cdots (4.8\text{-}2)$$

3) How to calculate the coefficient $C_1, C_2 ... C_n$

Calculate the coefficient by referring to Chapter 4 Motor and brake characteristics in TECHNICAL NOTE No.30.

4) How to calculate the motor current

Calculate the ratio of the motor current (%) to the load torque ratio TF_n (current-equivalent load torque ratio TF_I), which is obtained in 2) by referring to Chapter 4 Motor and brake characteristics in TECHNICAL NOTE No.30.

When the maximum frequency is higher than the base frequency during acceleration/deceleration, multiply the obtained motor current by the current compensation coefficient (k60 or k50). (Refer to Chapter 4 Motor and brake characteristics in TECHNICAL NOTE No.30.)

(Note) The current is higher during Cyclic operation under vector control. Multiply the above-obtained value by 1.2 times, and use that value as the motor current I_n.

When the average current is around 100%

When driving a standard motor by an inverter, higher motor current (about 1.1 times) is required to output the same amount of torque compared with when driving by the commercial power supply,

When the equivalent current of the motor torque is 100%, 110% current flows during inverter operation. Little margin for the temperature rise is left when driving a standard motor. Thoroughly consider the load condition and operation duty.

(3) Temperature calculation of the motor

If the following condition is satisfied in Figure 4.3, the use of motor is available regarding the temperature.

$$I_{MC}=\sqrt{\frac{\Sigma(I_n^2 \times t_n)}{\Sigma(C_n \times t_n)}} < 100\ [\%]\ \text{(Note)} \qquad \cdots(4.8\text{-}3)$$

I_{MC}	:	Equivalent current of motor torque considering the cooling coefficient [%]
$I_1, I_2, \ldots I_n$	:	Motor current in an operation block $t_1, t_2 \ldots t_n$ [%]
$C_1, C_2, \ldots C_n$	:	Cooling coefficient for the frequency f_1 to f_n in an operation block $t_1, t_2 \ldots t_n$

(Information) Calculation table for motor temperature

Operation block	Time period in the block [s]	Total torque in the operation block [N·m]	Load torque ratio [%]	Cooling coefficient	Motor current [%]	$I_n^2 \times t_n$	$C_n \times t_n$
1)	$t_1=$	$T_1=$	$TF_1=$	$C_1=$	$I_1=$	$I_1^2 \times t_1=$	$C_1 \times t_1=$
2)	$t_2=$	$T_2=$	$TF_2=$	$C_2=$	$I_2=$	$I_2^2 \times t_2=$	$C_2 \times t_2=$
3)	$t_3=$	$T_3=$	$TF_3=$	$C_3=$	$I_3=$	$I_3^2 \times t_3=$	$C_3 \times t_3=$
4)	$t_4=$	$T_4=$	$TF_4=$	$C_4=$	$I_4=$	$I_4^2 \times t_4=$	$C_4 \times t_4=$
5)	$t_5=$	$T_5=$	$TF_5=$	$C_5=$	$I_5=$	$I_5^2 \times t_5=$	$C_5 \times t_5=$

(4) Electronic thermal relay check

Check that the motor does not overheat even if the equivalent current of the motor torque I_{MC} drops to 100% or less in the operation blocks during acceleration and constant-speed operation.

1) Calculate the ratio of the electronic thermal relay operation time to the load torque ratio in each operation block

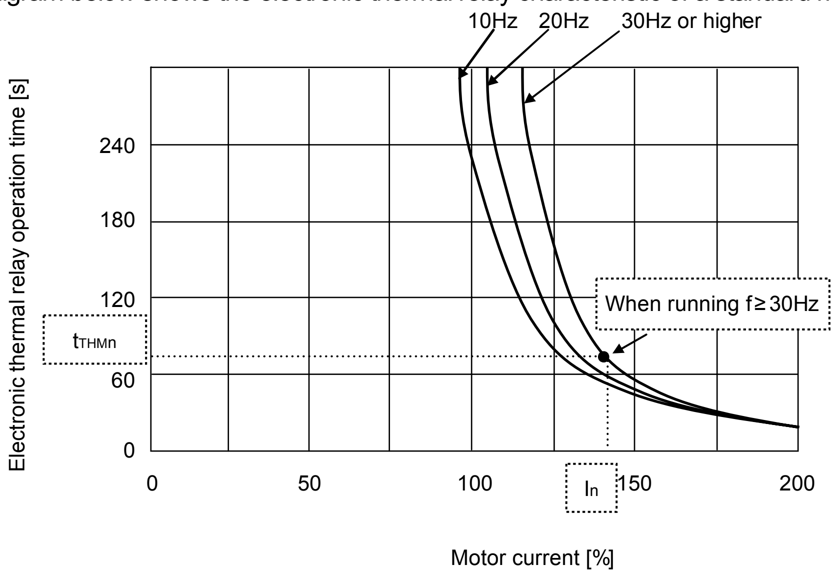
Operation block	Time period in the block [s]	Running frequency	Motor current [%]	Electronic thermal relay operation time [s]
1)	t_1	$\frac{f_1}{2}$	I_1	$t_{THM1}=$
2)	t_2	f_1	I_2	$t_{THM2}=$
3)	t_3	$\frac{(f_1+f_2)}{2}$	I_3	$t_{THM3}=$
4)	t_4	f_2	I_4	$t_{THM4}=$
5)	t_5	0	$I_5=0$	$t_{THM5}=0$

2) In the operation blocks where the motor current $I \geq 100$ [%], check that the time period in the block is shorter than the electronic thermal relay operation time.

$$t_n < t_{THMn} \qquad \cdots(4.8\text{-}4)$$

How to obtain the electronic thermal relay operation time t_{THMn}

Calculate the time using the average running frequency and the motor current by referring to the Electronic thermal relay characteristic in TECHNICAL NOTE No.30.
(Note) The diagram below shows the electronic thermal relay characteristic of a standard motor.



(5) Transistor protection thermal check

If the current larger than the 150% rated inverter current (120% for the FR-F500 series) flows, the transistor protection of the inverter is activated. To prevent this, check that the protective function does not get activated during the operation.

$$\text{Load ratio to the rated inverter current } TF_{INV}[\%] = \frac{I_n[\%] \times \text{Rated motor current [A]}}{\text{Rated inverter current [A]}} \quad \cdots (4.8\text{-}5)$$

I_n [%] : Motor current in each operation block

1) Calculate the load ratio to the rated inverter current in each operation block.

Operation block	Motor current [%]	Load ratio to the rated inverter current [%]
1)	I_1=	$TF_{INV1}=I_1\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
2)	I_2=	$TF_{INV2}=I_2\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
3)	I_3=	$TF_{INV3}=I_3\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
4)	I_4=	$TF_{INV4}=I_4\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
5)	I_5=0	$TF_{INV5}=I_5\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$

2) Check that the load ratio to the rated inverter current TF_{INV} is within 150% (within 120% for FR-F500) in each operation block.

$$TF_{INV} \leq 150\% \text{ (Note)} \quad \cdots (4.8\text{-}6)$$

(Note) It is 120% for the FR-F500 series inverters.

4. 9 Stop accuracy

This section describes about the stop operation using a mechanical brake in the speed pattern shown in Figure 4.4.

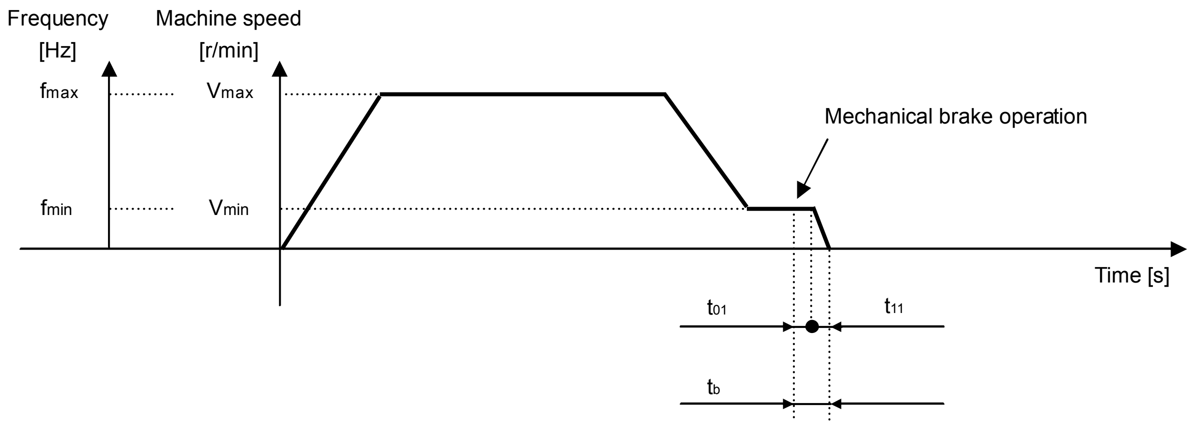


Figure 4.4 Speed pattern of a stop

(1) Characteristics of a mechanical brake

When using a T_B brake, calculate the following constants by referring to Chapter 4.6 Brake characteristic (Chapter 4 Motor and brake characteristics) in TECHNICAL NOTE No.30. (When using other brakes, refer to the manufacturer's characteristic table.)

Rated brake torque	:	T_B [N·m]
Coasting time (cut off in advance)	:	t_{01} [s]
Brake moment of inertia	:	J_B [kg·m^2]

(2) Stop accuracy when the machine stops from the low-speed (creep speed) operation

Calculate the time to stop and the distance to stop in the following formulas, and estimate the stop accuracy.

Time to stop t_b = Coasting time t_{01} + Braking time t_{11}

$$= t_{01} + \frac{\Sigma J \times Nmin}{9.55(T_B + T_{LR}min)} \quad [s] \qquad \cdots(4.9\text{-}1)$$

Distance to stop $S = S_{01} + S_{11}$

$$= \left(t_{01} \times \frac{Vmin}{60} + t_{11} \times \frac{1}{2} \times \frac{Vmin}{60}\right) \times 10^3 \quad [mm] \qquad \cdots(4.9\text{-}2)$$

Vmin : The speed immediate before a stop

= The machine speed equivalent to the motor speed Nmin [r/min]

(low-speed operation speed = creep speed) [m/min]

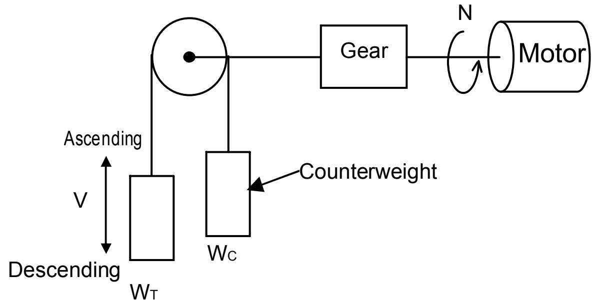
Estimated stop accuracy

$$\Delta\varepsilon = \pm\frac{S}{2} \quad [mm] \qquad \cdots(4.9\text{-}3)$$

CHAPTER 5 LIFT OPERATION

5.1 Calculation of required power and load torque

Calculate the required power for the load P_{LR} and the load torque T_{LR} (at motor shaft) in the following formulas for typical operations.



Operation	Condition	
	W_T-W_C≥0	W_T-W_C<0
Ascending	Power driving	Regenerative driving
Descending	Regenerative driving	Power driving

Figure 5.1 Mechanical structure for Lift operation

(1) Required power P_{LR}

$$P_{LR} = \frac{W \times V_{max}}{6120 \times \eta} \quad [kW] \quad \cdots(5.1\text{-}1)$$

· For W, use the absolute value of "W_T-W_C+ W_{CS}" or "W_C-W_T+ W_{CS}", whichever is larger.

W_T : Load mass [kg]
W_C : Counterweight mass [kg]
W_{CS} : Unbalanced load mass of the chain [kg]
V_{max} : Maximum ascending speed [m/min]
η : Machine efficiency
N_{max} : Motor speed at the ascending speed V_{max} [r/min]

What is the unbalanced load mass of the chain W_{CS} ?

Unbalanced load mass to the right or left due to the mass of chain itself.

(2) Load torque T_{LR}

1) During power driving

$$T_{LU} = \frac{9.8 \times W \times V_{max}}{2\pi N_{max} \times \eta} + \frac{\mu \times 9.8 \times W_{ALL} \times V_{max}}{2\pi N_{max} \times \eta} \quad [N·m]\cdots(5.1\text{-}2)$$

Points for W
When W_T-W_C≥0→W=W_T-W_C+W_{CS}
When W_T-W_C<0→W=W_C-W_T+W_{CS}

T_{LU} : Load torque during power driving [N·m]
W : Load mass [kg]
V_{max} : Maximum travel speed [m/min]
N_{max} : Maximum motor speed [r/min]
η : Machine efficiency
μ : Friction coefficient
W_{ALL} : Total mass (=W_T+W_C+W_{CH}) [kg]
W_{CH} : Chain mass [kg]

2) During regenerative driving (calculate with "machine efficiency η =1" and "friction coefficient μ =0" considering the safety.)

$$T_{Lf} = \frac{9.8 \times W \times \eta \times V_{max}}{2\pi N_{max}} \quad [N·m]\cdots(5.1\text{-}3)$$

Points for W
When W_T-W_C≥0→W=W_C-W_T-W_{CS}
When W_T-W_C<0→W=W_T-W_C-W_{CS}

T_{Lf} : Load torque during regenerative driving [N·m]
W : Load mass [kg]
V_{max} : Maximum travel speed [m/min]
N_{max} : Maximum motor speed [r/min]
η : Machine efficiency
W_{ALL} : Total mass (=W_T+W_C+W_{CH}) [kg]
W_{CH} : Chain mass [kg]

Compare T_{LU} and T_{Lf}, and use whichever with the larger absolute value as the load torque T_{LR} for the following calculations.

5.2 Selection of motor and inverter capacities (tentative)

LIFT OPERATION

(1) Selection of the motor capacity (tentative)

Select a motor capacity (tentative) based on the required power obtained in the last section. Select a motor capacity that is equal to or higher than the required power for typical operations.

Motor capacity $P_M \geq$ Required power $P_{LR} \times k_P$ [kW] ···(5.2-1)

k_P : Margin coefficient for tentative inverter selection 1.0 to 2.0

Example: When the required power P_{LR}=2.8 [kW] and k_p=1.0

Tentatively select the motor capacity 3.7kW, which is the closest to the required power.

Check if the tentatively selected motor capacity satisfies the following condition.
Check if the load torque is within the rated motor torque.
If the value does not satisfy the formula, try a larger-capacity motor, and re-evaluate.

$$T_M = \frac{9550 \times P_M}{N_M} \geq T_{LR} \quad [\text{N·m}] \qquad \cdots(5.2\text{-}2)$$

T_M : Rated motor torque [N·m]
P_M : Rated motor output [kW]
N_M : Rated motor speed [r/min]
(Use the synchronous speed for the calculation.)

Points for motor capacity selection

Example: Different motor speeds (1600r/min and 1200r/min) produce different load torques although the required power (2.8kW) is the same. Because of this, different motor capacity must be selected.

When the motor capacity 3.7kW is selected according to the required power 2.8kW :

$$\text{Rated motor torque } T_M = \frac{9550 \times 3.7}{1800} = 19.6 \quad [\text{N·m}]$$

- When the required torque is 2.8kW, and the motor speed is 1200r/min :

$$\text{Load torque } T_{LR} = \frac{9550 \times 2.8}{1200} = 22.3 \quad [\text{N·m}]$$

T_M=19.6<T_{LR}=22.3

The load torque T_{LR} is larger than the rated motor torque T_M although the required power is 2.8kW, so the 3.7kW motor cannot be used. In this case, select a 5.5kW motor.

- When the required torque is 2.8kW, and the motor speed is 1600r/min :

$$\text{Load torque } T_{LR} = \frac{9550 \times 2.8}{1600} = 16.7 \quad [\text{N·m}]$$

T_M=19.6>T_{LR}=16.7

Because the load torque T_{LR} is within the rated motor torque T_M, a 3.7kW motor can be used.

(2) Selection of the inverter capacity (tentative)

Select the inverter capacity (tentative) based on the motor capacity (tentative) obtained in the last section. When using a motor with six poles or more, check that the rated inverter current is equal to or higher than the rated motor current.

Selected inverter capacity (tentative) P_{INV} ≥ Rated motor output P_M [kW] ···(5.2-3)

If the acceleration torque is required to be 1.4 times or more of the standard load torque, tentatively select the inverter capacity that is one rank higher than the motor capacity.

Points for inverter capacity selection

Choice of an inverter model (series) affects the generated torque, the continuous operation range, and the braking efficiency of the motor. Consider this point when selecting an inverter model.

- Generated torque of the motor (Maximum short-time torque and starting torque)
  The generated torque under (Advanced) magnetic flux vector control is larger than the torque under conventional V/F control.
- Continuous operation range (the running frequency range where the 100% torque is generated)
  The continuous operation range widens when using a 1.5kW motor or less under (Advanced) magnetic flux vector control.
- Braking efficiency (built-in brake resistor)
  The inverter with a built-in brake resistor is suitable for outputting a brake torque and consuming the regenerative power during deceleration.

5.3 Assessment for the start

During inverter operation, the motor is started and accelerated with the current equal to or lower than the permissible current of the inverter (150% 1s). Because of this, the starting torque and the acceleration torque are smaller during inverter operation compared to commercial power supply operation.
Especially in ascending operation, the motor torque must be larger than the load torque T_{LR} to prevent the object from dropping due to a starting torque shortage after the holding brake for the machine has been released.
Usually the more torque is required to move a stand-still object than the load torque T_{LR} due to the static friction. Make an assessment after full consideration on machines.
For regenerative driving, calculate with "machine efficiency η=1" considering the safety.
To start driving a machine (load), the starting torque of the motor must be higher than the starting torque of the load.
Find out the starting torque of the motor, and assess if the start is available.

(1) Starting torque of the motor

The starting torque of the motor during inverter operation is smaller than the torque during commercial power supply operation.
The starting torque of the motor is affected by the following conditions.

- Inverter capacity
  The starting torque is larger when a larger-capacity inverter is connected to the motor.
  However, there is a limit to the connectable inverter capacity.
- Control method of the inverter
  The starting torque under (Advanced) magnetic flux vector control is larger than the torque under V/F control.
- Torque boost
  Under V/F control, the higher the torque boost setting is, the larger the starting torque becomes.
  (Starting torque······high torque boost setting>standard torque boost setting)

The maximum starting torque of the motor can be calculated by the following formula.

$$T_{MS} = T_M \times \alpha_S \times \delta \quad [N\cdot m] \cdots (5.3\text{-}1)$$

T_{MS} : Maximum starting torque [N·m]

α_S : Maximum starting torque coefficient······Select according to TECHNICAL NOTE No.30.

δ : Hot coefficient…Select according to TECHNICAL NOTE No.30

Calculate the load torque at start by the following formula.

1) During power driving

$$T_{LS} = \frac{9.8 \times W \times V_{max}}{2\pi N_{max} \times \eta} + \frac{\mu_S \times 9.8 \times W_{ALL} \times V_{max}}{2\pi N_{max} \times \eta} \ [N \cdot m] \quad \cdots (5.3\text{-}2)$$

2) During regenerative driving

$$T_{LS} = |T_{Lf}| \quad \cdots (5.3\text{-}3)$$

(2) Assessment for the start

The machine can be started when the following condition is satisfied.

Maximum starting torque of the motor T_{MS} > Load torque at start T_{LS} ···(5.3-4)

Example:
- Load torque at start T_{LS}=11 [N·m]
- Motor capacity of 3.7kW 4P(T_M =19.6 [N·m])
- FR-A520-3.7K inverter (V/F control with standard torque boost setting)

Starting torque of the motor $T_{MS} = T_M \times \alpha_s \times \delta$

$= 19.6 \times 0.8 \times 0.85 = 13.3 > T_{LS} = 11$ ⇒ The machine can start

α_s : Maximum starting torque coefficient 0.8 (Power driving performance data in TECHNICAL NOTE No.30)

δ : Hot coefficient 0.85 (Outline of Technical Note No.30 [DATA] in TECHNICAL NOTE No.30)

(Note) The output frequency (starting frequency) is determined for the starting torque coefficient of motor α_s. When the desired minimum running frequency is within the starting frequency, some limits are applied to the operation range.
Operation may not be performed at the frequency equal to or lower than the starting frequency.

(3) Countermeasures to take when the start is unavailable

1) Change V/F control ⇒ (Advanced) magnetic flux vector control.
2) Use a larger-capacity inverter.
3) Use a larger-capacity inverter and a larger-capacity motor.

5. 4 Assessment for the low-speed and high-speed operations

(1) Assessment for the low-speed operation

The low-speed operation is available when the output torque of the motor (maximum short-time torque) is larger than the load torque during the low-speed operation of less than 20Hz.

1) During power driving

$$T_M \times \alpha_m \times \delta > T_{LU} \quad \cdots (5.4\text{-}1)$$

α_m : Maximum short-time torque coefficient ··· Select according to TECHNICAL NOTE No.30

δ : Hot coefficient…Select according to TECHNICAL NOTE No.30

T_{LU} : Load torque during power driving [N·m]

2) During regenerative driving

$$T_M \times \beta \times \delta > |T_{Lf}| \quad \cdots (5.4\text{-}2)$$

β : Deceleration torque coefficient ··· Select according to TECHNICAL NOTE No.30

δ : Hot coefficient … Select according to TECHNICAL NOTE No.30

T_{Lf} : Load torque during regenerative driving [N·m]

(2) Assessment for the high-speed operation

The high-speed operation is available when the output torque of the motor (maximum short-time torque) is larger than the maximum load torque during the high-speed operation of 20Hz or higher.
Maximum frequency is limited in some motor capacities (frame number). Check TECHNICAL NOTE No.30 [DATA].

1) During power driving

$$T_M \times \alpha_m > T_{LU} \quad \cdots(5.4\text{-}3)$$

α_m : Maximum short-time torque coefficient··· Select according to Technical Note No.30
T_{LU} : Load torque during power driving [N·m]

2) During regenerative driving

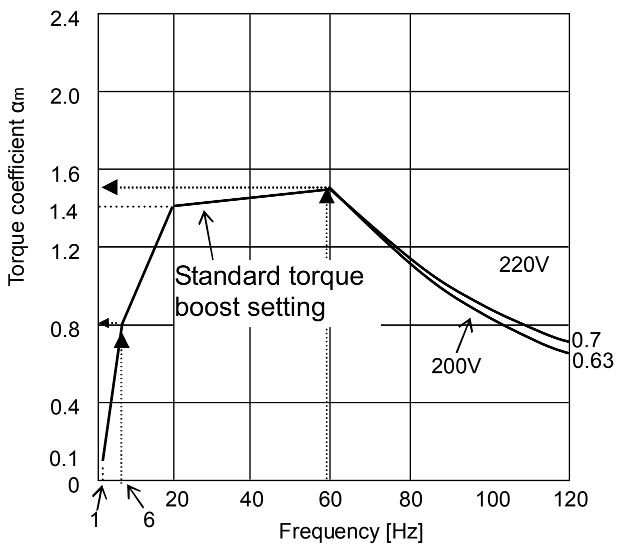
$$T_M \times \beta > |T_{Lf}| \quad \cdots(5.4\text{-}4)$$

β : Deceleration torque coefficient··· Select according to TECHNICAL NOTE No.30
T_{Lf} : Load torque during regenerative driving [N·m]

How to obtain the maximum short-time torque coefficient α_m

- Obtain the maximum short-time torque coefficient α_m by referring to the maximum short-time torque characteristic diagram (shown right) in Chapter 2 Power driving performance data in TECHNICAL NOTE No.30.

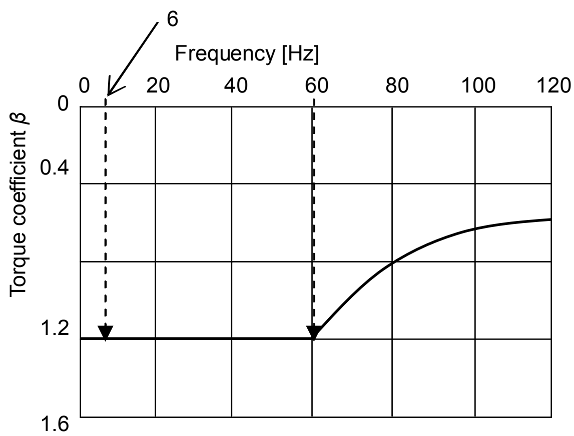
  Maximum short-time torque α_m is the following in the right diagram.
  When a low-speed operation is performed at 6Hz
  $\alpha_m = 0.8$
  When a high-speed operation is performed at 60Hz
  $\alpha_m = 1.5$



How to obtain the deceleration torque coefficient β

- Obtain the deceleration torque coefficient β by referring to the deceleration torque characteristic diagram (shown right) in Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30.

  Deceleration torque coefficient β is the following in the right diagram.
  When a low-speed operation is performed at 6Hz
  $\beta = 1.2$
  When a high-speed operation is performed at 60Hz
  $\beta = 1.2$



5.5 Assessment for the acceleration/deceleration

(1) Applied torque to the motor in each operation block

Assume the operation pattern of Figure 5.2 (power driving during ascending, regenerative driving during descending). Calculate the applied torque to the motor in operation blocks 1) to 8).

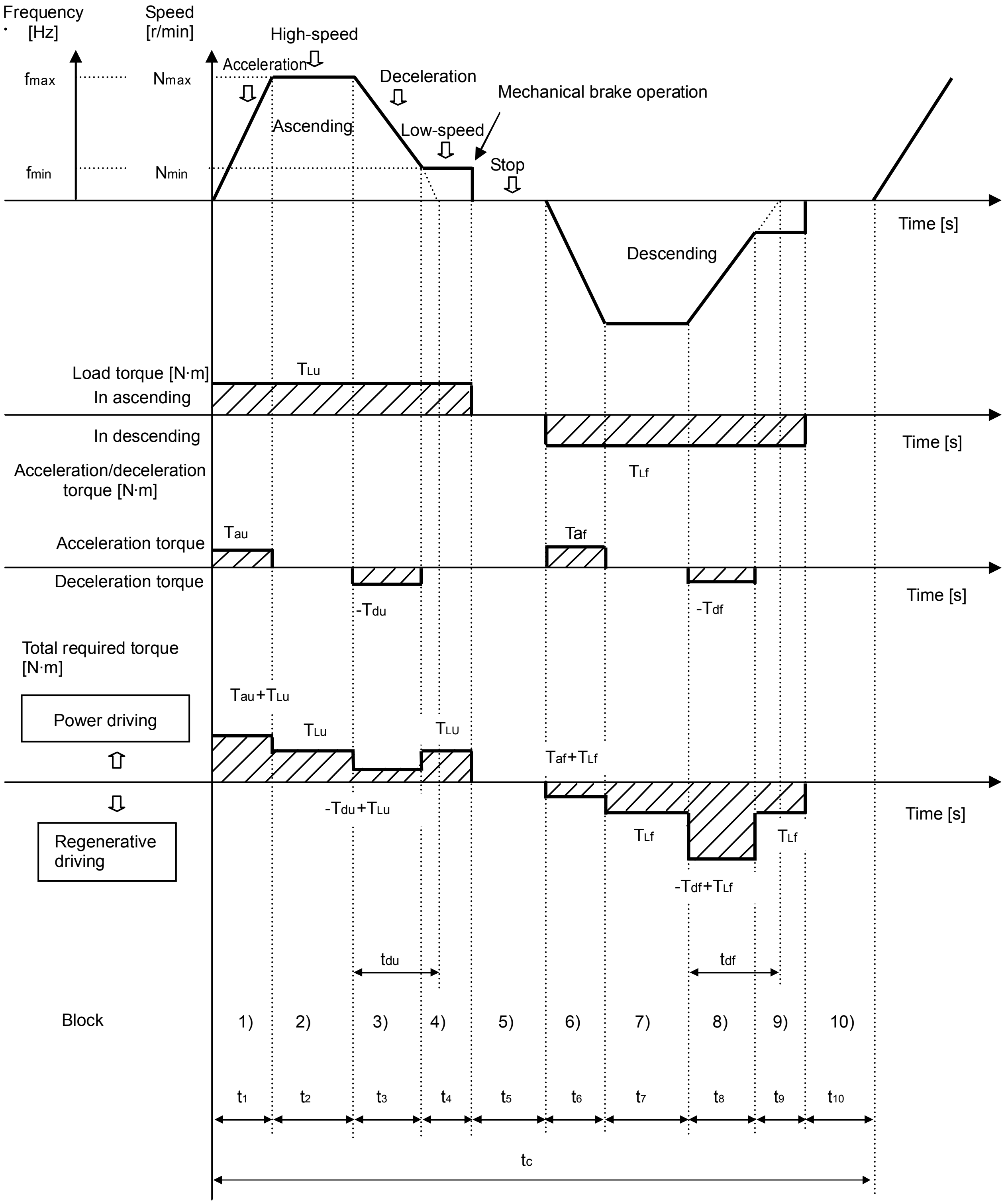


Figure 5.2 Operation pattern

(2) Acceleration torque T_{au}, T_{af}

Calculate the acceleration torque applied to the motor in each operation block of Lift operation.

1) Acceleration torque during ascending T_{au}

Calculate the acceleration torque T_{au} in the following formula.

$$T_{au} = \frac{\Sigma J \times N_{max}}{9.55 \times t_1} \quad [N \cdot m] \quad \cdots (5.5\text{-}1)$$

ΣJ : Total moment of inertia at motor shaft = J_M (motor) + J_B (brake) + J_L (load)

t_1 : Acceleration time during ascending [s]

N_{max} : Maximum motor speed [r/min]

2) Acceleration torque during descending T_{af}

Calculate the acceleration torque T_{af} in the following formula.

$$T_{af} = \frac{\Sigma J \times N_{max}}{9.55 \times t_6} \quad [N \cdot m] \quad \cdots (5.5\text{-}2)$$

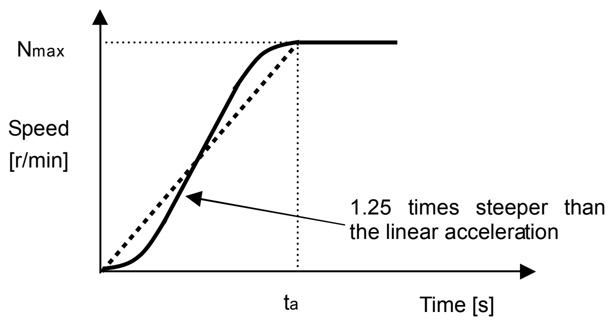
ΣJ : Total moment of inertia at motor shaft = J_M (motor) + J_B (brake) + J_L (load)

t_6 : Acceleration time during descending [s]

N_{max} : Maximum motor speed [r/min]

Acceleration/deceleration torque during S-pattern acceleration/deceleration (Pr.29=2)

When the S-pattern acceleration/deceleration is selected (Pr.29=2), the slope during S-pattern acceleration/deceleration is steeper than the slope during linear acceleration/deceleration in some area. Use the steepest area for the calculation.



In this S-pattern acceleration/deceleration (Pr.29=2), calculate the acceleration torque in the following formula.

$$T_a = \frac{\Sigma J \times N_{max}}{9.55 \times t_a} \times 1.25 \quad [N \cdot m]$$

How to calculate the acceleration time from the acceleration speed

When the time between the stop and the maximum speed N_{max} (maximum travel speed V_{max}) is indicated by the acceleration speed A_{cc}, the A_{cc} value can be converted to the acceleration time t_a by the following formula.

$$t_a = \frac{V_{max}}{60 \times A_{cc}} \quad [s]$$

V_{max} : Maximum travel speed [m/min]

A_{cc} : Acceleration speed [m/s^2]

Acceleration speed is sometimes expressed in gravitational acceleration G.

In that case, refer to the following equation.

(Example) 1G = 9.8 [m/s^2]

(3) Deceleration torque T_{du}, T_{df}

Calculate the deceleration torque applied to the motor in each operation block of Lift operation.

1) Deceleration torque during ascending T_{du}

Calculate the deceleration torque T_{du} in the following formula.

$$T_{du} = \frac{\Sigma J \times N_{max}}{9.55 \times t_{du}} = \frac{\Sigma J \times (N_{max} - N_{min})}{9.55 \times t_3} \text{ [N·m]} \quad \cdots(5.5\text{-}3)$$

$\sum J$: Total moment of inertia at motor shaft
= J_M (motor) + J_B (brake) + J_L (load)

t_3 : Deceleration time during ascending [s]

N_{max} : Maximum motor speed [r/min]

N_{min} : Minimum motor speed [r/min]

2) Deceleration torque during descending T_{df}

Calculate the deceleration torque T_{df} in the following formula.

$$T_{df} = \frac{\Sigma J \times N_{max}}{9.55 \times t_{df}} = \frac{\Sigma J \times (N_{max} - N_{min})}{9.55 \times t_8} \text{ [N·m]} \quad \cdots(5.5\text{-}4)$$

$\sum J$: Total moment of inertia at motor shaft
= J_M (motor) + J_B (brake) + J_L (load)

t_8 : Deceleration time during descending [s]

N_{max} : Maximum motor speed [r/min]

N_{min} : Minimum motor speed [r/min]

How to calculate the deceleration time from the acceleration speed

When the time between the maximum speed N_{max} (maximum travel speed V_{max}) and stop is indicated by the acceleration speed A_{cc}, the A_{cc} value can be converted to the deceleration time t_d by the following formula.

$$t_d = \frac{V_{max}}{60 \times A_{cc}} \text{ [s]}$$

V_{max} : Maximum travel speed [m/min]

A_{cc} : Acceleration speed [m/s^2]
Acceleration speed is sometimes expressed in gravitational acceleration G.
In that case, refer to the following equation.
(Example) 1G = 9.8 [m/s^2]

(4) Total torque

Calculate the total torque using the formulas in the table below.

Total torque	Operation	Operation block	Formula
Total acceleration torque	Power driving	1)	$T_1=T_{au}+T_{Lu}$ ···(5.5-5)
	Regenerative driving	6)	$T_6=T_{af}+T_{Lf}$ ···(5.5-6)
Total deceleration torque	Power driving	3)	$T_3=-T_{du}+T_{Lu}$ ···(5.5-7)
	Regenerative driving	8)	$T_8=-T_{df}+T_{Lf}$ ···(5.5-8)
Total torque during constant-speed operation (high/low speed)	Power driving	2), 4)	$T_2, T_4=T_{Lu}$ ···(5.5-9)
	Regenerative driving	7), 9)	$T_7, T_9=T_{Lf}$ ···(5.5-10)

(5) Assessment for the acceleration

Check that the output torque of the tentatively selected motor is larger than the torque required for the acceleration.

The total torque required for the acceleration T_{at} is T_1 in the operation block 1) or T_6 in the operation block 6), whichever is larger.

(Note) Regenerative acceleration is performed when $T_1<0$ and $T_6<0$. The maximum torque required for regenerative operation is calculated in the assessment for deceleration. It does not have to be calculated for the assessment for acceleration.

Output torque of the motor		Total required torque for the acceleration
$T_M \times \alpha_a$	>	T_{at} ···(5.5-11)

α_a : Linear acceleration torque coefficient······Select according to TECHNICAL NOTE No.30.

If the above condition is not satisfied, take the following measures to output larger torque from the motor.

1) If V/F control has been used, set the torque boost setting higher. Alternatively, use (Advanced) magnetic flux vector control.
2) Use an inverter capacity that is one rank higher than the motor capacity.
3) Use one-rank-higher motor and inverter capacities.

(6) Assessment for the deceleration

Check that the brake toque generated from the tentatively selected motor and inverter is larger than the torque required for the deceleration.

The total torque required for the deceleration T_{dt} is T_3 in the operation block 3) or T_8 in the operation block 8), whichever is smaller.

When "$T_{dt}<0$", assess for the deceleration by assuming "$T_{dt}=|T_{dt}|$."

(Note) Regenerative deceleration is performed when $T_3>0$ and $T_8>0$. The maximum torque required for power operation is calculated in the assessment for acceleration. It does not have to be calculated for the assessment for deceleration.

Output torque of the motor		Required torque for the deceleration
$T_M \times \beta$	>	T_{dt} ···(5.5-12)

β : Deceleration torque coefficient······Select according to TECHNICAL NOTE No.30.

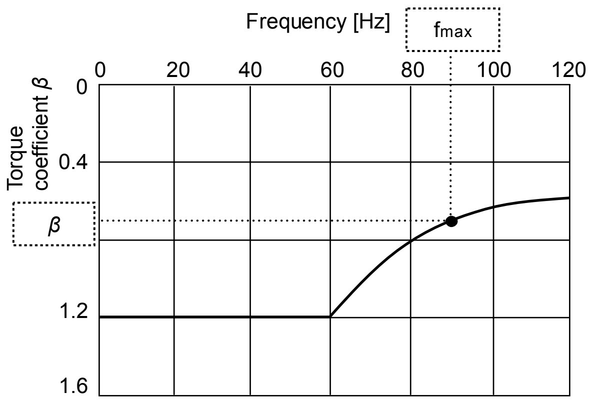
If the above condition is not satisfied, take the following measures to output larger torque from the motor.

1) Additionally use an external brake resistor or a brake unit.
2) Use a power regeneration converter.

How to obtain the deceleration torque coefficient β

(1) Refer to Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30. Select a braking option to be additionally used that satisfies the following condition: The value in first two digits of torque type (indicating the maximum torque %) is equal to or higher than the required brake torque.

(2) Calculate the torque coefficient when additionally using a braking option, which has been selected according to the brake torque data in Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30.



5.6 Regenerative power calculation (temperature calculation of the braking option)

(1) Regenerative power calculation

Assume the operation pattern of Figure 5.2. To assess the permissible temperature for deceleration, calculate the average regenerative power (W_{INV}) that is regenerated to the inverter in one cycle time (t_c). Then, check that the average regenerative power (W_{INV}) is less than the consumable power of the brake (the continuous operation permissible power of a braking option W_{RC} and the short-time permissible power of a braking option activation W_{RS}).

The following table shows the power at different operation blocks. When the obtained value is a negative value, it is a regenerative power.

Block	Power [W]
1)	$W_1 = 0.1047 \times \frac{Nmax}{2} \times T_1$ ···(5.6-1)
2)	$W_2 = 0.1047 \times Nmax \times T_2$ ···(5.6-2)
3)	$W_3 = 0.1047 \times \frac{Nmax + Nmin}{2} \times T_3$ ···(5.6-3)
4)	$W_4 = 0.1047 \times Nmin \times T_4$ ···(5.6-4)
6)	$W_6 = 0.1047 \times \frac{Nmax}{2} \times T_6$ ···(5.6-5)
7)	$W_7 = 0.1047 \times Nmax \times T_7$ ···(5.6-6)
8)	$W_8 = 0.1047 \times \frac{Nmax + Nmin}{2} \times T_8$ ···(5.6-7)
9)	$W_9 = 0.1047 \times Nmin \times T_9$ ···(5.6-8)

(2) Check for the short-time regenerative power

Check that the regenerative power W_n (W_1 to W_4, W_6 to W_9) is within the short-time permissible power W_{RS} in the operation block 1) to 4) and 6) to 9).

Assess only the operation blocks where Wn is a negative value.

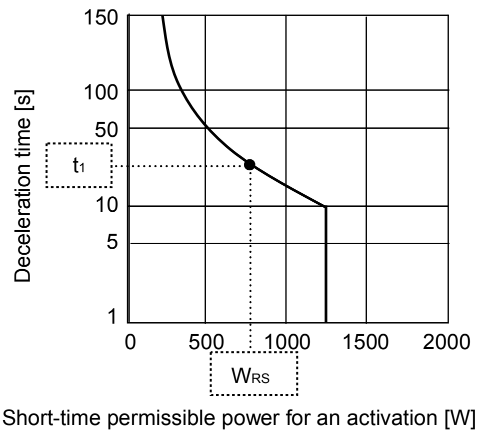
$$W_{RS} > |W_n| \times 0.9^* \quad \cdots (5.6\text{-}9)$$

* Calculate with 1.0 for the capacitor regeneration.

W_{RS}: Short-time permissible power of a braking option (Refer to TECHNICAL NOTE No.30)

How to obtain the short-time permissible power W_{RS}

Select the short-time permissible power of the braking option by referring to the permissible power data in Chapter 3 in TECHNICAL NOTE No.30.
Calculate the short-time permissible power from the deceleration time (regenerative constant-speed operation



(3) Check for the regenerative power generated in the continuous regenerative operation range

Assess the regenerative power for the operation blocks where the regenerative status is continuous (W_6 to W_9).

Calculate $W_n \times t_n$ and t_n only for the operation blocks where the power is continuously negative (regenerative status).

$$W_{nc} = \frac{|\Sigma(W_n \times t_n)|}{\Sigma t_n} \times 0.9^* \quad [W] \cdots (5.6\text{-}10)$$

* Calculate with 1.0 for the capacitor regeneration.

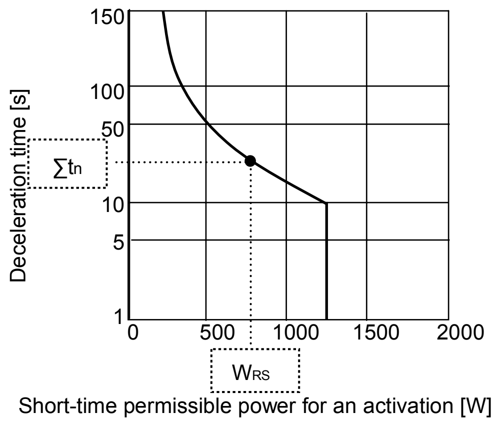
Check that the average power of the continuous regenerative operation range W_{nc} is within the short-time permissible power of the braking option W_{RS}.

$$W_{RS} > W_{nc} \quad \cdots (5.6\text{-}11)$$

W_{RS}: Short-time permissible power of a braking option (Refer to TECHNICAL NOTE No.30)

How to obtain the short-time permissible power W_{RS}

Select the short-time permissible power of the braking option by referring to the permissible power data in Chapter 3 in TECHNICAL NOTE No.30.
Calculate the permissible power for an activation by adding up the values in the operation blocks where the regenerative status is continuous.



(4) Check for the average regenerative power

Using the following formula, calculate the average power to be regenerated to the inverter W_{INV} in a cycle.
Calculate $W_n \times t_n$ and t_n only for the operation blocks where the power is negative (regenerative status).

$$W_{INV} = \frac{|\Sigma(W_n \times t_n)|}{t_c} \times 0.9^* \quad [W] \quad \cdots(5.6\text{-}12)$$

* Calculate with 1.0 for the capacitor regeneration.

Compare the average power regenerated to the inverter W_{INV} and the consumable power by the braking option W_{RC} in a cycle (t_c), and assess for the regenerative operation.

$$W_{RC} > W_{INV} \quad \cdots(5.6\text{-}13)$$

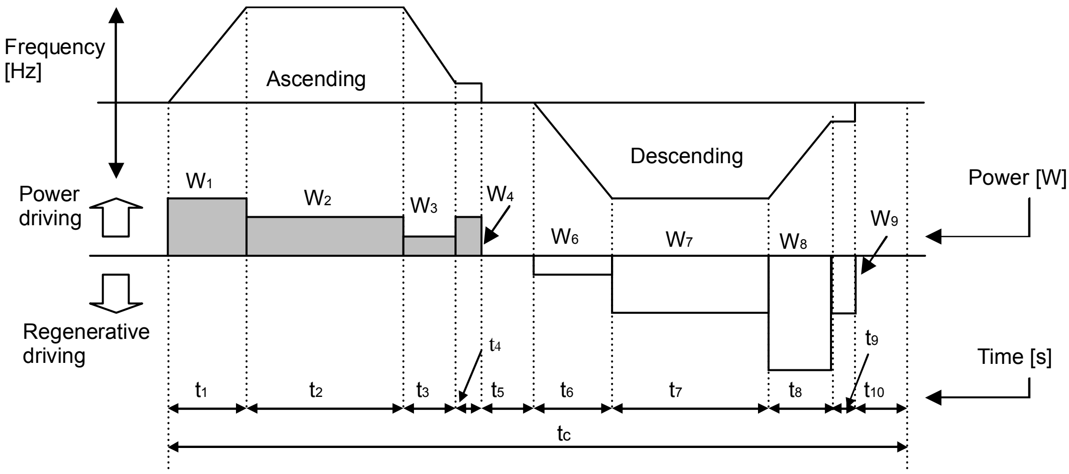
W_{RC}: Continuous operation permissible power of a braking option (Refer to TECHNICAL NOTE No.30)

Regenerative braking methods

- * When the capacity is small and the regenerative power is small, the power can be charged temporarily in the smoothing capacitor. This method is called capacitor regeneration and used for about 0.4kW or less.
- * For medium-size capacities, the power is consumed as heat by feeding current to a resistor. This method is called resistor regeneration. Larger resistor is required for higher regenerative power, and attention must be paid to how the heat affects the surrounding area.
- * For large-size capacities with high regenerative power, the regenerative power is returned to the power supply side. This method is called power regeneration.
  This method is recommended for a lift system with long continuous regeneration time, or for 15kW or higher capacities.

Regenerative power calculation example

The following section explains how the regenerative power can be calculated in operation patterns (power driving during ascending, regenerative driving during descending) of Figure 5.2.



- Check for the short-time regenerative power

  Check that the regenerative power W_n is within the short-time permissible power of the braking option W_{RS} in each operation block.

  Check that the power of W_6, W_7, W_8, and W_9 are within the short-time permissible power W_{RS}.

  W_{RS} (value at t_6)>$|W_6|\times0.9$
  W_{RS} (value at t_7)>$|W_7|\times0.9$
  W_{RS} (value at t_8)>$|W_8|\times0.9$
  W_{RS} (value at t_9)>$|W_9|\times0.9$

  W_{RS}: Short-time permissible power of a braking option (Refer to TECHNICAL NOTE No.30)

- Check for the regenerative power generated in the continuous regenerative operation range

  Assess the regenerative power for the operation blocks where the regenerative status is continuous.

  Regenerative operation is continuous in W_6,W_7,W_8, and W_9, so check these operation blocks.

$$W_{nc}=\frac{|(W_6\times t_6)+(W_7\times t_7)+(W_8\times t_8)+(W_9\times t_9)|}{(t_6+t_7+t_8+t_9)}\times0.9\quad[W]$$

  Check that the average power of the continuous regenerative operation range W_{nc} is within the short-time permissible power of the braking option W_{RS}.

  W_{RS} (value at "$t_6+t_7+t_8+t_9$")> W_{nc}

  W_{RS}: Short-time permissible power of a braking option (Refer to TECHNICAL NOTE No.30)

- Check for the average regenerative power

  Check that the average power to be regenerated to the inverter W_{INV} in a cycle is within the continuous operation permissible power of the braking option W_{RC}.

$$W_{INV}=\frac{|(W_6\times t_6)+(W_7\times t_7)+(W_8\times t_8)+(W_9\times t_9)|}{tc}\times0.9\quad[W]$$

  Assess by the average power regenerated to the inverter W_{INV} and the consumable power by the braking option W_{RC} in a cycle (tc).

  W_{RC} > W_{INV}

  W_{RC}: Continuous operation permissible power of a braking option (Refer to TECHNICAL NOTE No.30)

5.7 Temperature calculation of the motor and inverter

(1) Operation pattern

For a lift system with frequent starts/stops or with long-duration operation at low-speed, calculate the current in each operation block of one cycle. Then, check that the root mean square of the currents, which is the average current throughout the cycle, is within the rated current of the motor.

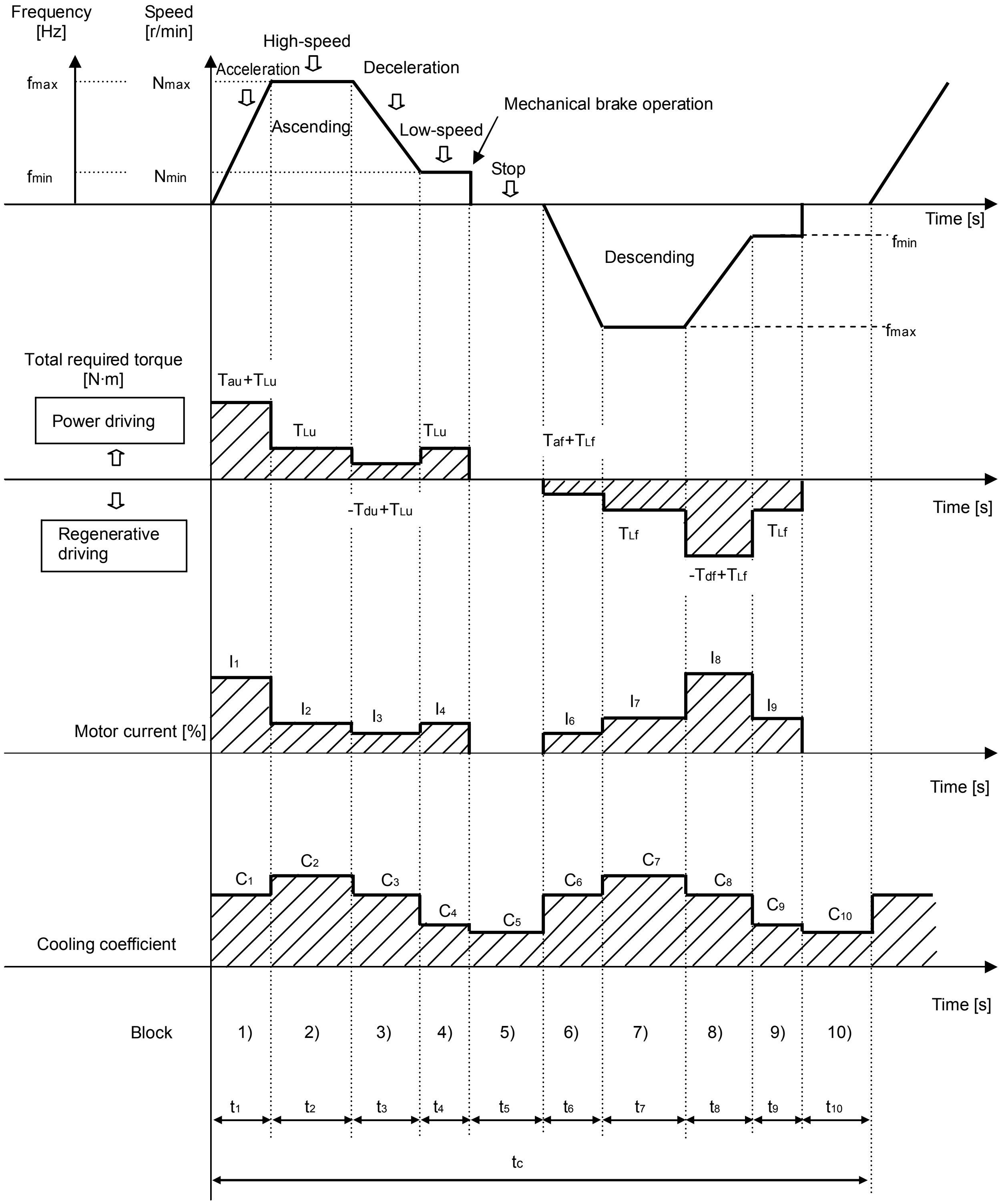


Figure 5.3 Operation pattern example

(2) How to calculate the motor current I_1, I_2…I_n [%] and the cooling coefficient C_1, C_2...C_n

1) Calculate the load torque ratio TF in each operation block.

$$\text{Load torque ratio } TF_n = \frac{\text{Total torque in each operation block } T_n}{\text{Rated motor torque } T_M} \times 100 \ [\%] \quad (n=1, 2, 3...) \qquad \cdots(5.7\text{-}1)$$

To drive at 60Hz or higher

Calculate the current-equivalent load torque ratio TF_I for the rated output range of the motor (the range equal to or higher than the base frequency)(example : 60 to 120Hz).

$$\text{Current-equivalent load torque ratio in the range equal to or higher than the base frequency } TF_I = \frac{\text{Total torque in each operation block } T_n}{\text{Rated motor torque } T_M} \times \frac{\text{Running frequency}}{\text{Base frequency}} \times 100[\%]$$

(Note) Total torque in an operation block is the total torque in each of T_1 to T_4 and T_6 to T_9.

2) How to calculate the cooling coefficient C_1, C_2...C_n

Calculate the coefficient by referring to Chapter 4 Motor and brake characteristics in TECHNICAL NOTE No.30.

3) How to calculate the motor current

Calculate the ratio of the motor current (%) to the load torque ratio TF (current equivalent load torque ratio TF_I), which is obtained in 1), by referring to Chapter 4 Motor and brake characteristics in TECHNICAL NOTE No.30.

When the maximum frequency is higher than the base frequency during acceleration/deceleration, multiply the obtained motor current [%] by the current compensation coefficient. (Refer to Chapter 4 Motor and brake characteristics in TECHNICAL NOTE No.30.)

(Note) The current is higher during Cyclic operation under vector control. Multiply the above-obtained value by 1.2 times, and use that value as the motor current I_n.

When the average current is around 100%

When driving a standard motor by an inverter, higher motor current (about 1.1 times) is required to output the same amount of torque compared with when driving by the commercial power supply.

When the equivalent current of the motor torque is 100%, 110% current flows during the inverter operation, and little margin for the temperature rise is left. Thoroughly consider the load condition and operation duty.

(3) Temperature calculation of the motor

If the following condition is satisfied in Figure 5.3, the use of motor is available regarding the temperature.

$$I_{MC}=\sqrt{\frac{\Sigma(I_n^2 \times t_n)}{\Sigma(C_n \times t_n)}} < 100 \quad [\%](\text{Note}) \qquad \cdots(5.7\text{-}2)$$

I_{MC} : Equivalent current of motor torque considering the cooling coefficient [%]

$I_1, I_2, ...I_n$: Current characteristic in the operation block $t_1, t_2...t_n$ [%]

$C_1, C_2, ...C_n$: Cooling coefficient for the frequency in the operation block $t_1, t_2...t_n$.

(Information) Calculation table for motor temperature

Operation block	Time period in the block [s]	Total torque in the operation block [N·m]	Load torque ratio [%]	Cooling coefficient	Motor current [%]	$I_n^2 \times t_n$	$C_n \times t_n$
1)	t_1=	T_1=	TF_1=	C_1=	I_1=	$I_1^2 \times t_1$=	$C_1 \times t_1$=
2)	t_2=	T_2=	TF_2=	C_2=	I_2=	$I_2^2 \times t_2$=	$C_2 \times t_2$=
3)	t_3=	T_3=	TF_3=	C_3=	I_3=	$I_3^2 \times t_3$=	$C_3 \times t_3$=
4)	t_4=	T_4=	TF_4=	C_4=	I_4=	$I_4^2 \times t_4$=	$C_4 \times t_4$=
5)	t_5=	T_5=	TF_5=	C_5=	I_5=	$I_5^2 \times t_5$=	$C_5 \times t_5$=
6)	t_6=	T_6=	TF_6=	C_6=	I_6=	$I_6^2 \times t_6$=	$C_6 \times t_6$=
7)	t_7=	T_7=	TF_7=	C_7=	I_7=	$I_7^2 \times t_7$=	$C_7 \times t_7$=
8)	t_8=	T_8=	TF_8=	C_8=	I_8=	$I_8^2 \times t_8$=	$C_8 \times t_8$=
9)	t_9=	T_9=	TF_9=	C_9=	I_9=	$I_9^2 \times t_9$=	$C_9 \times t_9$=
10)	t_{10}=	T_{10}=	TF_{10}=	C_{10}=	I_{10}=	$I_{10}^2 \times t_{10}$=	$C_{10} \times t_{10}$=

(4) Electronic thermal relay check

Check that the motor does not overheat even if the equivalent current of the motor torque I_{MC} drops to 100% or less during acceleration and constant-speed operation.

1) Calculate the ratio of the electronic thermal relay operation time to the load torque ratio in each operation block.

Operation block	Time period in the block [s]	Average running frequency [Hz]	Motor current [%]	Electronic thermal relay operation time [s]
1)	t_1	$\frac{fmax}{2}$	I_1	t_{THM1}=
2)	t_2	fmax	I_2	t_{THM2}=
3)	t_3	$\frac{fmax + fmin}{2}$	I_3	t_{THM3}=
4)	t_4	fmin	I_4	t_{THM4}=
5)	t_5	0	I_5=0	t_{THM5}=0
6)	t_6	$\frac{fmax}{2}$	I_6	t_{THM6}=
7)	t_7	fmax	I_7	t_{THM7}=
8)	t_8	$\frac{fmax + fmin}{2}$	I_8	t_{THM8}=
9)	t_9	fmin	I_9	t_{THM9}=
10)	t_{10}	0	I_{10}=0	t_{THM10}=0

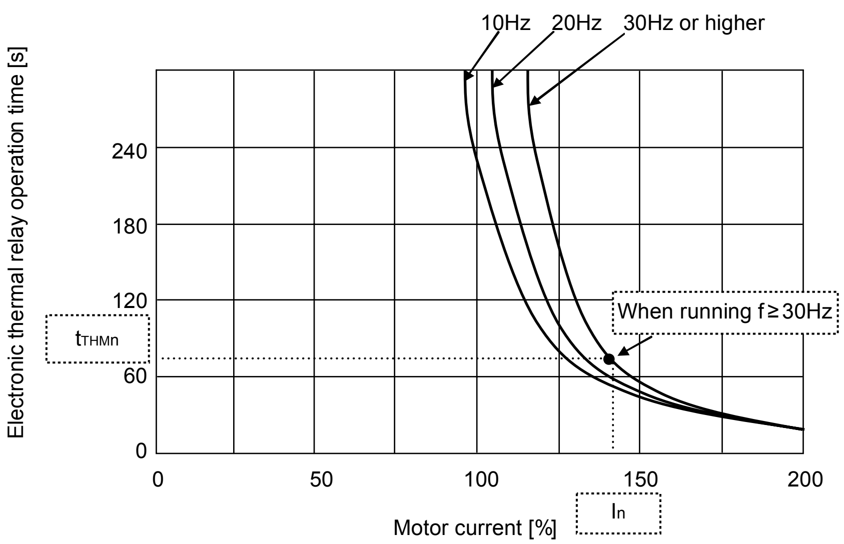
2) Check that the time period in each block is shorter than the electronic thermal relay operation time.

$$t_n < t_{THMn} \quad \cdots(5.7\text{-}3)$$

How to calculate the electronic thermal relay operation time t_{THMn}

Calculate the time using the average running frequency and the motor current by referring to Electronic thermal relay characteristic in TECHNICAL NOTE No.30.

(Note) The following diagram shows the electronic thermal relay characteristics of a standard motor.



(5) Transistor protection thermal check

If the current larger than the 150% rated inverter current (120% for the FR-F500 series) flows, the transistor protection of the inverter is activated. To prevent this, check the protective function does not get activated during the operation.

Load ratio to the rated inverter current $TF_{INV}[\%] = \frac{I_n[\%] \times \text{Rated motor current [A]}}{\text{Rated inverter current [A]}}$ ···(5.7-4)

$I_n[\%]$: Motor current in each operation block

1) Calculate the load ratio to the rated inverter current in each operation block.

Operation block	Motor current [%]	Load ratio to the rated inverter current [%]
1)	$I_1=$	$TF_{INV1}=I_1\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
2)	$I_2=$	$TF_{INV2}=I_2\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
3)	$I_3=$	$TF_{INV3}=I_3\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
4)	$I_4=$	$TF_{INV4}=I_4\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
5)	$I_5=0$	$TF_{INV5}=0$
6)	$I_6=$	$TF_{INV6}=I_6\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
7)	$I_7=$	$TF_{INV7}=I_7\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
8)	$I_8=$	$TF_{INV8}=I_8\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
9)	$I_9=$	$TF_{INV9}=I_9\times\frac{\text{Rated motor current}}{\text{Rated inverter current}}=$
10)	$I_{10}=0$	$TF_{INV10}=0$

2) Check that the load ratio to the rated inverter current TF_{INV} is within 150% (within 120% for FR-F500) in each operation block.

$TF_{INV} \leqq 150\%\text{(Note)}$ ···(5.7-5)

(Note) It is 120% for the FR-F500 series inverters.

5.8 Stop accuracy

This section describes about the stop operation using a mechanical brake in the speed pattern shown in Figure 5.4.

Mechanical brake is always installed next to lifting equipment to keep a status. The stop accuracy is affected by the characteristic of the mechanical brake at a stop. Stop accuracy can be improved by setting lower minimum speed f_{min} in the inverter. However, f_{min} must be 6Hz or higher for lifting equipment. Calculate the frequency at minimum speed f_{min} based on the mechanical brake characteristics and the required stop accuracy, and if f_{min} is less than 6Hz, re-evaluate the inverter's frequency output range.

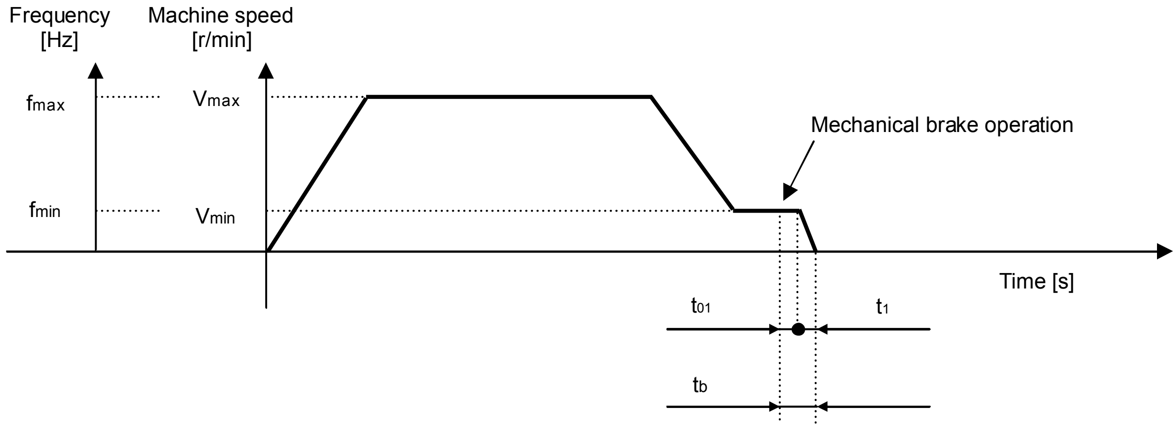


Figure 5.4 Speed pattern to a stop

(1) Characteristics of a mechanical brake

When using a TB brake, calculate the following constants by referring to Chapter 4.5 Brake characteristic (Chapter 4 Motor and brake characteristics) in TECHNICAL NOTE No.30.

Rated brake torque	:	T_B [N·m]
Coasting time (cutoff in advance)	:	t_{01} [s]
Brake moment of inertia	:	J_B [kg·m^2]

(2) Stop accuracy when the machine stops from the low-speed (creep speed) operation

Calculate the time to stop and the distance to stop in the following formulas, and estimate the stop accuracy.

1) For power driving

Time to stop t_b = Coasting time t_{01} + Braking time t_{11}

$$= t_{01} + \frac{\Sigma J \times N_{min}}{9.55\left(T_B + T_{LU}\right)} \quad [s] \quad \cdots(5.8\text{-}1)$$

2) For regenerative driving

Time to stop t_b = Coasting time t_{01} + Braking time t_{11}

$$= t_{01} + \frac{\Sigma J \times N_{min}}{9.55\left(T_B + T_{Lf}\right)} \quad [s] \quad \cdots(5.8\text{-}2)$$

Distance to stop $S = S_{01} + S_{11}$

$$= \left(t_{01} \times \frac{V_{min}}{60} + t_{11} \times \frac{1}{2} \times \frac{V_{min}}{60}\right) \times 10^3 \quad [mm] \quad \cdots(5.8\text{-}3)$$

V_{min} : The speed immediate before a stop
= The machine speed equivalent to the motor speed N_{min} [r/min]
(low-speed operation speed = creep speed) [m/min]

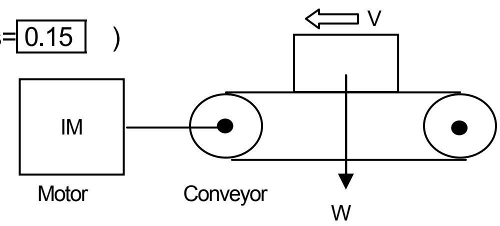
Estimated stop accuracy

$$\Delta\varepsilon = \pm\frac{S}{2} \quad [mm] \quad \cdots(5.8\text{-}4)$$

CHAPTER 6 SELECTION EXAMPLE FOR CONTINUOS OPERATION (SELECTION EXAMPLE FOR A CONVEYOR)

(Load/operation specification)

- Power supply voltage/frequency [220] [V] [60] [Hz]
- Friction coefficient μ = [0.1] (Friction coefficient at start μs= [0.15])
- Machine efficiency η = [0.85]
- Conveying mass W = [1800] [kg]
- Conveying speed V_{min} = [8.3] to V_{max} = [25] [m/min]
- Motor speed N_{min} = [600] to N_{max} = [1800] [r/min]
- Output frequency f_{min} = [20] to f_{max} = [60] [Hz]
- Load moment of inertia J_L = [0.0375] [kg·m^2]
- Desired acceleration/deceleration time Acceleration t_a= [8] [s] Deceleration time t_d= [8] [s]



Calculation of load-driving power and load torque

(1) Required power P_{LR}

- Required power $P_{LR} = \dfrac{\mu \times W \times V_{max}}{6120 \times \eta} = \boxed{\dfrac{0.1 \times 1800 \times 25}{6120 \times 0.85}} = \boxed{0.87}$ [kW]

(2) Torque at motor shaft T_{LR}

- Load torque at motor shaft $T_{LR} = \dfrac{9550 \times P_{LR}}{N_{max}} = \boxed{\dfrac{9550 \times 0.87}{1800}} = \boxed{4.62}$ [N·m]

Selection of motor and inverter capacities (tentative)

(1) Selection of the motor capacity (tentative)

- Because the required power is 0.87kW, select a [1.5kW] motor. → [SF-JR 1.5kW 4P]
- Rated motor torque $T_M = \dfrac{9550 \times P_M}{N_M} = \boxed{\dfrac{9550 \times 1.5}{1800}} = \boxed{7.96}$ [N·m]
- Assessment for the motor capacity (tentative)

◎ Assessment condition

Rated motor torque T_M ≥ Load torque T_{LR}

- Assessment

T_M= [7.96] [N·m] ≥ T_{LR}= [4.62] [N·m] → **OK**

(2) Inverter capacity

Tentatively select an inverter capacity that is same as the motor.

→ [FR-E520-1.5K V/F control (high torque boost setting)]

Assessment for the start

(1) Starting torque of the motor

· Starting torque of the motor $T_{MS}=T_M \times \alpha_S \times \delta =$ 7.96 × 1.15 × 0.85 = 7.78 [N·m]

Starting torque coefficient	α_S : 1.15	Power driving performance data in TECHNICAL NOTE No.30
Hot coefficient	δ : 0.85	Outline of Technical Note No.30 [DATA] in TECHNICAL NOTE No.30

·Load torque at start $T_{LS}= \dfrac{\mu_S \times 9.8 \times W \times V_{max}}{2\pi \times N_{max} \times \eta} = \dfrac{0.15 \times 9.8 \times 1800 \times 25}{2\pi \times 1800 \times 0.85} =$ 6.88 [N·m]

(2) Assessment for the start

◎Assessment condition

Maximum starting torque of motor T_{MS} > Load torque at start T_{LS}

· Assessment $T_{MS}=$ 7.78 [N·m] > $T_{LS}=$ 6.88 [N·m] → **OK**

Assessment for the continuous operation

(1) Continuous operation torque

Check if the load torque T_{LR} is less than the continuous motor operation torque in the continuous operation range (600 to 1800r/min).

1) Continuous motor operation torque at 1800r/min (60Hz)

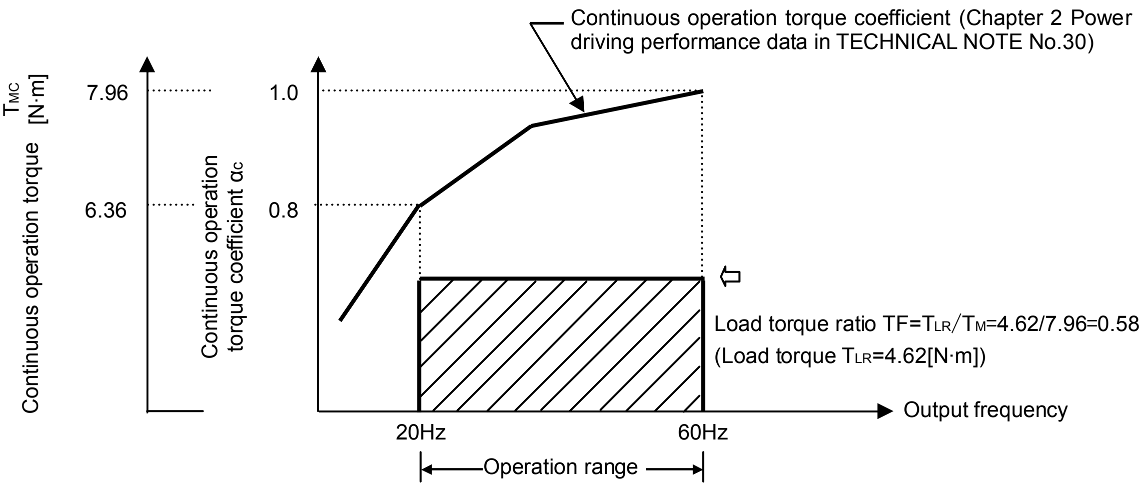
· Continuous motor operation torque $T_{MC}=T_M \times \alpha_C=$ 7.96 × 1.0 = 7.96 [N·m]

Continuous operation torque coefficient αc : 1.0 (at 60Hz) Power driving performance data in TECHNICAL NOTE No.30

2) Continuous motor operation torque at 600r/min (20Hz)

·Continuous motor operation torque $T_{MC}=T_M \times \alpha_C=$ 7.96 × 0.8 = 6.36 [N·m]

Continuous operation torque coefficient α_C : 0.8 (at 20Hz) Power driving performance data in TECHNICAL NOTE No.30



(2) Assessment for the continuous operation

◎Assessment condition

Continuous operation torque of the motor T_{MC} > Load torque T_{LR}

· Assessment T_{MC}= 6.36 [N·m] > T_{LR}= 4.62 [N·m] → **OK**

Assessment for the acceleration

(1) Shortest acceleration time tas

· Shortest acceleration time $t_{as}=\dfrac{(J_L+J_M+J_B)\times N_{max}}{9.55(T_M\times \alpha a-T_{LR}max)}=\dfrac{(0.0375+0.0068+0)\times 1800}{9.55(7.96\times 1.15-4.62)}=$ 1.8 [s]

Linear acceleration torque coefficient *αa*: 1.15	Power driving performance data in TECHNICAL NOTE No.30
Motor moment of inertia J_M: 0.0068 [kg·m^2]	Motor and brake characteristics in TECHNICAL NOTE No.30
Maximum load torque T_{LRmax}: 4.62 [N·m]	T_{LR} is used.

(2) Assessment for the acceleration

◎Assessment condition

Shortest acceleration time t_{as} < Desired acceleration time t_a

· Assessment t_{as}= 1.8 [s] < t_a= 8 [s] → **OK**

Assessment for the deceleration

(1) Shortest deceleration time tds

· Shortest deceleration time $t_{ds}=\dfrac{(J_L+J_M+J_B)\times N_{max}}{9.55(T_M\times \beta+T_{LR}min)}=\dfrac{(0.0375+0.0068+0)\times 1800}{9.55(7.96\times 0.2+0)}=$ 5.2 [s]

Deceleration torque coefficient *β*: 0.2	Power driving performance data in TECHNICAL NOTE No.30
Motor moment of inertia J_M: 0.0068[kg·m^2]	Motor and brake characteristics in TECHNICAL NOTE No.30
Minimum load torque T_{LRmin}: The toughest condition for the deceleration, T_{LRmin} = 0 [N·m], is used	

(2) Assessment for the deceleration

◎Assessment condition

Shortest deceleration time t_{ds} < Desired deceleration time t_d

· Assessment t_{ds}= 5.2 [s] < t_d= 8 [s] → **OK**

Regenerative power (when the deceleration time is 8s)

(1) Assessment for the consumable regenerative power

The regenerative power can be consumed by the capacitor regeneration, so the deceleration is confirmed to be available.

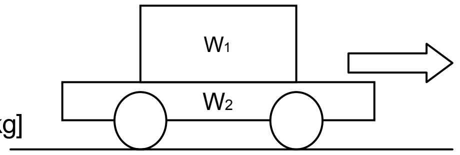
[Final selection]

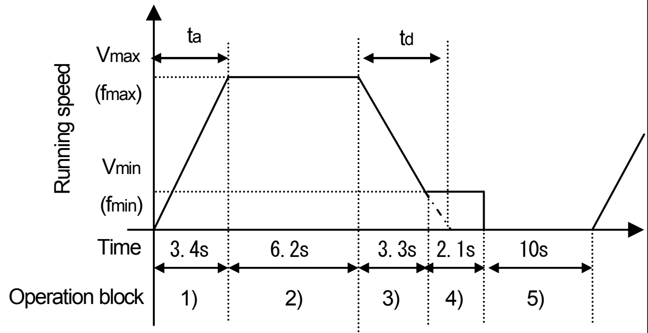
● Motor :	SF-JR 1.5kW 4P
● Inverter :	FR-E520-1.5K V/F control (high torque boost setting)
● Brake resistor :	Not required (capacitor regeneration)

CHAPTER 7 SELECTION EXAMPLE FOR CYCLIC OPERATION (SELECTION EXAMPLE FOR A BOGIE)

(Load/operation specification)

Power supply voltage/frequency		200 [V] 60 [Hz]	
Cargo mass	W_1	: 2500 [kg]	
Bogie mass	W_2	: 800 [kg]	
Total mass (traveling mass)	W	: 2500+800 = 3300 [kg]	
Running speed	V_{max}	: 100 [m/min]	
Motor speed (rpm) at the above speed	N_{max}	: 1500 [r/min]	
Lowest running speed (JOG operation or creep speed)	V_{min}	: 3 [m/min]	
Wheel-driving resistance	μ	: 0.05	
Driving resistance at start	μs	: 0.08	
Machine efficiency	η	: 0.75	
Acceleration time	ta	: 3.4 [s]	
Deceleration time	td	: 3.4 [s]	





Calculation of required power and load torque

(1) Required power for the load P_{LR}

· Required power for the load $P_{LR} = \dfrac{\mu \times W \times V_{max}}{6120 \times \eta} = \boxed{\dfrac{0.05 \times 3300 \times 100}{6120 \times 0.75}} = \boxed{3.60}$ [kW]

(2) Load torque at motor shaft T_{LR}

· Load torque $T_{LR} = \dfrac{\mu \times 9.8 \times W \times V_{max}}{2\pi N_{max} \times \eta} = \boxed{\dfrac{0.05 \times 9.8 \times 3300 \times 100}{2\pi \times 1500 \times 0.75}} = \boxed{22.9}$ [N·m]

(3) Load moment of inertia at motor shaft J_L

· Load moment of inertia at motor shaft $J_L = W \times \left(\dfrac{V_{max}}{2\pi N_{max}}\right)^2 = \boxed{3300 \times \left(\dfrac{100}{2\pi \times 1500}\right)^2} = \boxed{0.37}$ [kg·m^2]

Selection of motor and inverter capacities (tentative)

(1) Selection of the motor capacity P_M (tentative)

· $P_M = P_{LR} \times k_P = \boxed{3.60 \times 1.2} = \boxed{4.32}$ [kW] (Tentative selection with k_P =1.2 (20% margin))

From above, tentatively select SF-JR 5.5 [kW] 4P for the motor.

· Rated motor torque $T_M = \dfrac{9550 \times P_M}{N_M} = \boxed{\dfrac{9550 \times 5.5}{1800}} = \boxed{29.2}$ [N·m]

· Assessment for the motor capacity (tentative)

◎Assessment condition

Rated motor torque T_M ≥ Load torque T_{LR}

· Assessment $T_M = \boxed{29.2}$ [N·m] ≥ $T_{LR} = \boxed{22.9}$ [N·m] → **OK**

(2) Selection of the inverter capacity (tentative)

Tentatively select the inverter capacity FR-A520-7.5K, which is one rank higher than the tentatively selected motor.

Because the variable speed range is relatively wide (V:100m/min to Vmin:3m/min = 33.3:1), assume using Advanced magnetic flux vector control.

POINT

Variable speed range of the motor

Because of its structure (cooling, bearing, deceleration mechanism), the speed variation range of the motor is restricted under inverter operation. Refer to TECHNICAL NOTE No.30 (Appendix).

The motor capacity differs in the same required power

The motor capacity can be expressed by the following formula when the motor speed (travel speed of the machine) is within the rated motor speed with a constant-torque load such as a transportation machine.

$$\text{Motor capacity} = \text{Required power for the load} \times \frac{\text{Rated motor speed } (N_0)}{\text{Motor speed at the machine-driving speed (travel speed of the machine) } (N)}$$

(However $N_0 \geq N$)

When "$N_0 \leq N$," the rated output range of the motor is used, so the following equation is valid in general : Motor capacity=required power for the load

Variable speed range and mechanical speed reduction ratio

The variable speed range of a standard motor depends on the motor capacity and the number of motor poles. Refer to TECHNICAL NOTE No.30 (Appendix).

Setting a higher frequency with a lower reduction gear reduces the load torque ratio and the load moment of inertia at motor shaft and brings the following advantages.

1) Easier start
2) Continuous operation to the low-speed range
3) Wider variable speed range

Assessment for the start

(1) Starting torque of the motor

· Starting torque of the motor $T_{MS} = T_M \times \alpha s \times \delta =$ 29.2×2.0×0.85 = 49.6 [N·m]

Starting torque coefficient αs : 2.0 Power driving performance data in TECHNICAL NOTE No.30
Hot coefficient δ: 0.85 Outline of Technical Note No.30 [DATA] in TECHNICAL NOTE No.30

· Load torque at start $T_{LS} = \dfrac{\mu s \times 9.8 \times W \times V_{max}}{2\pi N_{max}\eta} = \dfrac{0.08 \times 9.8 \times 3300 \times 100}{2\pi \times 1500 \times 0.75} =$ 36.6 [N·m]

(2) Assessment for the start

◎Assessment condition

Maximum starting torque of the motor T_{MS} ≥ Load torque at start T_{LS}

· Assessment

$T_{MS}=$ 49.6 [N·m] ≥ $T_{LS}=$ 36.6 [N·m] → OK

Assessment for the low-speed and high-speed operations

(1) Assessment for the low-speed operation (JOG and creep speed)

· When V is 100m/min, the motor speed is 1500r/min, so the frequency range can be calculated as follow:

$$f = N \times \frac{P}{120} = 1500 \times \frac{4}{120} = 50\text{Hz}$$

At the lowest speed 3m/min: $50 \times \dfrac{3}{100} = 1.5\text{Hz}$

· Output torque of the motor at low-speed operation = $T_M \times \alpha m \times \delta =$ 29.2 × 1.7 × 0.85 = 42.2 [N·m]

Maximum short-time torque coefficient αm: 1.7 (at 1.5Hz) Power driving performance data in TECHNICAL NOTE No.30
Hot coefficient δ: 0.85 Outline of Technical Note No.30 [DATA] in TECHNICAL NOTE No.30

· Assessment for the low-speed operation

◎Assessment condition

$T_M \times \alpha m \times \delta$ > Load torque T_{LRmax}

· Assessment

$T_M \times \alpha m \times \delta =$ 42.2 [N·m] > $T_{LRmax} =$ 22.9 [N·m] → OK

(2) Assessment for the high-speed operation

· Output torque of the motor at high-speed operation = $T_M \times \alpha m$ = 29.2×2.0 = 58.4 [N·m]

Maximum short-time operation torque coefficient αm : 2.0 (at 50Hz) Power driving performance data in TECHNICAL NOTE No.30

· Assessment for the high-speed operation

◎Assessment condition $T_M \times \alpha m$ > Load torque T_{LRmax}

· Assessment

$T_M \times \alpha m$ = 58.4 [N·m] > $T_{LR max}$ = 22.9 [N·m] → **OK**

Assessment for the acceleration (calculation of the acceleration torque)

(1) Acceleration torque T_a

· Acceleration torque $T_a = \frac{\sum J \times N_{max}}{9.55 \times t_a} = \frac{(J_M + J_B + J_L) \times N_{max}}{9.55 \times t_a} = \frac{(0.028+0.0016+0.37) \times 1500}{9.55 \times 3.4}$

= 18.5 [N·m]

Motor moment of inertia J_M : 0.028[kg·m^2]	Motor characteristic table in TECHNICAL NOTE No.30.
Brake moment of inertia J_B : 0.0016[kg·m^2] (TB-7.5)	TB brake characteristic table in TECHNICAL NOTE No.30.
Load moment of inertia J_L : 0.37[kg·m^2]	From the calculation of the required power and load torque in (3)

(2) Total acceleration torque T_{at}

· Total acceleration torque $T_{at} = T_a + T_{LRmax}$ = 18.5 +22.9 = 41.4 [N·m]

(3) Assessment for the acceleration

· Output torque of the motor $T_M \times \alpha a$ = 29.2×1.86 = 54.3 [N·m]

Linear acceleration torque coefficient αa : 1.86	Powering driving performance data in TECHNICAL NOTE No.30

◎Assessment condition

$T_M \times \alpha a$ > Total acceleration torque T_{at}

· Assessment

$T_M \times \alpha a$ = 54.3 [N·m] > T_{at} = 41.4 [N·m] → **OK**

Assessment for the deceleration (calculation of the deceleration torque)

(1) Deceleration torque T_d

· Deceleration torque $T_d = \frac{\sum J \times N_{max}}{9.55 \times t_d} = \frac{(J_M + J_B + J_L) \times N_{max}}{9.55 \times t_d} = \frac{(0.028+0.0016+0.37) \times 1500}{9.55 \times 3.4}$

= 18.5 [N·m]

Motor moment of inertia J_M : 0.028[kg·m^2]	Motor characteristic table in TECHNICAL NOTE No.30
Brake moment of inertia J_B : 0.0016[kg·m^2] (TB-7.5)	TB brake characteristic table in TECHNICAL NOTE No.30
Load moment of inertia J_L : 0.37[kg·m^2]	From the calculation of the required power and load torque in (3)

(2) Total deceleration torque T_{dt}

Total deceleration torque T_{dt} = $-T_d$ + T_{LRmin} = | -18.5 + 17.2 | = | -1.3 | [N·m]

In this case, the minimum load torque (T_{LRmin}) is calculated with the machine efficiency η =1 considering the safety.

$$T_{LRmin} = \mu \times 9.8 \times W \times \frac{Vmax}{2\pi \, Nmax \, \eta} = 0.05 \times 9.8 \times 3300 \times \frac{100}{2\pi \times 1500 \times 1} = 17.2 \quad [N \cdot m]$$

(3) Assessment for the deceleration

· Output torque of the motor $T_M \times \beta$ = | 29.2×1.2 | = | 35.0 | [N·m]

Deceleration torque coefficient β (built-in brake) : 1.2 (Minimum value in the operation range 1.5 to 50Hz)
Regeneration performance data in TECHNICAL NOTE No.30

◎Assessment condition

$T_M \times \beta$ > Total deceleration torque T_{dt}

· Assessment

$T_M \times \beta$ = | 35.0 | [N·m] > $|T_{dt}|$ = | 1.3 | [N·m] → **OK**

Because "Tdt<0," assess for the deceleration as Tdt=｜Tdt｜.

Regenerative power calculation

(1) Check for the short-time permissible power

· Power regenerated from machine

$$W_{MECH} = 0.1047\times(-T_d + T_{LRmin})\times\frac{Nmax + Nmin}{2} \text{ [W]}$$

$$= \boxed{0.1047\times(-18.5 + 17.2)\times\frac{1500 + 45}{2}} = \boxed{-105.1} \text{ [W]}$$

· Power consumed at motor

$$W_M = (k_1 - k_2)\times P_{LR} = \boxed{(84-2)\times3.6} = \boxed{295} \text{ [W]}$$

Conversion coefficient k_1: 84 when f_{max} = 50 Hz, and the reference frequency = 60 Hz (Regeneration performance data in TECHNICAL NOTE No.30) Conversion coefficient k_2: 2 when f_{min} = 1.5 Hz, and the reference frequency = 60 Hz (Regeneration performance data in TECHNICAL NOTE No.30)

· Power regenerated to inverter

$$W_{INV} = |W_{MECH}| - W_M = \boxed{105.1-295} = \boxed{-189.9} \text{ [W]}$$

In this case, the power regenerated to the inverter is a negative value (power driving), so the operation system is not in the regenerative status.

$W_{INV} \le 0$ means that all the regenerative power is consumed at the motor and not regenerated to the inverter. Therefore, the following regenerative power assessments are not required, but assessed here for a reference.

· Assessment for the consumable regenerative power (short-time permissible power)

◎Assessment condition

Short-time permissible power of a braking option W_{RS} > Power regenerated to inverter W_{INV}

· Assessment W_{RS} = 2860 [W] > W_{INV} = -189.9 [W] → **OK**

Short-time permissible power of the braking option (built-in brake) W_{RS}: 2860 when the deceleration time (usage time) is 3.3s Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30

(2) Check for the average continuous regenerative power

· Average continuous regenerative power $W_{INV}\times\frac{t_3}{t_c}$

$$= \boxed{-189.9\times\frac{3.3}{3.4+6.2+3.3+2.1+10.0}} = \boxed{-25.1} \text{ [W]}$$

· Assessment for the consumable regenerative power (continuous operation permissible power)

◎Assessment condition

Continuous operation permissible power of a braking option W_{RC}	>	Average continuous regenerative power $\left(W_{INV}\times\frac{t_3}{t_c}\right)$

· Assessment

Continuous operation permissible power W_{RC} = 130 [W] > Average continuous regenerative power = -25.1 [W]→ **OK**

Motor temperature calculation

(1) Total torque and load torque ratio TF in each operation block

Calculate the load torque ratio from the total torque in each operation block.

Operation block	Operating status	Total torque in each operation block [N·m]	Load torque ratio [%]
1)	Acceleration	T_1= Acceleration torque T_a+ Maximum load torque T_{LRmax} = 18.5+22.9 = 41.4	$TF_1 = \frac{\lvert T_1 \rvert}{T_M} \times 100 = \frac{\lvert 41.4 \rvert}{29.2} \times 100$ = 141
2)	High-speed	T_2 = Load torque T_{LR} = 22.9	$TF_2 = \frac{\lvert T_2 \rvert}{T_M} \times 100 = \frac{\lvert 22.9 \rvert}{29.2} \times 100$ = 78
3)	Deceleration	T_3 = Deceleration torque – T_d+ Minimum load torque T_{LRmin} = -18.5+17.2 = -1.3	$TF_3 = \frac{\lvert T_3 \rvert}{T_M} \times 100 = \frac{\lvert -1.3 \rvert}{29.2} \times 100$ = 4
4)	Low-speed	T_4 = Load torque T_{LR} = 22.9	$TF_4 = \frac{\lvert T_4 \rvert}{T_M} \times 100 = \frac{\lvert 22.9 \rvert}{29.2} \times 100$ = 78
5)	Stop	T_5= 0 (Stop status in the block)	TF_5= 0

(2) The motor current $I_1, I_2 \ldots I_n$ [%] and the cooling coefficient $C_1, C_2 \ldots C_n$

Calculate the motor current $I_1, I_2 \ldots I_n$ [%] and the cooling coefficient $C_1, C_2 \ldots C_n$ from the average running frequency and the load torque ratio obtained in (1).

Operation block	Time period in the block [s]	Average running frequency [Hz]	Load torque ratio [%]	Cooling coefficient	Motor current [%]	$I_n^2 \times t_n$	$C_n \times t_n$
1)	t_1= 3.4	$\frac{fmax}{2} = \frac{50}{2}$ = 25	TF_1= 141	C_1= 0.70	I_1= 138	$I_1^2 \times t_1$ = 64749.6	$C_1 \times t_1$ = 2.38
2)	t_2= 6.2	fmax= 50	TF_2= 78	C_2= 0.93	I_2= 84	$I_2^2 \times t_2$ = 43747.2	$C_2 \times t_2$ = 5.77
3)	t_3= 3.3	$\frac{fmax + fmin}{2} = \frac{50+1.5}{2}$ = 25.75	TF_3= 4	C_3= 0.71	I_3= 50	$I_3^2 \times t_3$ = 8250	$C_3 \times t_3$ = 2.34
4)	t_4= 2.1	fmin= 1.5	TF_4= 78	C_4= 0.4	I_4= 84	$I_4^2 \times t_4$ = 14817.6	$C_4 \times t_4$ = 0.84
5)	t_5= 10.0	0 (Stop status in the block)	TF_5= 0	C_5= 0.4	I_5= 0	$I_5^2 \times t_5$ = 0	$C_5 \times t_5$ = 4.0

Cooling coefficient C_n: Motor and brake characteristics in TECHNICAL NOTE No.30
Motor current I_n: Motor and brake characteristics in TECHNICAL NOTE No.30

(3) Temperature assessment for the motor

· Equivalent current of motor torque I_{MC}

$$\text{Equivalent current of motor torque } I_{MC} = \sqrt{\frac{\Sigma(I_n^2 \times t_n)}{\Sigma(C_n \times t_n)}} = 91.8 \ [\%]$$

· Temperature assessment

◎Assessment condition

Equivalent current of motor torque I_{MC} < 100[%]

·Assessment I_{MC} = 91.8 [%] < 100 [%] → OK

(4) Electronic thermal relay check

· Calculate the ratio of the electronic thermal relay operation time to the motor current I_n in each operation block by referring to TECHNICAL NOTE No.30 (Electronic thermal relay characteristic).

Operation block	Time period in the block [s]	Average running frequency [Hz]	Motor current [%]	Electronic thermal relay operation time [s]
1)	t_1= 3.4	25	I_1 = 138	t_{THM1}= 70 (from the operation curve at 20Hz)
2)	t_2= 6.2	50	I_2 = 84	t_{THM2}= No operation
3)	t_3= 3.3	25.75	I_3 = 50	t_{THM3}= No operation
4)	t_4= 2.1	1.5	I_4 = 84	t_{THM4}= 300 (from the operation curve at 0.5Hz)
5)	t_5= 10.0	0	I_5 = 0	t_{THM5}= No operation

· Assessment for the electronic thermal relay operation

◎Assessment condition

Time in each operation block t_n < Electronic thermal relay operation time t_{THMn}

· Assessment t_1 = 3.4 < t_{THM1} = 70

· Assessment t_4 = 2.1 < t_{THM4} = 300

→ OK

(5) Transistor protection thermal check

· Calculate the load ratio to the rated inverter current in each operation block.

Operation block	Motor current [%]	Load ratio to the rated inverter current [%]
1)	I_1= 138	$TF_{INV1}=I_1\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}} = 138\times\frac{21}{33} = 87.8$
2)	I_2= 84	$TF_{INV2}=I_2\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}} = 84\times\frac{21}{33} = 53.5$
3)	I_3= 50	$TF_{INV3}=I_3\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}} = 50\times\frac{21}{33} = 31.8$
4)	I_4= 84	$TF_{INV4}=I_4\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}} = 84\times\frac{21}{33} = 53.5$
5)	I_5= 0	TF_{INV5}= 0

Rated motor current is 21 [A] for SF-JR 5.5kW 4P (200V, 60Hz)	Motor characteristic table in TECHNICAL NOTE No.30
Rated inverter current is 33 [A] for FR-A520-7.5K	Inverter catalogue

· Assessment for the transistor protection thermal operation

◎Assessment condition

Load ratio to the rated inverter current in each operation block TF_{INVn} ≦ 150[%] (Note)

(Note) It is 120% for the FR-F500 series inverters.

· Assessment TF_{INV1} to TF_{INV5} < 150[%] → OK

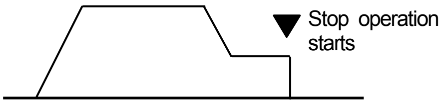
[Final selection]

- Motor : SF-JR 5.5kW 4P
- Inverter : FR-A520-7.5K(Advanced magnetic flux vector control)
- Brake resistor : Not required (inverter built-in brake)

Assessment for the stop accuracy

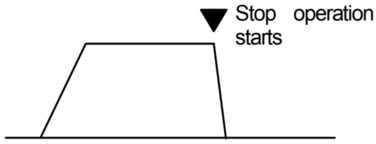
The following section assesses the stop accuracy in the two stop methods.

Stop from the low-speed (creep speed) operation



Low-speed (creep speed) operation

Stop from the high-speed operation with a TB brake



(1) Characteristics of a TB brake

Refer to TB-7.5 in (2) Brake characteristic (Chapter 4 Motor and brake characteristic) in TECHNICAL NOTE No.30.

Rated brake torque of TB-7.5 : $T_B =$ 75.0 [N·m]

Coasting time : $t_{01} =$ 0.1 [s]

Brake moment of inertia : $J_B =$ 0.0016 [kg·m^2]

(2) Stop accuracy when the machine stops from the low-speed (creep speed) operation

· Time to stop $t_b = t_{01} + t_{11}$

$$= t_{01} + \frac{(J_M + J_B + J_L) \times N_{min}}{9.55 \times (T_B + T_{LR}min)} = 0.1 + \frac{(0.028 + 0.0016 + 0.37) \times 45}{9.55 \times (75.0 + 17.2)}$$

$$= 0.1 + 0.020 = 0.120 \text{ [s]}$$

· Distance to stop $S = S_{01} + S_{11}$ (Creep speed V_{min} = 3m/min)

$$= \left(t_{01} \times \frac{V_{min}}{60} + t_{11} \times \frac{1}{2} \times \frac{V_{min}}{60} \right) \times 10^3 = \left(0.1 \times \frac{3}{60} + 0.020 \times \frac{1}{2} \times \frac{3}{60} \right) \times 10^3 = 5.5 \text{ [mm]}$$

· Estimated stop accuracy

$$\Delta\varepsilon = \pm \frac{S}{2} = \pm \frac{5.5}{2} = \pm 2.75 \text{ [mm]}$$

(3) Stop accuracy when the machine suddenly stops from the high-speed operation by a TB brake

· Time to stop $t_b = t_{01} + t_{11}$

$$= t_{01} + \frac{(J_M + J_B + J_L) \times N_{max}}{9.55 \times (T_B + T_{LR}min)} = 0.1 + \frac{(0.028 + 0.0016 + 0.37) \times 1500}{9.55 \times (75.0 + 17.2)}$$

$$= 0.1 + 0.681 = 0.781 \text{ [s]}$$

· Distance to stop $S = S_{01} + S_{11}$ (High speed V_{max} = 100m/min)

$$= \left(t_{01} \times \frac{V_{max}}{60} + t_{11} \times \frac{1}{2} \times \frac{V_{max}}{60} \right) \times 10^3 = 0.1 \times \frac{100}{60} + 0.681 \times \frac{1}{2} \times \frac{100}{60} \times 10^3 = 734 \text{ [mm]}$$

· Estimated stop accuracy

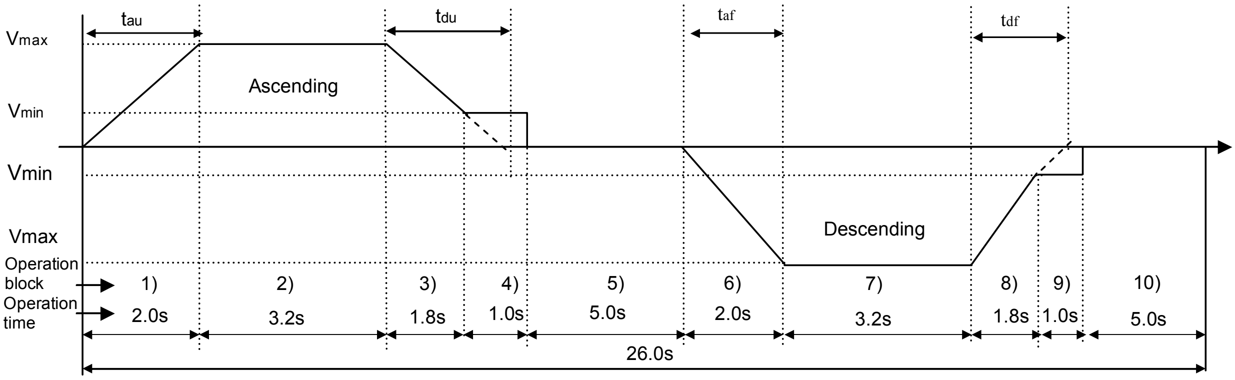
$$\Delta\varepsilon = \pm \frac{S}{2} = \pm \frac{734}{2} = \pm 367 \text{ [mm]}$$

From the above assessments, the following observation can be concluded; the stop accuracy radically improves by driving the motor at the low-speed (creep speed) operation first then stop it with the mechanical brake.

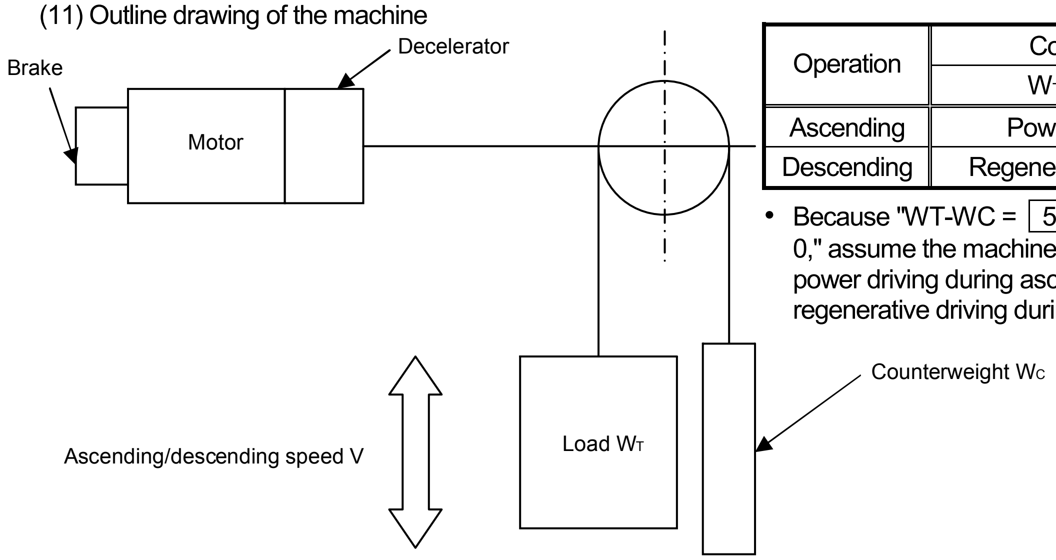
CHAPTER 8 SELECTION EXAMPLE FOR LIFT OPERATION (LIFT WITH COUNTERWEIGHT)

(Load/operation specification)

(1) Power supply voltage/frequency	200 [V] 60 [Hz]
(2) Speed range of the motor	N_{min} 180 to N_{max} 1800 [r/min]
(3) Number of motor poles	4 P
(4) Frequency range	f_{min} 6 to f_{max} 60 [Hz]
(5) Mass of driven object W	
(a) Load mass of the lifter	W_T 5200 [kg]
(b) Counterweight	W_C 4500 [kg]
(c) Chain mass	W_{CH} 350 [kg]
(d) Unbalanced load mass of the chain	W_{CS} 300 [kg]
(6) Ascending/descending speed	V_{min} 3 to V_{max} 30 [m/min]
(7) Machine efficiency of the driving part	η 0.9
(8) Friction coefficient	μ 0.01
(9) Friction coefficient at start	μ_S 0.015
(10) Operation pattern	
(a) Acceleration time during ascending/descending	t_{au}, t_{af} 2.0 [s]
(b) Deceleration time during ascending/descending	t_{du}, t_{df} 2.0 [s]
(c) Time per cycle	t_c 26.0 [s]



(11) Outline drawing of the machine



Operation	Condition W_T-W_C≥0
Ascending	Power driving
Descending	Regenerative driving

- Because "WT-WC = 5200 - 4500 ≥ 0," assume the machine performs power driving during ascending and regenerative driving during descending

Calculation of required power and load torque

(1) Required power for the load P_{LR}

· Required power for the load $P_{LR} = \dfrac{W \times V_{max}}{6120 \times \eta} = \boxed{\dfrac{1000 \times 30}{6120 \times 0.9}} = \boxed{5.45}$ [kW]

Mass of driven object W: $W = \vert W_T - W_C \vert + W_{CS} = \vert 5200 - 4500 \vert + 300 = 1000$[kg]

(2) Load torque at motor shaft T_{LR}

· Load torque during power driving T_{LU}=

$$\frac{9.8 \times W \times V_{max}}{2\pi N_{max} \times \eta} + \frac{\mu \times 9.8 \times W_{ALL} \times V_{max}}{2\pi N_{max} \times \eta} = \boxed{\frac{9.8 \times 1000 \times 30}{2\pi \times 1800 \times 0.9} + \frac{0.01 \times 9.8 \times 10050 \times 30}{2\pi \times 1800 \times 0.9}} = \boxed{31.8} \text{ [N·m]}$$

Mass of driven object W:	$W = W_T - W_C + W_{CS} = 5200 - 4500 + 300 = 1000$[kg]
	$W_{ALL} = 5200 + 4500 + 350 = 10050$[kg]

·Load torque during regenerative driving T_{Lf}=

$$\frac{9.8 \times W \times \eta \times V_{max}}{2\pi N_{max}} = \boxed{\frac{9.8 \times -1000 \times 1.0 \times 30}{2\pi \times 1800}} = \boxed{-26.0} \text{ [N·m]}$$

(Calculate with "machine efficiency η =1" and "friction coefficient μ =0" considering the safety.)

Mass of driven object W: $W = W_C - W_T - W_{CS} = 4500 - 5200 - 300 = -1000$[kg]

· Load torque at motor shaft T_{LR}

Because the load torque during power driving T_{LU} > the load torque during regenerative driving T_{Lf}, perform the following calculations as $T_{LR} = T_{LU}$.

(3) Load moment of inertia at motor shaft J_L

· Load moment of inertia of the lifter $J_T = W_T \times \left(\dfrac{V_{max}}{2\pi \times N_{max}}\right)^2 = \boxed{5200 \times \left(\dfrac{30}{2\pi \times 1800}\right)^2} = \boxed{0.0366}$ [kg·m²]

· Load moment of inertia of the counterweight $J_C = W_C \times \left(\dfrac{V_{max}}{2\pi \times N_{max}}\right)^2 = \boxed{4500 \times \left(\dfrac{30}{2\pi \times 1800}\right)^2} = \boxed{0.0317}$ [kg·m²]

· Load moment of inertia of the chain $J_{CH} = W_{CH} \times \left(\dfrac{V_{max}}{2\pi \times N_{max}}\right)^2 = \boxed{350 \times \left(\dfrac{30}{2\pi \times 1800}\right)^2} = \boxed{0.0025}$ [kg·m²]

· Load moment of inertia at motor shaft $J_L = J_T + J_C + J_{CH} = \boxed{0.0366 + 0.0317 + 0.0025} = \boxed{0.0708}$ [kg·m²]

Selection of motor and inverter capacities (tentative)

(1) Selection of the motor capacity P_M (tentative)

$P_M = P_{LR} \times k_P = \boxed{5.45} \times \boxed{1.2} = \boxed{6.54}$ [kW] (Tentative selection with k_P = 1.2 (20% margin))

From above, tentatively select SF-JR 7.5 [kW] 4P

· Rated motor torque $T_M = \dfrac{9550 \times P_M}{N_M} = \boxed{\dfrac{9550 \times 7.5}{1800}} = \boxed{39.8}$ [N·m]

· Assessment for the motor capacity (tentative)

◎Assessment condition

Rated motor torque T_M ≥ Load torque T_{LR}

· Assessment T_M= 39.8 [N·m] ≥ T_{LR} = 31.8 [N·m] → **OK**

(2) Selection of the inverter capacity (tentative)

Tentatively select the inverter capacity FR-A520-7.5K, which has the same capacity with the tentatively selected motor. Because the inverter is used for a lift, assume using Advanced magnetic flux vector control.

Assessment for the start

(1) Starting torque of the motor

· Starting torque of the motor $T_{MS}=T_M\times\alpha_S\times\delta$ = 39.8×1.5×0.85 = 50.7 [N·m]

Starting torque coefficient α_S : 1.5	Power driving performance data in TECHNICAL NOTE No.30
Hot coefficient δ : 0.85	Outline of Technical Note No.30 [DATA] in TECHNICAL NOTE No.30

· Load torque at start T_{LS} =

$$\frac{9.8\times W\times V_{max}}{2\pi N_{max}\times\eta}+\frac{\mu_S\times 9.8\times W_{ALL}\times V_{max}}{2\pi N_{max}\times\eta}=\frac{9.8\times1000\times30}{2\pi\times1800\times0.9}+\frac{0.015\times9.8\times10050\times30}{2\pi\times1800\times0.9}=33.3\ [\text{N·m}]$$

(2) Assessment for the start

◎Assessment condition

Maximum starting torque of the motor T_{MS} ≥ Load torque at start T_{LS}

· Assessment T_{MS}= 50.7 [N·m] ≥ T_{LS}= 33.3 [N·m] → **OK**

Assessment for the low-speed and high-speed operations

(1) Assessment for the power low-speed operation

· Output torque of the motor at power low-speed operation

Output torque of the motor at power low-speed operation
$=T_M\times\alpha_m\times\delta$= 39.8×1.5×0.85 = 50.7 [N·m]

Maximum short-time torque coefficient α_m : 1.5 (f_{min} at 6Hz)	Power driving performance data in TECHNICAL NOTE No.30
Hot coefficient δ : 0.85	Outline of Technical Note No.30 [DATA] in TECHNICAL NOTE No.30

·Assessment for the power low-speed operation

◎Assessment condition

$T_M\times\alpha_m\times\delta$ > Load torque T_{LU}

· Assessment $T_M\times\alpha_m\times\delta$= 50.7 [N·m] > T_{LU}= 33.3 [N·m] → **OK**

(2) Assessment for the regenerative low-speed operation

· Output torque of the motor at regenerative low-speed operation

Output torque of the motor at regenerative low-speed operation
$=T_M \times \beta \times \delta =$ [39.8×1.0×0.85] = [33.8] [N·m]

Deceleration torque coefficient β	: 1.0 (f_{min} at 6Hz)	Power driving performance data in TECHNICAL NOTE No.30
Hot coefficient	δ : 0.85	Outline of Technical Note No.30 [DATA] in TECHNICAL NOTE No.30

· Assessment for the regenerative low-speed operation

◎Assessment condition [$T_M \times \beta \times \delta$ > Load torque $|T_{Lf}|$]

· Assessment $T_M \times \beta \times \delta =$ [33.8] [N·m] > $|T_{Lf}| =$ [26.0] [N·m] → [OK]

(3) Assessment for the power high-speed operation

· Output torque of the motor at power high-speed operation

Output torque of the motor at power high-speed operation
$=T_M \times \alpha m =$ [39.8 × 1.5] = [59.7] [N·m]

Maximum short-time operation torque coefficient αm : 1.5 (f_{max} at 60Hz)
Power driving performance data in TECHNICAL NOTE No.30

· Assessment for the power high-speed operation

◎Assessment condition [$T_M \times \alpha m$ > Load torque T_{LU}]

· Assessment $T_M \times \alpha m =$ [59.7] [N·m] > $T_{LU} =$ [33.3] [N·m] → [OK]

(4) Assessment for the regenerative high-speed operation

· Output torque of the motor at regenerative high-speed operation

Output torque of the motor at regenerative high-speed operation
$=T_M \times \beta =$ [39.8 × 1.0] = [39.8] [N·m]

Deceleration torque coefficient β:1.0 (f_{max} at 60Hz)
Regeneration performance data in TECHNICAL NOTE No.30

· Assessment for the regenerative high-speed operation

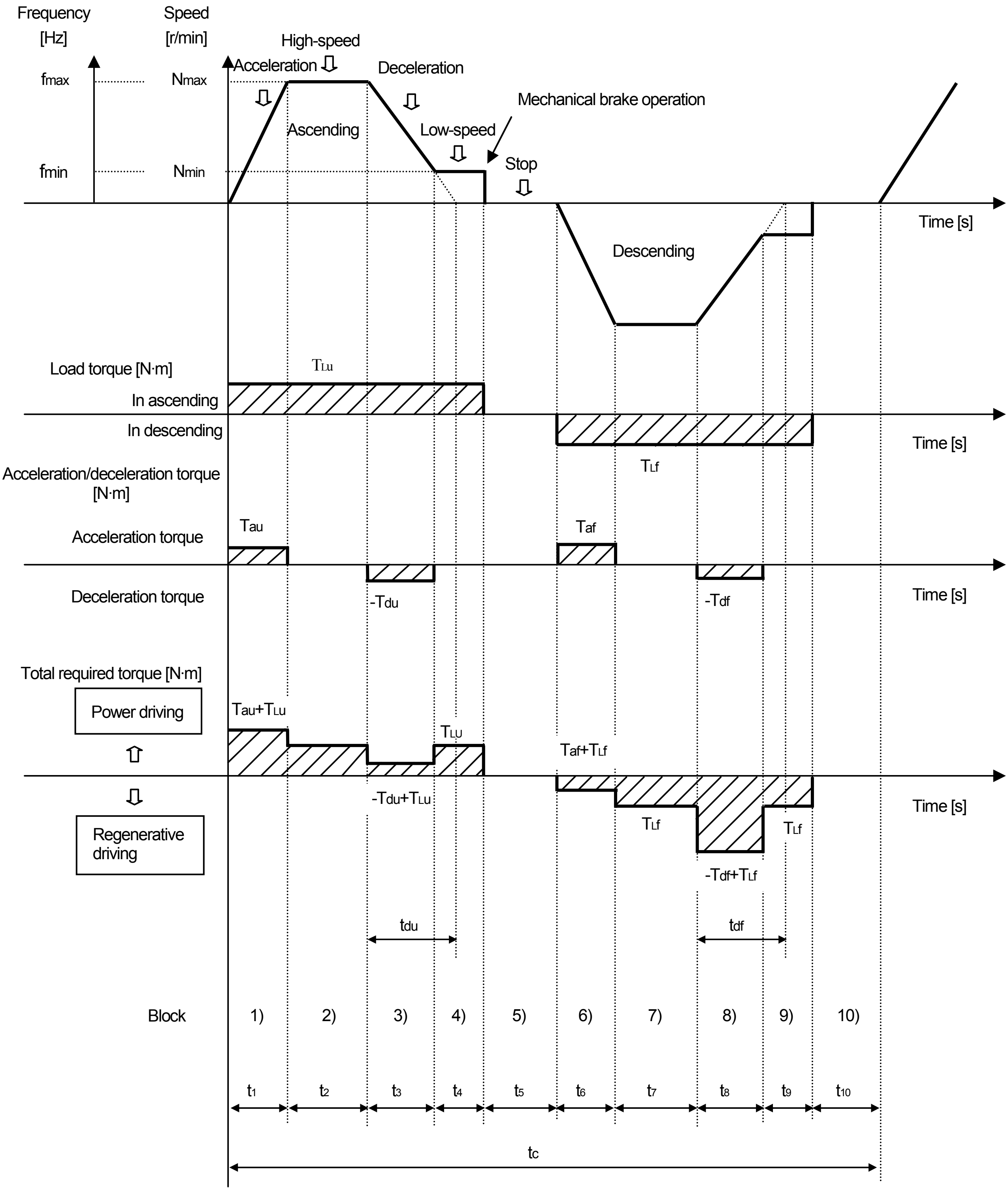
◎Assessment condition [$T_M \times \beta$ > Load torque $|T_{Lf}|$]

· Assessment $T_M \times \beta =$ [39.8] [N·m] > $|T_{Lf}| =$ [26.0] [N·m] → [OK]

Assessment for the acceleration/deceleration

(1) Applied torque to the motor in each operation block

Assume the operation pattern of the figure below (power driving during ascending, regenerative driving during descending). Calculate the applied torque to the motor in operation blocks 1) to 10).



(2) Acceleration torque T_{au}, T_{af}

· Acceleration torque during ascending T_{au} $= \dfrac{\sum J \times N_{max}}{9.55 \times t_{au}} = \dfrac{(J_M+J_B+J_L) \times N_{max}}{9.55 \times t_{au}} = \boxed{\dfrac{(0.04+0.0016+0.0708) \times 1800}{9.55 \times 2.0}}$

$= \boxed{10.6}$ [N·m]

Motor moment of inertia J_M : 0.04[kg·m^2]	Motor characteristic table in TECHNICAL NOTE No.30
Brake moment of inertia J_B : 0.0016[kg·m^2] (TB-7.5)	Brake characteristic in TECHNICAL NOTE No.30
Load moment of inertia J_L : 0.0708[kg·m^2]	From the required power and the load torque calculation (3)

· Acceleration torque during descending T_{af} $= \dfrac{\sum J \times N_{max}}{9.55 \times t_{af}} = \dfrac{(J_M+J_B+J_L) \times N_{max}}{9.55 \times t_{af}} = \boxed{\dfrac{(0.04+0.0016+0.0708) \times 1800}{9.55 \times 2.0}}$

$= \boxed{10.6}$ [N·m]

Motor moment of inertia J_M : 0.04[kg·m^2]	Motor characteristic table in TECHNICAL NOTE No.30
Brake moment of inertia J_B : 0.0016[kg·m^2] (TB-7.5)	Brake characteristic in TECHNICAL NOTE No.30
Load moment of inertia J_L : 0.0708[kg·m^2]	From the required power and the load torque calculation (3)

(3) Deceleration torque T_{du}, T_{df}

· Deceleration torque during ascending T_{du} $= \dfrac{\sum J \times N_{max}}{9.55 \times t_{du}} = \dfrac{(J_M+J_B+J_L) \times N_{max}}{9.55 \times t_{du}} = \boxed{\dfrac{(0.04+0.0016+0.0708) \times 1800}{9.55 \times 2.0}}$

$= \boxed{10.6}$ [N·m]

Motor moment of inertia J_M : 0.04[kg·m^2]	Motor characteristic table in TECHNICAL NOTE No.30
Brake moment of inertia J_B : 0.0016[kg·m^2] (TB-7.5)	Brake characteristic in TECHNICAL NOTE No.30
Load moment of inertia J_L : 0.0708[kg·m^2]	From the required power and the load torque calculation (3)

· Deceleration torque during descending T_{df} $= \dfrac{\sum J \times N_{max}}{9.55 \times t_{df}} = \dfrac{(J_M+J_B+J_L) \times N_{max}}{9.55 \times t_{df}} = \boxed{\dfrac{(0.04+0.0016+0.0708) \times 1800}{9.55 \times 2.0}}$

$= \boxed{10.6}$ [N·m]

Motor moment of inertia J_M : 0.04[kg·m^2]	Motor characteristic table in TECHNICAL NOTE No.30
Brake moment of inertia J_B : 0.0016[kg·m^2] (TB-7.5)	Brake characteristic in TECHNICAL NOTE No.30
Load moment of inertia J_L : 0.0708[kg·m^2]	From the calculation of the required power and load torque in (3)

(4) Total torque

· Calculate the total torque in each operation block using the formulas in the table below.

Total torque	Operation	Operation block	Total torque [N·m]
Total acceleration torque	Power driving	1)	$T_1 = T_{au} + T_{Lu}$ = 10.6+33.3 = 43.9
	Regenerative driving	6)	$T_6 = T_{af} + T_{Lf}$ = 10.6+(-26.0) = -15.4
Total deceleration torque	Power driving	3)	$T_3 = -T_{du} + T_{Lu}$ = -10.6+33.3 = 22.7
	Regenerative driving	8)	$T_8 = -T_{df} + T_{Lf}$ = -10.6+(-26.0) = -36.6
Total torque during constant-speed operation (high/low speed)	Power driving	2), 4)	T_2, $T_4 = T_{Lu}$ = 33.3
	Regenerative driving	7), 9)	T_7, $T_9 = T_{Lf}$ = -26.0

(5) Assessment for the acceleration

· Output torque of the motor $T_M \times \alpha a$ = 39.8×1.4 = 55.7 [N·m]

Linear acceleration torque coefficient αa: 1.4 Power driving performance data in TECHNICAL NOTE No.30

◎Assessment condition

$T_M \times \alpha a$ > Total acceleration torque T_{at}

For the total acceleration torque T_{at}, use T_1 in the operation block 1) or T_6 in the operation block 6), whichever is larger. Because $T_1 > T_6$ at this machine, assess for the acceleration as the total acceleration torque $T_{at} = T_1$. Regenerative acceleration is performed when $T_1 < 0$ and $T_6 < 0$. The maximum torque required for regenerative operation is calculated in the assessment for deceleration. It does not have to be calculated for the assessment for acceleration.

· Assessment $T_M \times \alpha a$ = 55.7 [N·m] > T_{at}= 43.9 [N·m] → OK

(6) Assessment for the deceleration

· Output torque of the motor $T_M \times \beta$ = 39.8×1.0 = 39.8 [N·m]

Deceleration torque coefficient β : 1.0 (minimum value in the operation range of 6 to 60Hz) Regeneration performance data in TECHNICAL NOTE No.30

◎Assessment condition

$T_M \times \beta$ > Total deceleration torque $\lvert T_{dt} \rvert$

For the total deceleration torque T_{dt}, use T_3 in the operation block 3) or T_8 in the operation block 8), whichever is smaller. Because $T_3 > T_8$ at this machine, assess for the deceleration as the total deceleration torque $T_{dt} = \lvert T_8 \rvert$. Power deceleration is performed when $T_3 > 0$ and $T_8 > 0$. The maximum torque required for power operation is calculated in the assessment for acceleration. It does not have to be calculated for the assessment for deceleration.

· Assessment $T_M \times \beta$ = 39.8 [N·m] > $\lvert T_{dt} \rvert$ = 36.6 [N·m] → OK

Permissible temperature calculation for the brake unit

(1) Regenerative power calculation

The following table shows how the power in different operation blocks are calculated.
When the obtained value is a negative value, it is a regenerative power.

Operation block	Power [W]	Operating status
1)	$W_1=0.1047\times\frac{Nmax}{2}\times T_1=$ $0.1047\times\frac{1800}{2}\times43.9$ = 4137	Power acceleration
2)	$W_2=0.1047\times Nmax\times T_2=$ $0.1047\times1800\times33.3$ = 6276	Power high-speed operation
3)	$W_3=0.1047\times\frac{Nmax+Nmin}{2}\times T_3=$ $0.1047\times\frac{1800+180}{2}\times22.7$ = 2353	Power deceleration
4)	$W_4=0.1047\times Nmin\times T_4=$ $0.1047\times180\times33.3$ = 628	Power low-speed operation
5)	W_5=Not calculated as the machine is in the stop status.	Stop
6)	$W_6=0.1047\times\frac{Nmax}{2}\times T_6=$ $0.1047\times\frac{1800}{2}\times(-15.4)$ = -1451	Regenerative acceleration
7)	$W_7=0.1047\times Nmax\times T_7=$ $0.1047\times1800\times(-26.0)$ = -4900	Regenerative high-speed operation
8)	$W_8=0.1047\times\frac{Nmax+Nmin}{2}\times T_8=$ $0.1047\times\frac{1800+180}{2}\times(-36.6)$ = -3794	Regenerative deceleration
9)	$W_9=0.1047\times Nmin\times T_9=$ $0.1047\times180\times(-26.0)$ = -490	Regenerative low-speed operation
10)	W_{10}=Not calculated as the machine is in the stop status.	Stop

(2) Check for the short-time regenerative power

Assess only the operation blocks where the power W_n is a negative value (in regenerative status). Assess the operation blocks 6), 7), 8), and 9) based on the calculation result of (1).

◎Assessment condition

Short-time permissible power of a braking option W_{RS}	>	Regenerative power in each operation block $\lvert W_n \rvert\times0.9$

· Assessment

Operation block 7) $W_{RS}=$ 2860 [W] < $\lvert W_7\rvert\times0.9=\lvert-4900\rvert\times0.9$ = 4410 [W]→ **Not acceptable**

Short-time permissible power (built-in brake) W_{RS}: 2860 when the deceleration time (usage time) is 1.8s
Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30

· The result shows that the inverter's built-in brake does not consume enough regenerative power. Therefore, consider using the braking option FR-BU-15K (FR-BR-15K). Assess the regenerative power of the braking option.
(The continuous operation permissible power is not enough with FR-ABR-7.5. The short-time permissible power is not enough with BU-7.5.)

· Assessment

Operation block 6) W_{RS}= 16500 [W] > $|W_6|$ ×0.9 = $|-1451|$ ×0.9 = 1306 [W]→
Operation block 7) W_{RS}= 16500 [W] > $|W_7|$ ×0.9 = $|-4900|$ ×0.9 = 4410 [W]→
Operation block 8) W_{RS}= 16500 [W] > $|W_8|$ ×0.9 = $|-3794|$ ×0.9 = 3415 [W]→
Operation block 9) W_{RS}= 16500 [W] > $|W_9|$ ×0.9 = $|-490|$ ×0.9 = 441 [W]→

OK

Short-time permissible power (FR-BU-15K) W_{RS}: 16500 when the deceleration time (usage time) is 2.0s, 3.2s, 1.8s, or 1.0s
Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30

(3) Check for the regenerative power in the continuous regenerative operation range

Assess the regenerative power for the operation blocks where the regenerative status is continuous. Regenerative operation is continuous in the operation blocks 6) to 9) in this machine, so check these operation blocks.

· Average regenerative power in the continuous regenerative operation range

$$W_{nc} = \frac{|\Sigma(W_n \times t_n)|}{\Sigma t_n} \times 0.9 = \frac{|(W_6 \times t_6) + (W_7 \times t_7) + (W_8 \times t_8) + (W_9 \times t_9)|}{t_6 + t_7 + t_8 + t_9} \times 0.9$$

$$= \frac{|(-1451 \times 2.0) + (-4900 \times 3.2) + (-3794 \times 1.8) + (-490 \times 1.0)|}{2.0 + 3.2 + 1.8 + 1.0} \times 0.9 = 3238 \times 0.9 = 2914 \text{ [W]}$$

◎Assessment condition

Short-time permissible power of a braking option W_{RS}	>	Average regenerative power in the continuous regenerative operation range W_{nc}

· Assessment W_{RS}= 16500 [W] > W_{nc}= 2914 [W] → OK

Short-time permissible power (FR-BU-15K) W_{RS}:16500 when the deceleration time (usage time) is 8.0s
Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30

(4) Check for the average continuous regenerative power

Check the average power to be regenerated to the inverter in a cycle.

The operation blocks in the regenerative status are 6) to 9) in this cycle.

· Average regenerative power $W_{INV} = \frac{|\Sigma(W_n \times t_n)|}{t_c} \times 0.9 = \frac{|(W_6 \times t_6) + (W_7 \times t_7) + (W_8 \times t_8) + (W_9 \times t_9)|}{t_c} \times 0.9$

$= \frac{|(-1451 \times 2.0) + (-4900 \times 3.2) + (-3794 \times 1.8) + (-490 \times 1.0)|}{26.0} \times 0.9 = \boxed{897}$ [W]

◎Assessment condition

Average regenerative power W_{INV} < Continuous operation permissible power of a braking option W_{RC}

· Assessment

Continuous operation permissible power of the braking option $W_{RC} = \boxed{990}$ [W] > Average regenerative power $W_{INV} = \boxed{897}$ [W] → **OK**

Continuous operation permissible power (FR-BU-15K) W_{RC}: 990 Chapter 3 Regeneration performance data in TECHNICAL NOTE No.30

Motor temperature calculation

(1) Total torque and load torque ratio TF in each operation block

Calculate the load torque ratio from the total torque obtained in the acceleration/deceleration assessment (4).

Operation block	Operating status	Total torque in the operation block [N·m]	Load torque ratio [%]
1)	Power acceleration	T_1= 43.9	$TF_1 = \frac{\mid T_1 \mid}{T_M} \times 100 = \frac{\mid 43.9 \mid}{39.8} \times 100$ = 110
2)	Power high-speed operation	T_2= 33.3	$TF_2 = \frac{\mid T_2 \mid}{T_M} \times 100 = \frac{\mid 33.3 \mid}{39.8} \times 100$ = 84
3)	Power deceleration	T_3= 22.7	$TF_3 = \frac{\mid T_3 \mid}{T_M} \times 100 = \frac{\mid 22.7 \mid}{39.8} \times 100$ = 57
4)	Power low-speed operation	T_4= 33.3	$TF_4 = \frac{\mid T_4 \mid}{T_M} \times 100 = \frac{\mid 33.3 \mid}{39.8} \times 100$ = 84
5)	Stop	T_5= 0 (Stop status in the block)	TF_5= 0
6)	Regenerative acceleration	T_6= -15.4	$TF_6 = \frac{\mid T_6 \mid}{T_M} \times 100 = \frac{\mid -15.4 \mid}{39.8} \times 100$ = 39
7)	Regenerative high-speed operation	T_7= -26.0	$TF_7 = \frac{\mid T_7 \mid}{T_M} \times 100 = \frac{\mid -26.0 \mid}{39.8} \times 100$ = 65
8)	Regenerative deceleration	T_8= -36.6	$TF_8 = \frac{\mid T_8 \mid}{T_M} \times 100 = \frac{\mid -36.6 \mid}{39.8} \times 100$ = 92
9)	Regenerative low-speed operation	T_9= -26.0	$TF_9 = \frac{\mid T_9 \mid}{T_M} \times 100 = \frac{\mid -26.0 \mid}{39.8} \times 100$ = 65
10)	Stop	T_{10}= 0 (Stop status in the block)	TF_{10}= 0

(2) The motor current $I_1, I_2 \ldots I_n$ [%] and the cooling coefficient $C_1, C_2 \ldots C_n$

Calculate the motor current $I_1, I_2 \ldots I_n$ [%] and the cooling coefficient $C_1, C_2 \ldots C_n$ from the average running frequency and the load torque ratio obtained in (1).

Operation block	Time period in the block [s]	Average running frequency [Hz]	Load torque ratio [%]	Cooling coefficient	Motor current [%]	$I_n^2 \times t_n$	$C_n \times t_n$
1)	t_1= 2.0	$\frac{fmax}{2}$ = 30	TF_1= 110	C_1= 0.76	I_1= 109	$I_1^2 \times t_1$ = 23762	$C_1 \times t_1$ = 1.52
2)	t_2= 3.2	fmax= 60	TF_2= 84	C_2= 1.0	I_2= 88	$I_2^2 \times t_2$ = 24781	$C_2 \times t_2$ = 3.2
3)	t_3= 1.8	$\frac{fmax + fmin}{2}$ = 33	TF_3= 57	C_3= 0.79	I_3= 72	$I_3^2 \times t_3$ = 9331	$C_3 \times t_3$ = 1.42
4)	t_4= 1.0	fmin= 6	TF_4= 84	C_4= 0.4	I_4= 88	$I_4^2 \times t_4$ = 7744	$C_4 \times t_4$ = 0.4
5)	t_5= 5.0	0	TF_5= 0	C_5= 0.4	I_5= 0	$I_5^2 \times t_5$ = 0	$C_5 \times t_5$ = 2.0
6)	t_6= 2.0	$\frac{fmax}{2}$ = 30	TF_6= 39	C_6= 0.76	I_6= 62	$I_6^2 \times t_6$ = 7688	$C_6 \times t_6$ = 1.52
7)	t_7= 3.2	fmax= 60	TF_7= 65	C_7= 1.0	I_7= 76	$I_7^2 \times t_7$ = 18483	$C_7 \times t_7$ = 3.2
8)	t_8= 1.8	$\frac{fmax + fmin}{2}$ = 33	TF_8= 92	C_8= 0.79	I_8= 92	$I_8^2 \times t_8$ = 15235	$C_8 \times t_8$ = 1.42
9)	t_9= 1.0	fmin= 6	TF_9= 65	C_9= 0.4	I_9= 76	$I_9^2 \times t_9$ = 5776	$C_9 \times t_9$ = 0.4
10)	t_{10}= 5.0	0	TF_{10}= 0	C_{10}= 0.4	I_{10}= 0	$I_{10}^2 \times t_{10}$ = 0	$C_{10} \times t_{10}$ = 2.0

Cooling coefficient C_n : Motor and brake characteristics in TECHNICAL NOTE No.30
Motor current I_n : Motor and brake characteristics in TECHNICAL NOTE No.30

(3) Temperature assessment for the motor

· Equivalent current of motor torque I_{MC}

Equivalent current of motor torque $I_{MC} = \sqrt{\dfrac{\Sigma(In^2 \times tn)}{\Sigma(Cn \times tn)}}$ = 81.3 [%]

· Temperature assessment

◎Assessment condition

Equivalent current of motor torque I_{MC} < 100 [%]

· Assessment

I_{MC} = 81.3 [%] < 100 [%] → OK

(4) Check for the electronic thermal relay

Calculate the ratio of the electronic thermal relay operation time to the motor current I_n in each operation block by referring to TECHNICAL NOTE No.30 (Electronic thermal relay characteristic).

Operation block	Time period in the block [s]	Average running frequency [Hz]	Motor current [%]	Electronic thermal relay operation time [s]
1)	t_1= 2.0	$\frac{fmax}{2}$ = 30	I_1= 109	t_{THM1}= 600s
2)	t_2= 3.2	fmax= 60	I_2= 88	t_{THM2}= No operation
3)	t_3= 1.8	$\frac{fmax + fmin}{2}$ = 33	I_3= 72	t_{THM3}= No operation
4)	t_4= 1.0	fmin= 6	I_4= 88	t_{THM4}= 400s or longer
5)	t_5= 5.0	0	I_5= 0	t_{THM5}= No operation
6)	t_6= 2.0	$\frac{fmax}{2}$ = 30	I_6= 62	t_{THM6}= No operation
7)	t_7= 3.2	fmax= 60	I_7= 76	t_{THM7}= No operation
8)	t_8= 1.8	$\frac{fmax + fmin}{2}$ = 33	I_8= 92	t_{THM8}= No operation
9)	t_9= 1.0	fmin= 6	I_9= 76	t_{THM9}= 600s or longer
10)	t_{10}= 5.0	0	I_{10}= 0	t_{THM10}= No operation

· Assessment for the electronic thermal relay operation

◎Assessment condition

Operation time in each operation block t_n < Electronic thermal relay operation time t_{THMn}

· Assessment

t_1 = 2.0 < t_{THM1} = 600s

t_4 = 1.0 < t_{THM4} = 400s or longer

t_9 = 1.0 < t_{THM9} = 600s or longer

→ OK

(5) Check for the transistor protection thermal

Calculate the load ratio to the rated inverter current in each operation block.

Operation block	Motor current [%]	Load ratio to the rated inverter current [%]
1)	I_1= 99	$TF_{INV1}=I_1\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}}=109\times\frac{28}{33}$ = 92.5
2)	I_2= 81	$TF_{INV2}=I_2\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}}=88\times\frac{28}{33}$ = 74.7
3)	I_3= 65	$TF_{INV3}=I_3\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}}=72\times\frac{28}{33}$ = 61.1
4)	I_4= 81	$TF_{INV4}=I_4\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}}=88\times\frac{28}{33}$ = 74.7
5)	I_5= 0	TF_{INV5}= 0
6)	I_6= 62	$TF_{INV6}=I_6\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}}=62\times\frac{28}{33}$ = 52.6
7)	I_7= 76	$TF_{INV7}=I_7\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}}=76\times\frac{28}{33}$ = 64.5
8)	I_8= 92	$TF_{INV8}=I_8\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}}=92\times\frac{28}{33}$ = 78.1
9)	I_9= 76	$TF_{INV9}=I_9\times\frac{\text{Rated motor current [A]}}{\text{Rated inverter current [A]}}=76\times\frac{28}{33}$ = 64.5
10)	I_{10}= 0	TF_{INV10}= 0

Rated motor current	28[A] : SF-JR 7.5kW 4P(200V, 60Hz)
Rated inverter current	33[A] : FR-A520-7.5K

· Assessment for the transistor protection thermal operation

◎Assessment condition

Load ratio to the rated inverter current in each operation block $TF_{INVn} \leq$ 150[%] (Note)

(Note) It is 120% for the FR-F500 series inverters.

· Assessment TF_{INV1} to TF_{INV10} < 150 [%] → OK

[Final selection]

- Motor : SF-JR 7.5kW 4P
- Inverter : FR-A520-7.5K (Advanced magnetic flux vector control)
- Brake resistor : FR-BU-15K(FR-BR-15K)

Assessment for the stop accuracy

(1) Characteristics of a brake

The following characteristic of the mechanical brake TB-7.5 are obtained from TECHNICAL NOTE No.30 [DATA].

- Rated brake torque : T_B = 75 [N·m]
- Coasting time (cutoff in advance) : t_{01} = 0.1 [s]
- Brake moment of inertia : J_B = 0.0016 [kg·m^2]

(2) Stop accuracy when the machine stops from the low-speed (creep speed) operation

· Time to stop $t_b = t_{01} + t_{11}$

$$= t_{01} + \frac{(J_M + J_B + J_L) \times N_{min}}{9.55 \times (T_B + T_{LRmin})} = \boxed{0.1 + \frac{(0.04+0.0016+0.0708) \times 180}{9.55 \times (75.0+33.3)}}$$

$$= \boxed{0.1 + 0.020} = \boxed{0.120} \text{ [s]}$$

· Distance to stop $S = S_{01} + S_{11}$ (Creep speed V_{min} = 3m/min)

$$= \left(t_{01} \times \frac{V_{min}}{60} + t_{11} \times \frac{1}{2} \times \frac{V_{min}}{60} \right) \times 10^3 = \boxed{\left(0.1 \times \frac{3}{60} + 0.020 \times \frac{1}{2} \times \frac{3}{60} \right) \times 10^3} = \boxed{5.5} \text{ [mm]}$$

· Estimated stop accuracy

$$\Delta\varepsilon = \pm \frac{S}{2} = \pm \frac{\boxed{5.5}}{2} = \pm \boxed{2.75} \text{ [mm]}$$

INVERTER