FREQROL

MITSUBISHI
TRANSISTORIZED INVERTER

TECHNICAL NOTE

No. 23

CAPACITY SELECTION
FOR
CONTINUOUS OPERATION

MITSUBISHI

CONTENTS

CHAPTER 1 DEFINITION OF CONTINUOUS OPERATION AND POINTS ABOUT CAPACITY SELECTION

1.1 Definition of Continuous Operation

Operation patterns are largely classified by operation time into constant-speed long operation and repeated short operation (repetition of start, constant-speed operation and deceleration to a stop).
The former is referred to as "continuous operation" and the latter as "cyclic operation".
Continuous operation and cyclic operation are largely classified in terms of the following frequency of operations (operation time):

Operation	Frequency of Starts/Stops (Operation Time)	Applied Data
Continuous operation	Less than 10 times/hour	(This technical note)
Cyclic operation	10 or more times/hour	Technical Note No. 24

<Data required for selection> Technical Note No. 22 "Capacity Selection: Data Section".

1.2 Points about Capacity Selection

(1) The permissible temperature of the motor should not be exceeded during operation.
Since constant-speed operation time is longer than acceleration or deceleration time during continuous operation, a motor temperature rise is mainly determined by the temperature during constant-speed operation.
Hence, the point of capacity selection for continuous operation is to select a motor so that the permissible motor temperature is not exceeded during constant speed use.

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┌──── Temperature Characteristics of a Motor ─────────────────────────────────────┐
                                                                                    
 The temperature characteristics of a motor differs according to:                  
 1) Motor type ............................ Standard motor and constant-torque motor (inverter-dedicated motor);
 2) Inverter control system ......... V/F control and magnetic flux vector control (including general-purpose
                                         magnetic flux vector control etc.)          
 3) Output frequency .................. Frequencies of not more than 60Hz and frequencies over 60Hz
                                         (frequencies up to base frequency and greater than base frequency.)
     Note: For further information on the characteristics, refer to page 11.       
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(2) Can the motor be started.
The starting torque of a motor operated by an inverter is smaller than that of a motor operated by a commercial power supply. Therefore, select motor and inverter capacities so that the motor can be started.

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┌──── Factors Which Determine the Amount of Starting Torque ─────────────────────┐
                                                                                  
 The starting torque of a motor varies according to:                             
 1) Inverter capacity ................... As the capacity of the inverter used with the motor increases, the starting
                                            torque increases.                     
 2) Inverter control system ......... The starting torque is larger under advanced magnetic flux vector control
                                            (including general-purpose magnetic flux vector control etc.) than under
                                            V/F control.                           
 3) Torque boost ......................... Under V/F control, the starting torque increases as the setting of the
                                            torque boost is increased.             
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(3) Acceleration and deceleration capabilities should be taken into consideration when selecting the inverter capacity.
While the conditions in (1) should be satisfied to select the motor capacity, consider the following points to determine the inverter:

    (a) Acceleration ...... Since the motor current is larger during acceleration than during constant speed, it is necessary to select an inverter that can supply this current. (Refer to Fig. 1.1.)

In addition to the load specifications (load torque, GD^2, speed), the current during acceleration is determined by acceleration time and operation pattern.
<u>When there are no restrictions on acceleration time during operation, it would be wise to maximize acceleration time.</u>

    (b) Deceleration ...... <u>As with acceleration, it would be wise to maximize deceleration time.</u>
The capability of handling (consuming) regenerative power is required for deceleration. However, since the brake torque needed for deceleration decreases as deceleration time increases, burdens on the inverter capacity and brake option reduce. (Refer to Fig. 1.1.)

1.3 Load Type

(1) Constant-torque load .... Conveyors, etc.
The load torque is always constant independent of speed (output frequency). Hence, the motor capacity must be selected to satisfy the permissible continuous operation of the motor in a low-speed region (or an over 60Hz (50Hz) region).

(2) Square law torque-speed load .... Fans, pumps
The load torque reduces as speed lowers. Therefore, it is not necessary to examine temperatures during low-speed operation if the load torque is within the permissible continuous operation value of the motor at rated speed (rated frequency).
    <Note> The following positive-displacement pumps and fans are "constant-torque loads". The capacity selection is the same as for conveyors.
- Gear pump, vane pump, plunger pump, etc.
- Roots blower, etc.

(3) Constant-output load .... Wind-up drum for wind-up gear
As the take-up rate decreases, the load torque increases. Hence, with this load the load torque increases during low-speed operation.
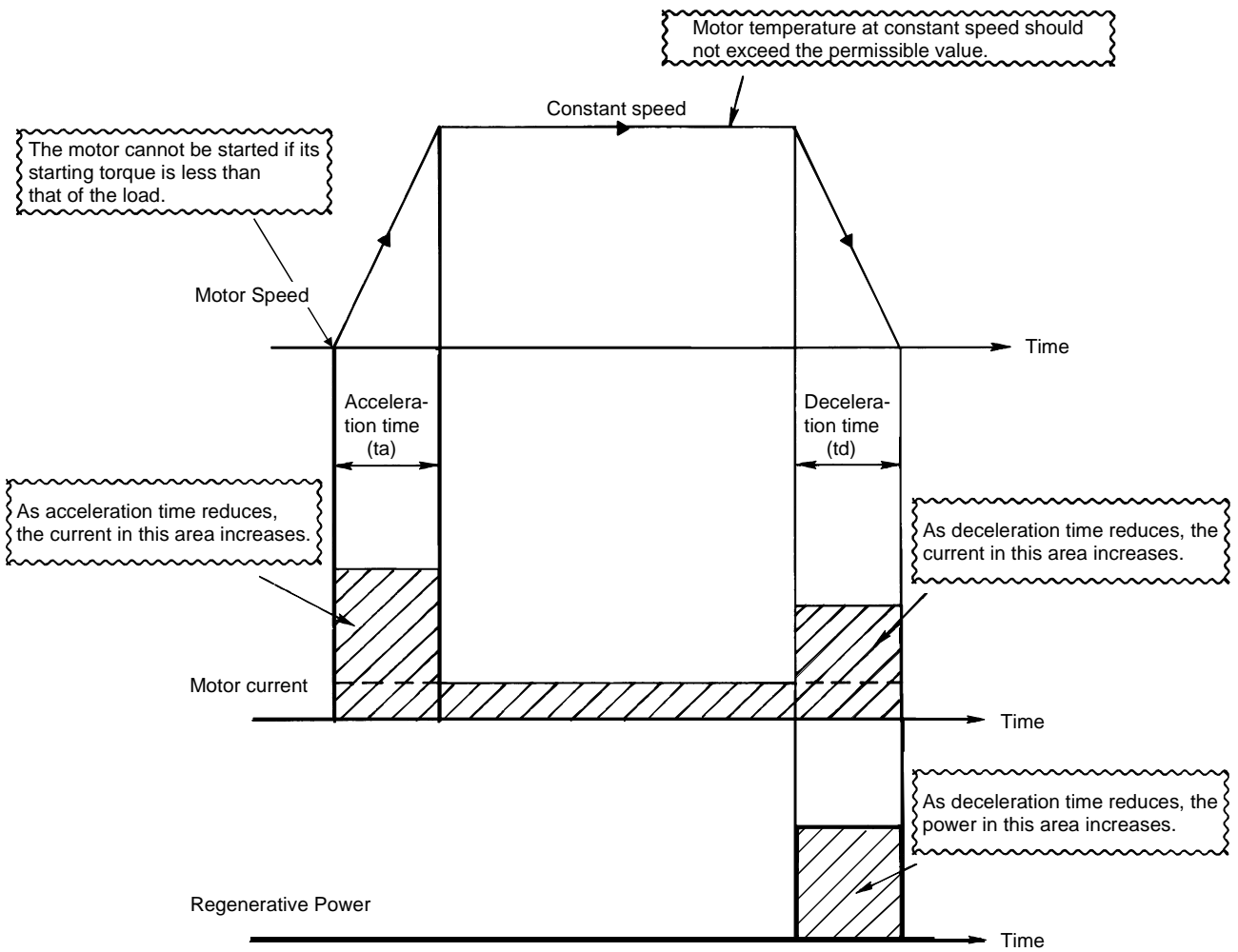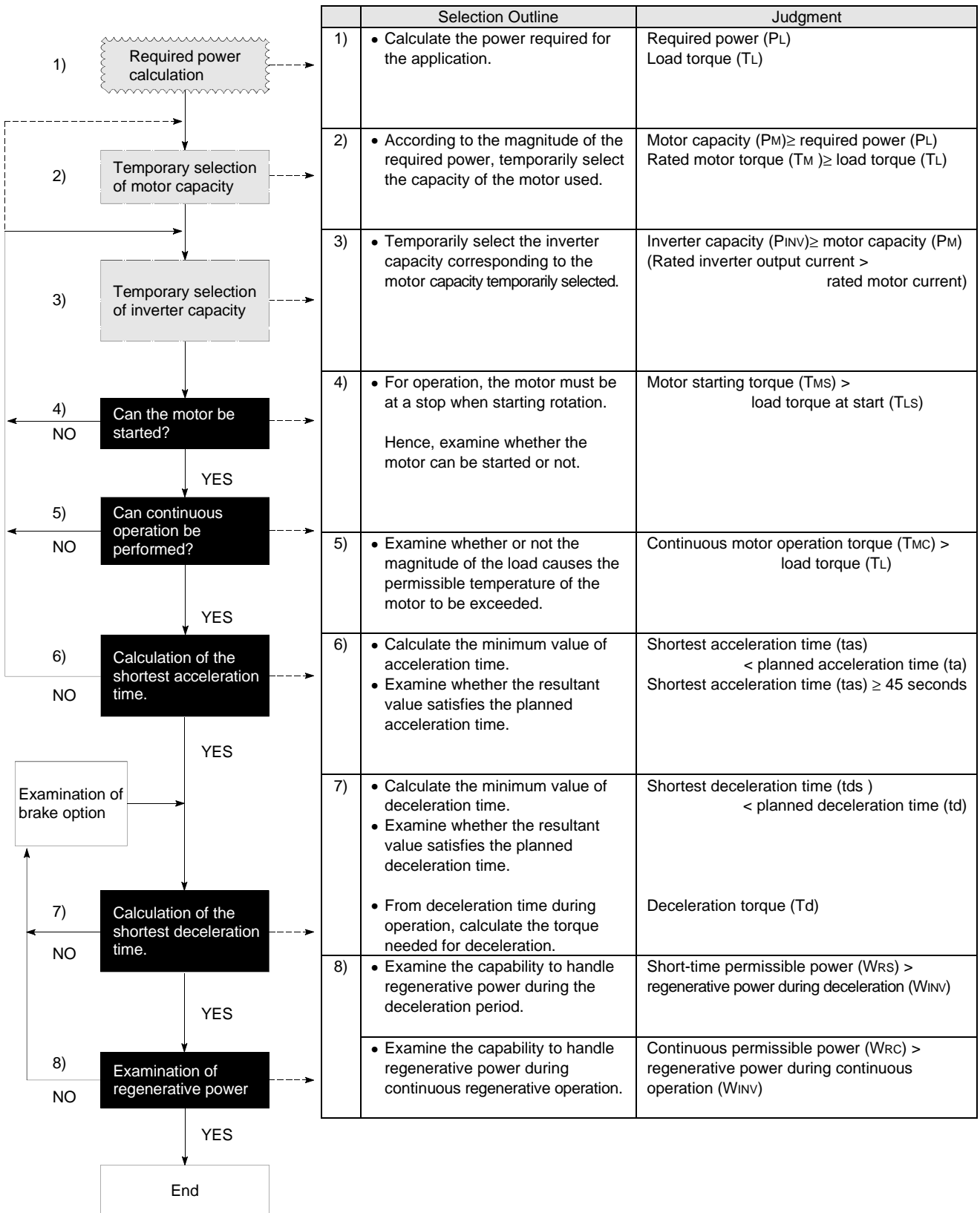Compared to the above loads, the motor and inverter capacity are larger.

Motor temperature at constant speed should not exceed the permissible value.

Constant speed

The motor cannot be started if its starting torque is less than that of the load.

Motor Speed

Time

Acceleration time (ta)

Deceleration time (td)

As acceleration time reduces, the current in this area increases.

As deceleration time reduces, the current in this area increases.

Motor current

Time

As deceleration time reduces, the power in this area increases.

Regenerative Power

Time

Fig. 1.1 Points of Selection in Operation Pattern

CHAPTER 2   SELECTION PROCEDURE

2.1 Selection Flowchart

		Selection Outline	Judgment
1)	1)	• Calculate the power required for the application.	Required power (P_L) Load torque (T_L)
2)	2)	• According to the magnitude of the required power, temporarily select the capacity of the motor used.	Motor capacity (P_M)≥ required power (P_L) Rated motor torque (T_M)≥ load torque (T_L)
3)	3)	• Temporarily select the inverter capacity corresponding to the motor capacity temporarily selected.	Inverter capacity (P_{INV})≥ motor capacity (P_M) (Rated inverter output current > rated motor current)
4) NO	4)	• For operation, the motor must be at a stop when starting rotation. Hence, examine whether the motor can be started or not.	Motor starting torque (T_{MS}) > load torque at start (T_{LS})
5) NO	5)	• Examine whether or not the magnitude of the load causes the permissible temperature of the motor to be exceeded.	Continuous motor operation torque (T_{MC}) > load torque (T_L)
6) NO	6)	• Calculate the minimum value of acceleration time. • Examine whether the resultant value satisfies the planned acceleration time.	Shortest acceleration time (t_{as}) < planned acceleration time (t_a) Shortest acceleration time (t_{as}) ≥ 45 seconds
7) NO	7)	• Calculate the minimum value of deceleration time. • Examine whether the resultant value satisfies the planned deceleration time. • From deceleration time during operation, calculate the torque needed for deceleration.	Shortest deceleration time (t_{ds}) < planned deceleration time (t_d) Deceleration torque (T_d)
8) NO	8)	• Examine the capability to handle regenerative power during the deceleration period. • Examine the capability to handle regenerative power during continuous regenerative operation.	Short-time permissible power (W_{RS}) > regenerative power during deceleration (W_{INV}) Continuous permissible power (W_{RC}) > regenerative power during continuous operation (W_{INV})

Flowchart (left column):

1) Required power calculation
2) Temporary selection of motor capacity
3) Temporary selection of inverter capacity
4) Can the motor be started? — NO / YES
5) Can continuous operation be performed? — NO / YES
6) Calculation of the shortest acceleration time. — NO / YES
Examination of brake option
7) Calculation of the shortest deceleration time. — NO / YES
8) Examination of regenerative power — NO / YES
End

	Calculation Formula, Etc.	Data Used/Item	Remarks (Note, Etc.)	Refer To Page
1)	• Load torque (T_L) $T_L = 9550 \times P_L / N$ [N•m] **974** **[kgf•m]**	• Technical Note No. 22 Refer to "Calculation of Required Power" in Appendices.	• Since the output torque of the motor reduces during operation at 60Hz (50Hz) or higher, take care to ensure that the torque will be sufficient.	7
2)	• Rated motor torque (T_M) $T_M = 9550 \times P_M / N_M$ [N•m] **974** **[kgf•m]**	• Motor Catalog, Technical Data • Technical Note No. 22 Refer to Chapter 4 "Motor and Brake Characteristics".	• The permissible speed (operating frequency range) varies according to the capacity, number of poles and model of the motor.	8
3)	_____	• Inverter Catalogue (Standard specifications)	• Motor-generated torque differs according to the type and control system of the inverter (magnetic flux vector control > V/F control). • Whether the brake circuit is included or not depends on the inverter type.	9
4)	• Motor starting torque = maximum starting torque Maximum starting torque (T_{MS})=$T_M \times \alpha s \times \sigma > T_{LS}$	• Technical Note No. 22 Refer to "Data Classified by Torque Type" in Chapter 2 Driving Capability Data. αs: Maximum starting torque coefficient σ : Heat coefficient	• Starting torque is larger under magnetic flux vector control than under V/F control. • Starting torque is improved only if the inverter is increased in capacity.	9
5)	• Continuous operation torque coefficient (αc) > load torque factor (TF)=T_L/T_M or Continuous operation torque (T_M) $\times \alpha c$ > load torque (T_L)	• Technical Note No. 22 Refer to "Continuous Torque" in Chapter 2 Driving Capability Data. αc: Continuous operation torque coefficient	• Under magnetic flux vector control, the continuous operation torque range increases for some motor capacities.	11
6)	• Shortest acceleration time tas $$tas = \frac{\left(GD^2_L + GD^2_M\right) \times N}{38.2 \times \left(T_M \times \alpha h - T_L\,max\right)}$$ [N•m] **375** **[kgf•m]**	• Technical Note No. 22 Refer to "Torque Type" in Chapter 2 Driving Capability Data. αh: Non-linear acceleration torque coefficient	• Acceleration torque is larger under magnetic flux vector control than under V/F control. • When the shortest acceleration time is longer than 45 seconds, use the linear acceleration torque coefficient and recalculate.	14
7)	• Shortest deceleration time (tds) $$tds = \frac{\left(GD^2_L + GD^2_M\right) \times N}{38.2 \times \left(T_M \times \beta + T_L\,min\right)}$$ [N•m] **375** **[kgf•m]** • Deceleration torque (Td)	• Technical Note No. 22 Refer to "Braking Capability Torque Type" in Chapter 3 Braking Capability Data. β : Deceleration torque coefficient	• The value of the shortest deceleration time differs according to whether the brake resistor is included or not. • When the shortest deceleration time is longer than planned, examine the use of the brake option.	15
8)	• Regenerative power from the load (W_{MECH}) • Motor-absorbed power (W_M) • Regenerative power to the inverter $W_{INV} = W_{MECH} - W_M$ [W]	• Technical Note No. 22 Refer to "Braking Capability Permissible Power" in Chapter 3 Braking Capability Data. W_{RS}: Short-time permissible power W_{RC}: Continuous permissible power	• The capability of regenerative power (permissible power) differs according to the type and capacity of the inverter. • For continuous regeneration, a power return converter may be needed.	17

Note: The units are in the SI Systems of Units. The half-tone screen indicates the gravitational systems of units.

2.2 Specification Symbols Related to the Load and Operation Required for Selection

Table 2.1 List of Specification Symbols and Units

Specifications		Symbol	SI Systems of Units	Gravitational Systems of Units
Machine side specifications	Required power	P_L	kW	kW
	Motor capacity	P_M	kW	kW
	Number of motor poles	P	—	—
	Motor speed	N	r/min	rpm
	Frequency	f	Hz	Hz
	Moving velocity	V	m/min	m/min
	Load weight	W	kgf	kgf
	Machine efficiency	η	—	—
	Friction coefficient	μ	—	—
	Load torque converted into equivalent value at motor shaft	T_L	N•m	kgf•m
	Starting load torque converted into equivalent value at motor shaft	T_{LS}	N•m	kgf•m
	Load GD^2 converted into equivalent value at motor shaft	GD^2_L	kgf•m^2	kgf•m^2
	GD^2 of mechanical brake converted into equivalent value at motor shaft	GD^2_B	kgf•m^2	kgf•m^2
	Acceleration time	ta	s	s
	Deceleration time	td	s	s
	Acceleration	Acc	m/s^2	m/s^2
Specifications used for examination	Rated motor speed	N_M	r/min	rpm
	Rated motor torque	T_M	N•m	kgf•m
	Maximum motor starting torque	T_{MS}	N•m	kgf•m
	Deceleration torque	Td	N•m	kgf•m
	Load torque ratio	TF	%	%
	Motor GD^2	GD^2_M	kgf•m^2	kgf•m^2
	Minimum acceleration time	tas	s	s
	Minimum deceleration time	tds	s	s
	Continuous operation torque coefficient	αc	—	—
	Maximum starting torque coefficient	αs	—	—
	Non-linear acceleration torque coefficient	αh	—	—
	Linear acceleration torque coefficient	αa	—	—
	Brake torque coefficient (generic term)	β	—	—
	Heat coefficient	δ	—	—
Regenerative power	Average power absorbed by motor	W_M	W	W
	Average power returned to inverter	W_{INV}	W	W
	Average power returned from motor	W_{MECH}	W	W
	Continuous permissible power of brake unit	W_{RC}	W	W
	Short-time permissible power per braking of brake unit	W_{RS}	W	W

CHAPTER 3   SELECTION PROCEDURE

3.1 Calculation of Load Power

Before examination, the specification (power, operation pattern, etc. Refer to Table 2.1.) of the load must be made clear. If, among others, the value of power is obscure, the results will be inaccurate. Therefore, make calculations in accordance with the following sections:

(1) Required power (P_L)
The magnitude of a load differs according to the machine (load type).
Loads are largely classified into "constant-torque loads" typically such as conveyors, "variable torque loads" such as fans and pumps, and "constant-output loads" such as wind-up gears.
For details of required power calculation, refer to Technical Note No. 22 (Appendices)
   (a) When calculated from the specification values of the machine
      Example: Conveyor

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

W : Load weight (Conveyed weight) [kgf]
V : Moving velocity [m/min]
μ : Friction coefficient
η : Machine efficiency

   (b) When calculated from the motor current (for the existing machine operated from a commercial power supply)
      By measuring the motor current, the required power can be calculated from this value. Specifically, it can be found from the test report of the motor used.

(2) Load torque converted into equivalent value at motor shaft (T_L)
The load torque is found from the above required power by the following formulae:
<SI systems of units>   <Gravitational systems of units>

$$T_L = \frac{9550 \times P_L}{N} \text{ [N•m]}$$ $$T_L = \frac{974 \times P_L}{N} \text{ [kgf•m]}$$

N: Motor speed [r/min]

Note: <u>Motor speed (N) is the value obtained at the required power (P_L).</u> (N is not the rated motor speed.)

(3) Starting load torque converted into equivalent value at motor shaft (T_{LS})
The load torque when starting is the starting torque of a machine. When the machine is started under load, the load torque at the start is larger than the load torque (T_L) under the influence of static friction. When the load torque when starting is unknown, either an experimental value or load torque (T_L) may be used instead.

3.2 Temporary Selection of Motor, Inverter Capacity

(1) Temporary Selection of Motor Capacity
According to the above required power, temporarily select the motor capacity used.
Basically, the motor capacity should be equal to or greater than the required power.

$$\boxed{\text{Motor capacity } (P_M) \geq \text{ required power } (P_L)[kW]}$$

Example: If required power (P_L) = 2.8[kW]
Temporarily select the motor capacity 3.7[kW] which is closest to the required power.

According to the motor capacity temporarily selected, check the following condition:
• Check that the load torque is within the rated motor torque. If this condition is not satisfied, increase the motor capacity and re-examine.

<SI systems of units>   <Gravitational systems of units>

$$\boxed{\text{Rated motor torque } (T_M) = \frac{9550 \times P_M}{N_M} \geq T_L\,[N{\bullet}m]}$$ $$\boxed{\text{Rated motor torque } (T_M) = \frac{974 \times P_M}{N_M} \geq T_L\,[kgf{\bullet}m]}$$

P_M: Rated motor output [kW]
N_M: Rated motor speed [r/min] (For calculation, use synchronous speed.)

• How to find the rated motor torque
Example: When the motor is 3.7kW 4P (rated speed of the motor is 1800r/min)

<SI systems of units>   <Gravitational systems of units>

$$\boxed{\text{Rated motor torque } (T_M) = \frac{9550 \times 3.7}{1800} = 19.6\,[N{\bullet}m]}$$ $$\boxed{T_M = \frac{974 \times 3.7}{1800} = 2.0\,[kgf{\bullet}m]}$$

Note regarding Motor Capacity Selection

Example: If the required power is the same (2.8[kW]), the magnitude of the load torque differs between when the motor speed at the required power is 1750[r/min] and when it is 1350[r/min], leading to a difference in the motor capacity selected.

When a 3.7kW motor has been selected because of the required power 2.8kW,
rated motor torque = 9550 × 3.7/1800 = 19.6[N•m]

· When the motor speed is 1750[r/min],
  load torque = 9550 × 2.8/1750 = 13.5[N•m] ←—Within the rated motor torque
· When the motor speed is 1350[r/min],
  load torque = 9550 × 2.8/1350 = 19.8[N•m] ←— In excess of the rated motor torque

   When the motor speed is 1350[r/min],
   a motor capacity of 5.5kW must be selected.

(2) Temporary Selection of Inverter Capacity

According to the temporary motor capacity selected, temporarily select an inverter capacity which will satisfy the following condition:

$$\text{Inverter capacity } (P_{INV}) \geq \text{rated motor output } (P_M) \text{ [kW]}$$

┌──────── Note regarding Inverter Capacity Selection ────────┐

Inverters differ according to series in motor-generated torque, permissible continuous operation speed range and brake capability. Consider these points when selecting the inverter model.

- Motor-generated torque (short-time maximum torque and starting torque)
  Torque generated by the motor is larger under advanced magnetic flux vector control than under conventional V/F control.
- Continuous operation range (operation frequency range in which operation can be performed at 100% torque)
  When advanced magnetic flux vector control is used, the continuous operation range of a 1.5kW motor (or less) increases.
- Brake capability (incorporation of a brake resistor)
  An inverter containing a brake resistor has excellent braking torque during deceleration and the consuming capability of regenerative power.

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3.3 Examination of Whether the Motor Can be Started or Not

To start the load or machine, the motor is required to provide a starting torque which will overcome the starting torque of the load. Whether the motor can be started or not can be judged by calculating the magnitude of the motor starting torque.

(1) Starting torque of the motor

The starting torque of the motor operated by an inverter is not as large as that of a motor operated from a commercial power supply.

The value of the motor starting torque varies according to the following conditions:

┌──┐

- Inverter capacity
  As the capacity of the inverter used with the motor increases, the starting torque increases.
- Inverter control system
  Starting torque is larger under advanced magnetic flux vector control than under V/F control.
- Torque boost
  For V/F control, as the setting of the torque boost is increased, the starting torque increases.
  (Starting torque ..... torque boost maximum > torque boost standard)

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The maximum motor starting torque can be found by the following formula:

<SI systems of units>

$$\text{Starting torque } (T_{MS}) = T_M \times \alpha_S \times \delta \text{ [N•m]}$$ T_M: Rated motor torque [N•m]

<Gravitational systems of units>

$$\text{Starting torque } (T_{MS}) = T_M \times \alpha_S \times \delta \text{ [kgf•m]}$$ T_M: Rated motor torque [kgf•m]

α_S: Maximum starting torque coefficient, δ: Heat coefficient ..... Select from the values in Technical Note No. 22.

(2) Analysis of whether the motor can be started or not
The following condition should be satisfied to start the motor:

> The maximum motor starting torque (T_{MS})> load torque at start (T_{LS})

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

Motor starting torque (T_{MS}) = $T_M \times \alpha s \times \delta$
  = $19.6 \times 0.8 \times 0.85 = 13.3 > T_{LS} = 11 \Rightarrow$ Motor starts
  αs: Maximum starting torque coefficient 0.8 Chapter 2 Driving Capability Data, Technical Note No. 22
  δ : Heat coefficient 0.85 Chapter 1 How to Use the Data Collection, Technical Note No. 22

Note: The output frequency at the motor starting torque coefficient αs(frequency at start) is fixed.
Hence, if the minimum value of the planned operation frequency is less than the start frequency, the operation range is restricted.
Operation may not be performed at less than the starting frequency.

(3) Measures to be taken when the motor cannot be started
  1) Change from V/F control to advanced magnetic flux vector control.
  2) Increase only the inverter capacity.
  3) Increase the inverter and motor capacities.

3.4 Examination of Whether Continuous Operation Can Be Performed or Not

When load torque (T_L) is within the short-time maximum torque range of the motor-generated torque, the motor can rotate. For continuous operation, however, the permissible temperature value of the motor must not be exceeded.
Since the permissible temperature value of the motor varies according to the running frequency, judge whether continuous operation can be performed or not by the "continuous operation torque characteristic".

(1) Motor temperature characteristic during continuous operation
As the output frequency decreases, the cooling capability of the motor reduces and therefore the permissible temperature value of the motor generally reduces.
Note that when advanced magnetic flux vector control (or general-purpose magnetic flux vector control) is exercised for Mitsubishi motors of 1.5kW or less or when an inverter-dedicated motor is used, the permissible temperature value does not reduce even in a low-speed region, indicating that they are more excellent in temperature characteristic than V/F control.

* When advanced magnetic flux vector control is used (1.5kW or less) or when inverter-dedicated motor (SF-JRCA) is used
* When V/F control is used

Note: On 60Hz basis

Continuous operation torque coefficient (αc)

* 6Hz when general-purpose magnetic flux vector control is used or SF-JRC is used.
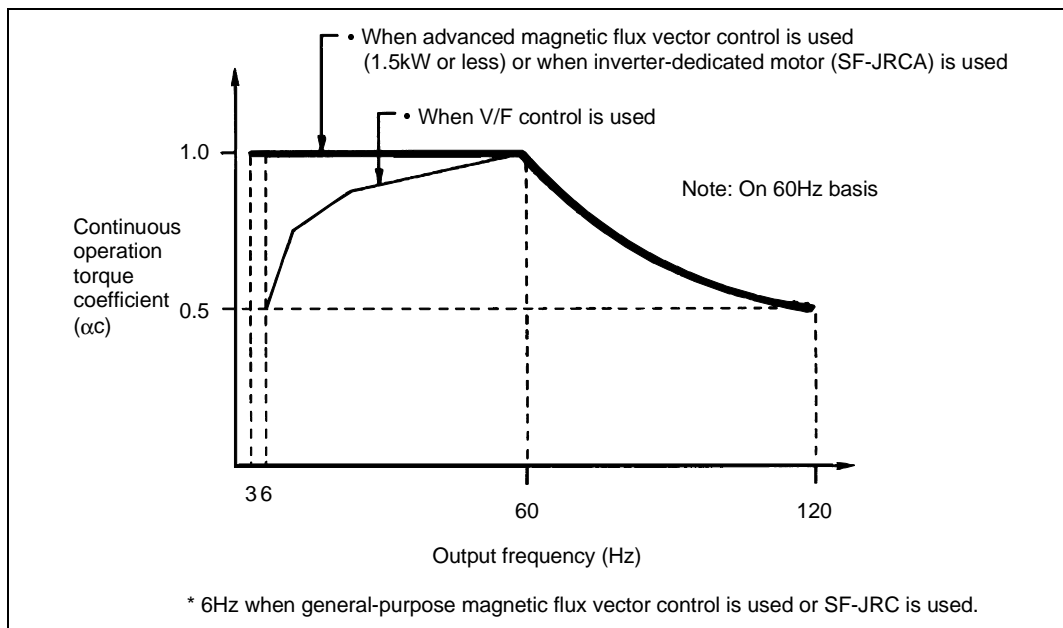
Fig. 3.1 Continuous Operation Torque Characteristic of Motor

Note: 1. Under V/F control, the continuous operation range changes according to the setting of the torque boost.
When the maximum setting of the torque boost is used, continuous operation cannot be performed at less than 15Hz.
2. If the inverter capacity only is increased, the temperature characteristic of the motor will not be improved.

"Torque Basis Value" and Motor Characteristic

When a machine is to be manufactured, it is designed on the basis of motor-generated torque (rated torque).
The rated motor torque is found from the rated speed at 50Hz or 60Hz.
The rated torque at 50Hz is 1.2 times greater than that at 60Hz and similarly the current at 50Hz is also greater.
For this reason, the permissible continuous operation value (torque coefficient) of the motor differs between 50Hz and 60Hz and two types of data, "50Hz torque basis" and "60Hz torque basis", are available.
* Select the data to be used according to the torque basis value used at the time of machine designing. (Independent of the power supply frequency)
Also treat the maximum starting torque coefficient and acceleration/deceleration torque coefficient similarly.
* Care should be taken when an existing machine (designed on the basis of the commercial power supply frequency) is operated by an inverter.

(2) Analysis of whether continuous operation can be performed or not
The load torque should be within the continuous operation torque range of the motor for operation to perform continuously.

> Continuous motor operation torque (T_M) x α_c > load torque (T_L)

or

> Motor continuous operation torque coefficient (α_c) > load torque factor (TF)*

*Load torque factor (TF)=T_L/T_M

If the load torque factor exceeds the continuous operation torque coefficient of the motor (region indicated by the hatched area) in the operation range (operation frequency range) planned as shown below, continuous operation cannot be performed in that region.
For the continuous operation torque characteristic, refer to "Continuous operation torque coefficient" in Technical Note No. 22.
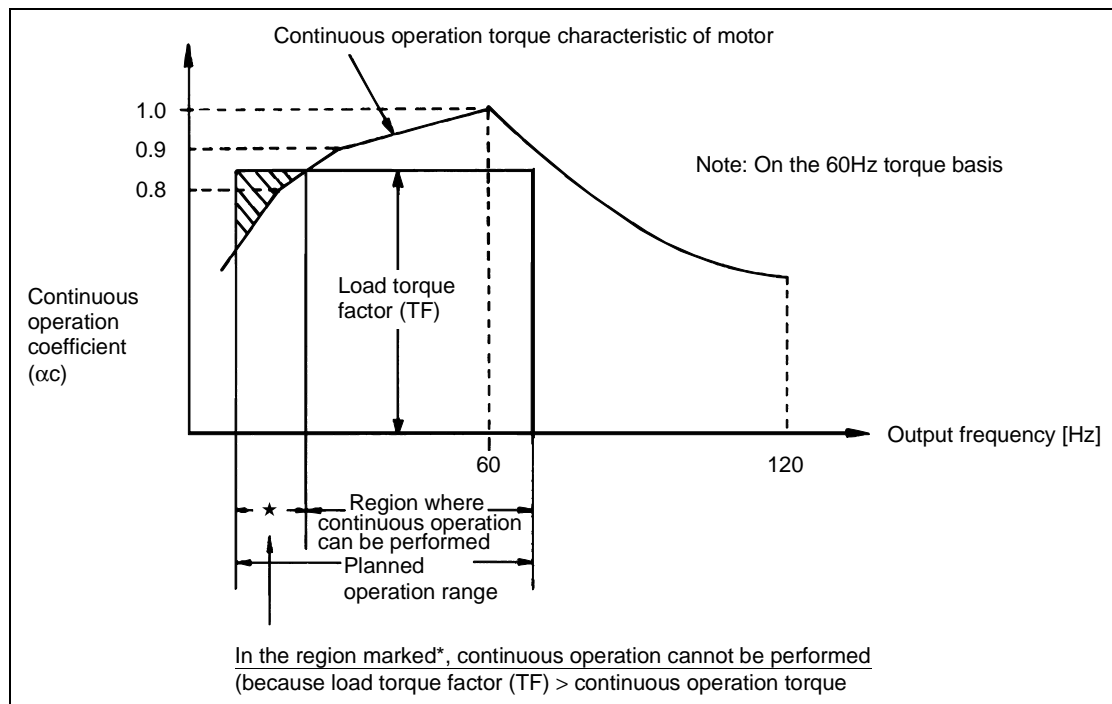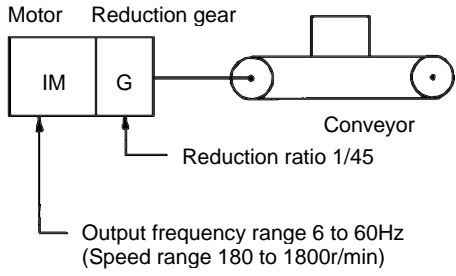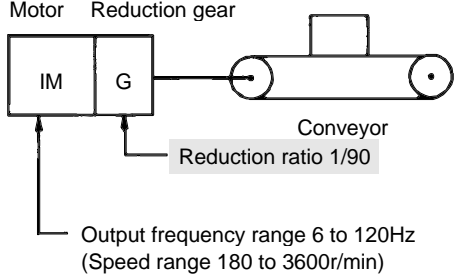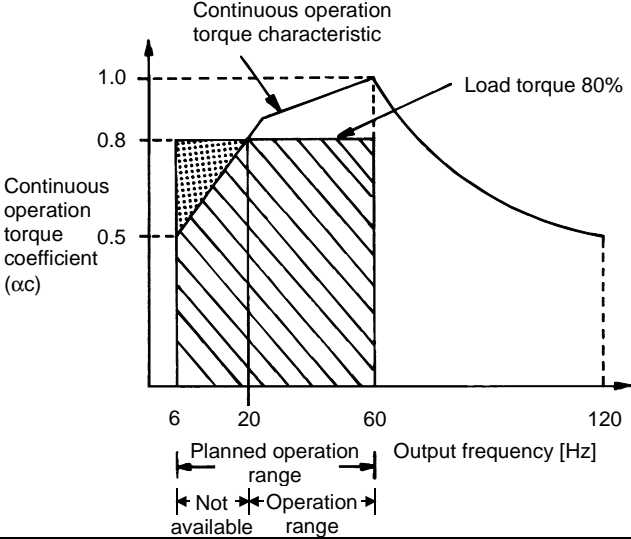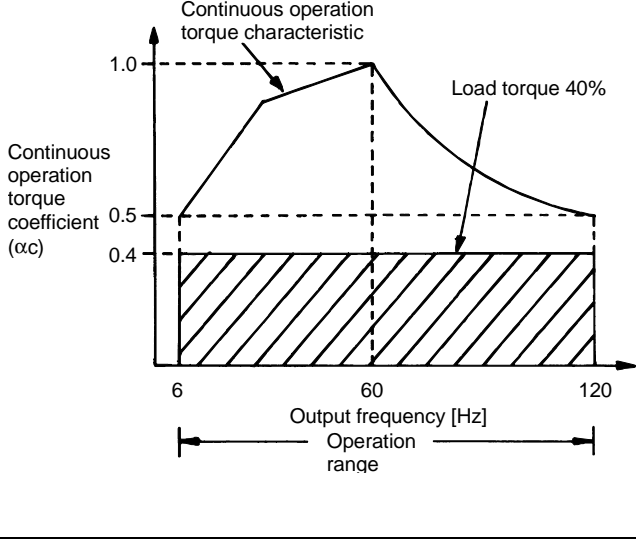
Fig. 3.2 Analysis of Permissible Continuous Operation Range

(3) Measures to be taken when continuous operation cannot be performed
    1) Increase the motor capacity and inverter capacity.
       Increase the motor capacity to improve the temperature characteristic of the motor.
    2) Use advanced magnetic flux vector control (or general-purpose magnetic flux vector control).
       The temperature characteristic in the low-speed region is improved.
       Note that the conditions that our motor is used and the applied capacity is 1.5kW or less must be satisfied.
    3) Use an inverter-dedicated motor.
       An inverter dedicated motor has a better temperature characteristic for low-speed operation than a standard motor.
    4) Increase the reduction ratio of the machine.
       When continuous operation cannot be performed in some region as described above, examine the following:
Note: This method is valid when the motor capacity cannot be increased.
       In order to bring the load torque within the continuous operation torque range, change the reduction mechanism (reduction ratio) of the machines design to reduce the value of the load torque which is converted into the equivalent value at the motor shaft.

–12–

<Example of measures taken to change the reduction ratio of the machine>

Load/operation specifications

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

Design A	Design B

Motor   Reduction gear   Conveyor
IM   G
Reduction ratio 1/45
Output frequency range 6 to 60Hz
(Speed range 180 to 1800r/min)

$\Rightarrow$

Motor   Reduction gear   Conveyor
IM   G
Reduction ratio 1/90
Output frequency range 6 to 120Hz
(Speed range 180 to 3600r/min)

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

  80% of the rated motor torque

  Maximum speed   1800[r/min]

- Load torque (T_L) (converted into the equivalent value at the motor shaft)
  As the reduction ratio is made twice larger than that of design A;

  load torque = 80% ÷ 2 = 40%

- Maximum speed   3600[r/min]

In design B, the reduction ratio of the reduction gear has been doubled to halve the load torque of the motor shaft and allow operation to be performed in the region where continuous operation cannot be performed in design A (6 to 20Hz).

Note: As operation may not be performed at 120Hz according to the motor capacity, number of poles or reduction gear type, it is necessary to check the operating frequency range.

3.5 Calculation of the Shortest Acceleration Time

Calculate the shortest acceleration time required to reach a predetermined operation frequency.
The shortest acceleration time is a period of time when the maximum acceleration capability is exercised without the protective circuit of the inverter being activated.

(1) Restrictions on acceleration time
1) When there are no restrictions on acceleration time during operation
For actual operation, set the acceleration time longer than the shortest acceleration time.
<u>As the acceleration time increases, stresses on the motor and inverter decrease.</u>

2) When there are restrictions on acceleration time
When the value found by calculation is not acceptable for the application, acceleration time must be made shorter. At this time, take the following measures:

- Change from V/F control to advanced magnetic flux vector control.
  Motor-generated torque (short-time torque) increases and acceleration torque improves.
- Increase the inverter capacity only.
  As in the above method, acceleration torque improves.
- Increase the inverter and motor capacities.
  This method most improves acceleration torque.

(2) Calculation of the shortest acceleration time
<SI systems of units>

$$\text{Shortest acceleration time } (t_{as}) = \frac{(GD^2_L + GD^2_M) \times N}{38.2 \, (T_M \times \alpha h - T_L max)} \ [s]$$

GD^2_L : Load GD^2 (converted into the equivalent value at the motor shaft) [kgf•m^2]
GD^2_M : Motor GD^2 (including the brake portion) [kgf•m^2]
T_M : Rated torque of the motor [N•m]
αh : Non-linear acceleration torque coefficient
$T_L max$: Maximum load torque [N•m]
N : Motor speed [r/min]

<Gravitational systems of units>

$$\text{Shortest acceleration time } (t_{as}) = \frac{(GD^2_L + GD^2_M) \times N}{375 \, (T_M \times \alpha h - T_L max)} \ [s]$$

T_M : Rated torque of the motor [kgf•m]
$T_L max$: Maximum load torque [kgf•m]

Note: For non-linear acceleration torque coefficient (αh), refer to 'Short-time maximum torque/torque type data' in Technical Note No. 22.

(3) Comments on the shortest acceleration time

The non-linear acceleration torque coefficient (αh) is an acceleration coefficient converted from the motor torque generated when the current for executing the stall prevention function of the inverter (150% of the rated inverter current) flows.

When this current flows for a long time, the temperature rise of the motor exceeds the permissible value.

1) When the shortest acceleration time is less than 45 seconds
The non-linear acceleration torque coefficient can be used since the temperature rise of the motor is within the permissible value.

2) When the shortest acceleration time is longer than 45 seconds
The non-linear acceleration torque coefficient cannot be used since the temperature rise of the motor may exceed the permissible value. In this case, recalculate using the linear acceleration torque coefficient (αa) instead of the non-linear acceleration torque coefficient (αh). In this case, the linear acceleration torque coefficient can be used if the shortest acceleration time (t_{as}) is less than 150 seconds. If it exceeds 150 seconds, refer to Technical Note No. 24 "Capacity Selection for Cyclic Operation" and perform a thermal examination of the motor during acceleration.
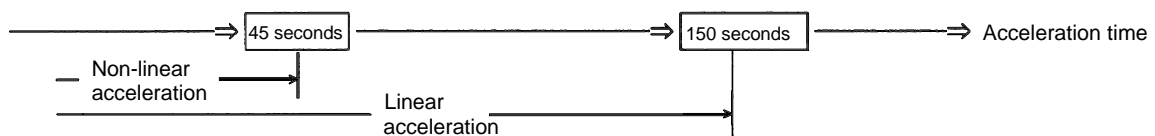
3.6 Calculation of the Shortest Deceleration Time

Calculate the shortest deceleration time required from a predetermined operation frequency to a stop. The shortest deceleration time is a period of time when the maximum deceleration capability is exercised without the protective circuit of the inverter being activated.

(1) Restrictions on deceleration time

1) When there are no restrictions on deceleration time during operation
For actual operation, set the deceleration time longer than the shortest deceleration time.
As the deceleration time increases, stresses on the motor and inverter decrease.

2) When there are restrictions on deceleration time
When the value found by calculation poses a problem during operation, deceleration time must be made shorter. At this time, take the following measures:

• Increase only the inverter capacity.
For an inverter containing a brake resistor, increasing only the inverter capacity improves deceleration torque. For an inverter not containing a brake resistor, increasing the capacity does not increase the deceleration capability.

• Increase the inverter and motor capacities.

• Use the optional braking unit (brake resistor, brake unit) or power return converter.

Table 3.1 Usability of the Braking Options with Inverters
(with the exception of the FR-U series)

Braking Option / Inverter	Inverter Containing Brake Circuit		Inverter without Brake Circuit
	With built-in brake resistor	Without brake resistor	
Brake resistor	May be used.	May be used.	Must not be used.
Brake unit	May be used.	May be used.	May be used.
Power return converter	Must not be used with small capacity models	Must not be used.	May be used.

–15–

(2) Calculation of the shortest deceleration time
The shortest deceleration time can be found by the following formulae:

<SI systems of units>

$$\text{Shortest deceleration time (tds)} = \frac{(GD^2{}_L + GD^2{}_M) \times N}{38.2\,(T_M \times \beta + T_L\text{min})} \ [s]$$

       $GD^2{}_L$: Load GD^2 (converted into the equivalent value at the motor shaft) [kgf•m^2]
       $GD^2{}_M$: Motor GD^2 (including the brake portion) [kgf•m^2]
       T_M : Rated torque of the motor [N•m]
       *β : Deceleration torque coefficient
       $T_L$min : Minimum load torque [N•m]
       N   : Motor speed [r/min]

<Gravitational systems of units>

$$\text{Shortest deceleration time tds} = \frac{(GD^2{}_L + GD^2{}_M) \times N}{375\,(T_M \times \beta + T_L\text{min})} \ [s]$$

       T_M :Rated torque of the motor [kgf•m]
       *β : Deceleration torque coefficient
       $T_L$min : Minimum load torque [kgf•m]

      *Note: For the deceleration torque coefficient (β), refer to Technical Note No. 22 (pages 3-1 to 3-22).

How to find the deceleration torque coefficient (β)

When calculating the shortest deceleration time, <u>use the minimum deceleration torque coefficient within the operation output frequency range</u> in the deceleration torque characteristic (shown on the right).

In the operation range shown on the right, the value of $\beta1$ is used in calculations as the deceleration torque coefficient β because $\beta1$ is smaller than $\beta2$.
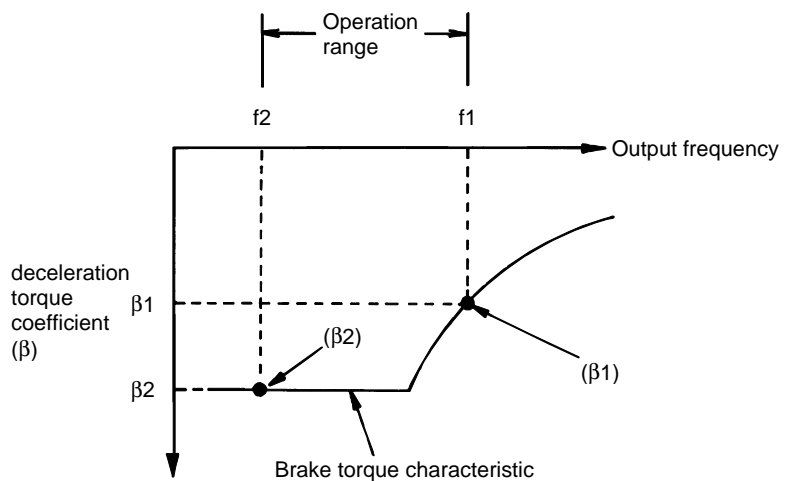
Note: 1. The deceleration torque (absolute value) can be found by "rated motor torque (T_M) $\times$ β".
     2. Differently to acceleration, the deceleration torque coefficient is handled as a linear deceleration torque coefficient. (There is no non-linear deceleration torque coefficient.)

(3) Calculation of deceleration torque

For operation, the deceleration time must be set to a value larger than the shortest deceleration time.
The relationship between deceleration time and deceleration torque is indicated by the following formulae. As deceleration time increases, torque required for deceleration reduces.

<SI systems of units>

$$\text{Deceleration torque (Td)} = \frac{(GD^2{}_L + GD^2{}_M) \times N}{38.2 \times td} \ [\text{N} \bullet \text{m}]$$

<Gravitational systems of units>

$$\text{Deceleration torque (Td)} = \frac{(GD^2{}_L + GD^2{}_M) \times N}{375 \times td} \ [\text{kgf} \bullet \text{m}]$$

td: Deceleration time [s]

3.7 Examination of Regenerative Power

If the ability to handle power returned to the inverter is insufficient during deceleration or under negative load, the protective circuit of the inverter will be activated. According to the magnitude of regenerative power, examine the regenerative power handling capacity of the inverter.

(1) Magnitude of regenerative power
  (a) Power returned from the machine
    • During deceleration
    <SI systems of units>

$$W_{MECH} = 0.1047 \times (Td - T_L min) \times N/2 \ [W]$$

    <Gravitational systems of units>

$$W_{MECH} = 1.027 \times (Td - T_L min) \times N/2 \ [W]$$

    • During constant speed (negative load)
    <SI systems of units>
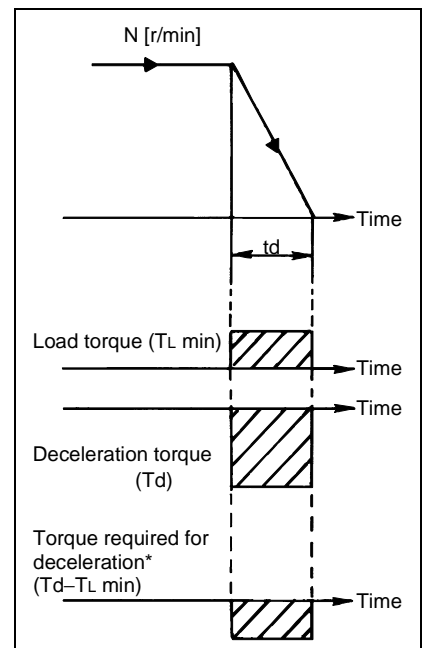
$$W_{MECH} = 0.1047 \times T_L \times N \ [W]$$

    T_L: Load torque [N•m]

    <Gravitational systems of units>

$$W_{MECH} = 1.027 \times T_L \times N \ [W]$$

    T_L: Load torque [kgf•m]

* Torque required for deceleration
  When the calculated value of (Td–$T_L$min) is negative, it is not necessary to examine regenerative power.

(b) Power absorbed by the motor

$$\boxed{W_M = k \times P_L \text{ [W]}}$$

k : Conversion coefficient (found from the graph in 3.6 Motor-Absorbed Power in Chapter 3 "Braking Capability Data" in Technical Note No. 22)

P_L : Required power [kW]

(c) Power returned to the inverter

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

(2) Analysis of regenerative power capability

1) <u>When the value of regenerative power (W_{INV}) is negative, a driving state occurs as in acceleration (regenerative state does not occur) and therefore regenerative analysis is not needed.</u>

2) Select a braking unit which makes the permissible power of the braking unit, e.g. brake resistor, larger than the power returned to the inverter (W_{INV}).

• During deceleration

$$\boxed{W_{INV} < W_{RS}}$$

W_{RS} : Short-time permissible power of the braking unit [W]

• During continuous regeneration (operation in which a negative load continues, e.g. wind-up operation of a wind-up gear)

$$\boxed{W_{INV} < W_{RC}}$$

W_{RC} : Continuous permissible power of the braking unit [W]

Note: For the permissible power of the braking unit, refer to Chapter 3 "Braking Capability Data" in Technical Note No. 22.

How to find short-time permissible power (W_{RS}) and continuous permissible power (W_{RC})

• Short-time permissible power (W_{RS})

Calculation procedure
1. Select the braking unit in accordance with "Combinations of Connectable Braking Units and Inverters" in Technical Note No. 22 (Chapter 3 Braking Capability Data).
2. Find the short-time permissible power of the selected braking unit in accordance with "Permissible Power Data" in Technical Note No. 22 (Chapter 3 Braking Capability Data).
Specifically, calculate the short-time permissible power from the intersecting point of deceleration time (td) (operating time (td)) and characteristic line.

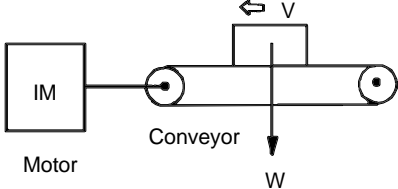• Continuous permissible power (W_{RC})

Calculation procedure
1. Select the braking unit in accordance with "Combinations of Connectable Braking Units and Inverters" in Technical Note No. 22 (Chapter 3 Braking Capability Data).
2. Find the continuous permissible power of the selected braking unit in accordance with "Permissible Power List" in Technical Note No. 22 (Chapter 3 Braking Capability Data).

CHAPTER 4   SPECIFIC SELECTION EXAMPLES

4.1 Conveyor Operation (Operation at 60Hz or less)

Perform variable-speed operation at the conveyor speed ratio of 1:3.
1) Power supply   220V 60Hz
2) Load conditions
   - Conveyed object load   W=1800 [kgf]
   - Friction coefficient μ=0.1
   - Conveying velocity   V=25 [m/min]
     (Motor speed N=1800 [r/min])
   - Machine efficiency η=0.85
   - Load GD^2 GD^2_L =0.15 [kgf•m^2]
3) Variable speed range   600 to 1800 [r/min]
4) Acceleration/ deceleration time   ta = within 8 seconds

Note: Calculation is made in the SI systems of units and the gravitational systems of units are also given in half-tone screen.

(1) Required power (P_L), load torque (T_L)
     1) Required power (P_L)
$$= \frac{\mu \times W \times V}{6120 \times \eta} = \frac{0.1 \times 1800 \times 25}{6120 \times 0.85} = 0.87 \ [kW]$$
     2) Load torque (T_L)
$$= \frac{\boxed{974}\ 9550 \times P_L}{N} = \frac{\boxed{974}\ 9550 \times 0.87}{1800} = \boxed{0.47\ [kgf•m]}\ 4.62 \ [N•m]$$

(2) Temporary selection of motor capacity and inverter capacity
     1) Motor capacity
        As the required power is 0.87kW, temporarily select 1.5kW.

       SF-JR 1.5kW 4P
       Rated motor torque (T_M)
$$= \frac{\boxed{974}\ 9550 \times P_M}{N_M} = \frac{\boxed{974}\ 9550 \times 1.5}{1800} = \boxed{0.81\ [kgf•m]}\ 7.96 \ [N•m]$$

     2) Inverter capacity
        Temporarily select the inverter capacity identical to the motor capacity.

       FR-E520-1.5K   **• Use V/F control.**

(3) Whether the motor can be started or not
     1) Starting torque
$$T_{MS} = T_M \times \alpha s \times \sigma = \boxed{0.81}\ 7.96 \times 0.8 \times 0.85 = \boxed{0.55\ [kgf•m]}\ 5.41 \ [N•m]$$

        Starting torque coefficient αs : 0.8
                               Technical Note No. 22 (Chapter 2 Driving Capability Data)
        Heat coefficient σ : 0.85
                               Technical Note No. 22 (Chapter 1 How to Use the Data Collection)

     2) Judgment of whether the motor can be started or not

       Motor starting torque (T_{MS}) = 5.41> load starting torque (T_L) = 4.62 $\Rightarrow$ Able to start

(4) Whether continuous operation can be performed or not

Examine whether the load torque (T_L) falls within the continuous operation torque of the motor in the continuous operation range (600 to 1800r/min).

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

$$T_{MC} = T_M \times \alpha c = \underset{0.81}{7.96} \times 1.0 = \underset{0.81 \,[kgf\bullet m]}{7.96} \;[N\bullet m]$$

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

$$T_{MC} = T_M \times \alpha c = \underset{0.81}{7.96} \times 0.8 = \underset{0.65 \,[kgf\bullet m]}{6.36} \;[N\bullet m]$$

> Continuous operation torque coefficient (αc) : 1.0 (60Hz)
> : 0.8 (20Hz)
> Technical Note No. 22 (Chapter 2 Driving Capability Data)

3) Judgment of whether continuous operation can be performed or not

> Continuous operation torque of motor (T_{MC}) = 6.36 > load torque (T_L) =4.62

$\Rightarrow$ Continuous operation can be performed.
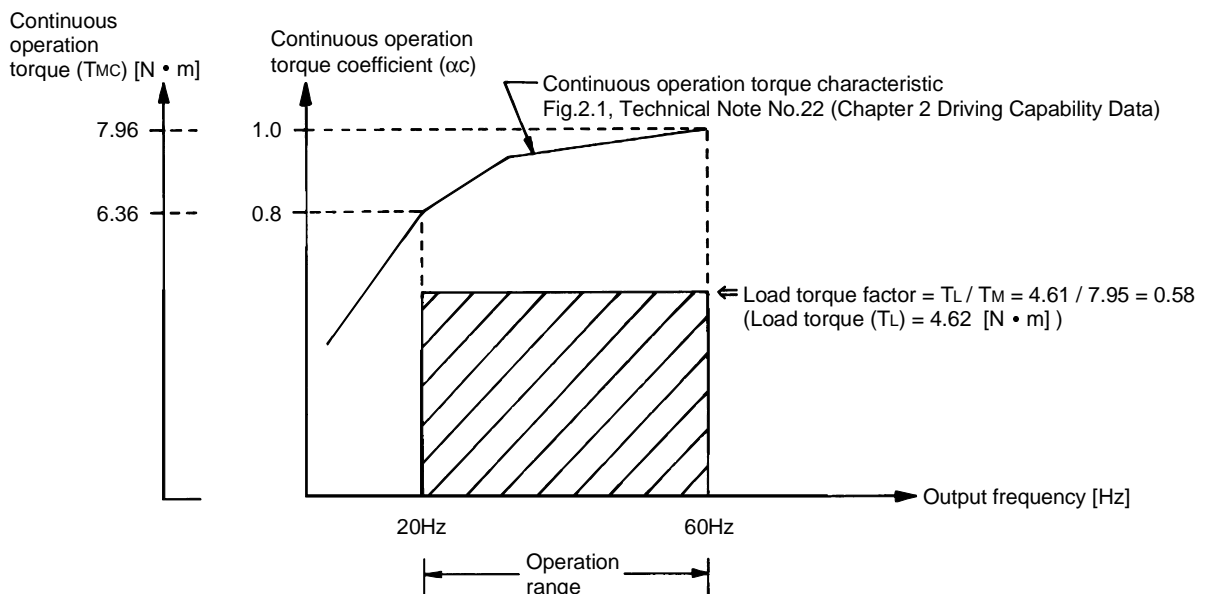
Continuous operation torque (T_{MC}) [N • m]

Continuous operation torque coefficient (αc)

Continuous operation torque characteristic
Fig.2.1, Technical Note No.22 (Chapter 2 Driving Capability Data)

7.96 — 1.0

6.36 — 0.8

$\Leftarrow$ Load torque factor = T_L / T_M = 4.61 / 7.95 = 0.58
(Load torque (T_L) = 4.62 [N • m])

Output frequency [Hz]

20Hz   60Hz

Operation range

(5) Shortest acceleration time

1) Shortest acceleration time (t_{as})

$$= \frac{(GD^2_L + GD^2_M) \times N}{38.2 \times (T_M \times \alpha h - T_L max)} = \frac{(0.15 + 0.027) \times 1800}{38.2(7.96 \times 1.25 - 4.62)} = 1.6[s]$$

(375)   (375, 0.81, 0.47)

> Motor GD^2_M: 0.027[kgf•m^2]
> From Technical Note No. 22 (Chapter 4 Motor and Brake Characteristics)
> Non-linear acceleration torque coefficient (αh): 1.25
> From Technical Note No. 22 (Chapter 2 Driving Capability Data)
> [Torque boost standard]

Analysis | As the shortest acceleration time is within the planned acceleration time of 8 seconds ($t_{as} < t_a$), the operation condition is satisfied.

(6) Shortest deceleration time
  1) Shortest deceleration time (t_ds)

$$= \frac{(GD^2_L + GD^2_M) \times N}{375 \times 38.2 \times (T_M \times \beta + T_L min)} = \frac{(0.15 + 0.027) \times 1800}{375 \times 38.2(7.96 \times 0.2 + 0)\ 0.81} = 5.2 \text{ [s]}$$

> Deceleration torque coefficient (β): 0.2
> From Technical Note No. 22 (Chapter 3 Braking Capability Data)
> [60Hz torque basis]

Analysis   As the shortest deceleration time is within the planned deceleration time of 8 seconds ($t_ds < td$), the operation condition is satisfied.

  2) Deceleration torque (td) (supposing that the deceleration time is 8 seconds)

$$= \frac{(GD^2_L + GD^2_M) \times N}{375 \times 38.2 \times td} = \frac{(0.15 + 0.027) \times 1800}{375 \times 38.2 \times 8} = 1.04 \text{ [N•m]}\ 0.11 \text{ [kgf•m]}$$

(7) Regenerative power (supposing that the planned deceleration time is 8 seconds)
  1) Power returned from the machine
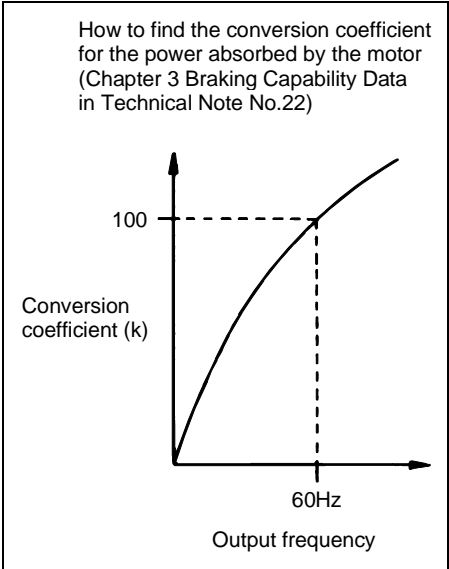$$W_{MECH} = 0.1047 \times (Td - T_L min) \times N / 2$$
$$= 0.1047 \times (1.04\ 1.027 - 0\ 0.11) \times 1800 / 2 = 98 \text{ [W]}$$

  2) Power absorbed by the motor
$$W_M = k \times P_L = 100 \times 0.87 = 87 \text{ [W]}$$

> Conversion coefficient k: 100
> From Technical Note No. 22
> (Chapter 3 Braking Capability Data)
> [Refer to the diagram on the right.]

How to find the conversion coefficient for the power absorbed by the motor (Chapter 3 Braking Capability Data in Technical Note No.22)

  3) Power returned to the inverter
$$W_{INV} = W_{MECH} - W_M = 98 - 87 = 11 \text{ [W]}$$

<Judgment of regenerative power handling capability>
  As power is returned to the inverter, use the brake resistor MRS120W60.

  $W_{INV} = 11 < W_{RS} = 660$ $\Rightarrow$ Deceleration regenerative power can be handled.

> Short-time permissible power (W_{RS}): 660 [W]
> From Technical Note No. 22 (Chapter 3 Braking Capability Data)

Selection result   • Motor SF-JR 1.5kW 4P   • Inverter FR-E520-1.5K
            • Brake resistor MRS120W60

4.2 Conveyor Operation (Operation at more than 60Hz)

Perform operation in the motor speed range of 360 to 3600r/min (variable speed ratio 1:10).

1) Power supply   220V 60Hz
2) Load conditions   • Required power (P_L) = 4.11 [kW] (at 3600r/min)
                     • Load torque (stationary) T_L = 10.9 [N•m]
                                  (converted into the equivalent value at the motor shaft)
                     • Load torque (at start) T_{LS} = 14.9 [N•m]
                                  (converted into the equivalent value at the motor shaft)
                     • Load GD^2 GD^2_L=0.17 [kgf•m^2]
                                  (converted into the equivalent value at the motor shaft)
                     • Output frequency range   12 to 120Hz
3) Acceleration/deceleration time
                 ta = within 5 seconds

Note: Calculation is made in the SI systems of units and the gravitational systems of units are also given in half-tone screen.

(1) Temporary selection of motor capacity and inverter capacity
     1) Motor capacity
        As the required power is 4.11kW, temporarily select 5.5kW.

     SF-JR 5.5kW 4P
         • Rated motor torque (T_M)

$$= \frac{974 \quad 9550 \times P_M}{N_M} = \frac{974 \quad 9550 \times 5.5}{1800} = \frac{2.98 \, [\text{kgf•m}]}{29.2 \, [\text{N•m}]}$$

Notes regarding Motor Capacity Selection for Operation at More Than 60Hz

1) The required power P_L should be found from the maximum speed.
2) The operable frequency ranges of the motor and electromagnetic brake should be satisfied.
    (Refer to Appendices in Technical Note No. 22.)

---

     2) Inverter capacity
        Temporarily select the inverter capacity identical to the motor capacity.

     FR-A220E-5.5K   **• Use advanced magnetic flux vector control.**

(2) Whether the motor can be started or not
     1) Starting torque

$$T_{MS} = T_M \times \alpha s \times \sigma = \overset{2.98}{29.2} \times 1.5 \times 0.85 = \overset{3.8 \,[\text{kgf•m}]}{37.2} \quad [\text{N•m}]$$

Starting torque coefficient (αs) : 1.5
                    Technical Note No. 22 (Chapter 2 Driving Capability Data)
Heat coefficient (σ)   : 0.85
                    Technical Note No. 22 (Chapter 1 How to Use the Data Collection)

     2) Judgment of whether the motor can be started or not

Motor starting torque (T_{MS}) = 37.2 > load torque at start (T_{LS}) = 14.9 $\Rightarrow$ Startable

(3) Whether continuous operation can be performed or not

Examine whether the load torque (T_L) falls within the continuous operation torque of the motor in the continuous operation range (360 to 3600r/min).

  1) Continuous operation torque of motor at 3600r/min (120Hz)

  $$T_{MC} = T_M \times \alpha c = \underset{2.98}{29.2} \times 0.45 = \underset{1.34 \text{ [kgf•m]}}{13.14} \text{ [N•m]}$$

  2) Continuous operation torque of motor at 360r/min (12Hz)

  $$T_{MC} = T_M \times \alpha c = \underset{2.98}{29.2} \times 0.62 = \underset{1.85 \text{ [kgf•m]}}{18.1} \text{ [N•m]}$$
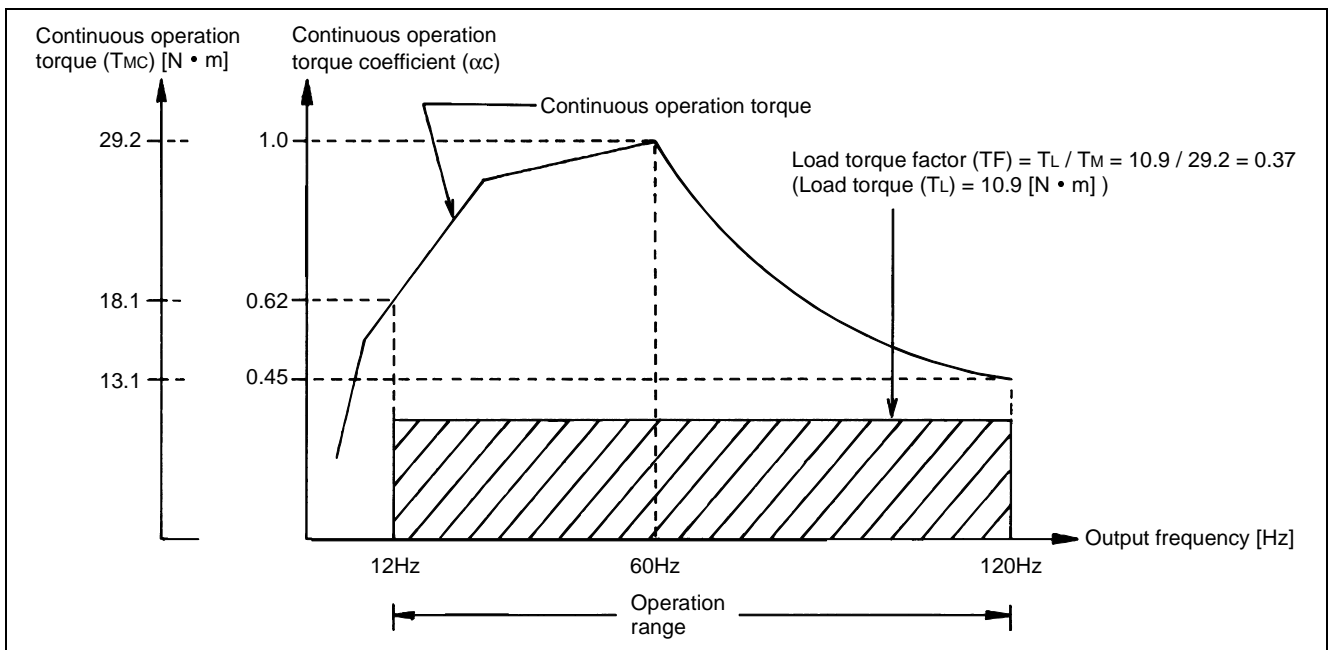
  > Continuous operation torque coefficient (αc) : 0.45 (120Hz)
  > : 0.62 (12Hz)
  > From Fig. 2.1 in Technical Note No. 22 (Chapter 2 Driving Capability Data)

  3) Judgment of whether continuous operation can be performed or not

  > ∗ Continuous operation torque of motor (T_{MC}) = 13.14 > T_L = 10.9

  ⇒ Continuous operation can be performed.

  * Note: Minimum value of the motor continuous operation torque (permissible value) in the planned operation range

(4) Shortest acceleration time
  1) Shortest acceleration time (t_{as})

$$= \cfrac{(GD^2_L + GD^2_M) \times N}{\cfrac{38.2 \times (T_M \times \alpha h - T_L max)}{375}} \qquad (T_L max = T_L)$$

$$= \cfrac{\underset{375}{(0.17 + 0.11)} \times 3600}{\underset{375 \quad 2.98 \qquad 1.11}{38.2 \,(29.2 \times 1.25 - 10.9)}} = 1.8 \,[s]$$

> Motor GD^2_M: 0.11[kgf•m^2]
>   Technical Note No. 22 (Chapter 4 Motor and Brake Characteristics)
> Non-linear acceleration torque coefficient (αh): 1.25
>   Technical Note No. 22 (Chapter 2 Driving Capability Data
>   [0 to 120Hz advanced magnetic flux vector control]

Analysis   Judgment of whether the shortest acceleration time is within the planned acceleration time of 5 seconds (t_{as} < ta), the operation condition is satisfied.

(5) Shortest deceleration time
  1) Shortest deceleration time (t_{ds})

$$= \cfrac{(GD^2_L + GD^2_M)\,N}{\cfrac{38.2\,(T_M \times \beta + T_L min)}{375}} = \cfrac{\underset{375 \quad 2.98}{(0.17 + 0.11) \times 3600}}{38.2\,(29.2 \times 0.5 + 0)} = 1.8 \,[s]$$

> Deceleration torque coefficient (β): 0.5   Technical Note No. 22 (Chapter 3 Braking Capability Data)
> (Built-in brake used ...
> Use the deceleration torque coefficient at 120Hz which is the smallest in the operation range.)

Analysis   As the shortest deceleration time is within the planned deceleration time of 5 seconds (t_{ds} < td), the operation condition is satisfied.

  2) Deceleration torque (Td) *

$$= \cfrac{(GD^2_L + GD^2_M) \times N}{\underset{375}{38.2 \times td}} = \cfrac{\underset{375}{(0.17 + 0.11) + 3600}}{38.2 \times 5} = \underset{0.54\,[kgf• m]}{5.3\,[N• m]}$$

*Note: Deceleration torque supposing that the planned deceleration time is 5 seconds

(6) Regenerative power (supposing that the planned deceleration time is 5 seconds)
  1) Power returned from the machine

$$W_{MECH} = 0.1047 \times (Td - T_L min) \times N / 2$$
$$= \underset{1.027 \quad\quad 0.54}{0.1047 \times (5.3 - 0) \times 3600 / 2} = 999 \,[W]$$

  2) Power absorbed by the motor
$$W_M = k \times P_L = 150 \times 4.11 = 617 \,[W]$$

> Conversion coefficient (k): 150   Technical Note No. 22 (Chapter 3 Braking Capability Data)

  3) Power returned to the inverter
$$W_{INV} = W_{MECH} - W_M = 999 - 617 = 382 \,[W]$$

< Analysis of regenerative power handling capability>
Find the short-time permissible power of the built-in brake resistor in the FR-A520-5.5K inverter and examine whether the power returned to the inverter (W_{INV}) satisfies the short-time permissible power (W_{RS}).

If it does not satisfy, examine the same on the assumption that the optional braking unit is used.

- Short-time permissible power (W_{RS}) = 1430[W]
  $\Leftarrow$ Permissible power at the operating time of 5 seconds

Calculation procedure 1. Select the built-in brake resistor in accordance with "Combinations of Connectable Braking Units and Inverters" in Technical Note No. 22 (Chapter 3 Braking Capability Data). 2. Select the brake specifications [220W 25] in accordance with "Torque Type" in Technical Note No. 22 (Chapter 3 Braking Capability Data). 3. Find the short-time permissible power 1430W at the operating time of 5 seconds in accordance with "Permissible power of the built-in brake resistor 220W25" in Technical Note No. 22 (Chapter 3 Braking Capability Data). (For the operating time of 10 seconds or less, refer to the short-time permissible power value given on the permissible power list.)

$\boxed{\text{Short-time permissible power } (W_{RS}) = 1430 \text{ [W]} > W_{INV} = 382 \text{ [W]}}$ $\Rightarrow$ Built-in brake can be used.

The inverter temporarily selected can be used.

Selection result
- Motor SF-JR 5.5kW 4P
- Inverter FR-A520-5.5K

APPENDICES

Calculation Sheets <For SI Systems of Units>

<Load/operation specifications>

- Power supply voltage, frequency ⬚ [V] ⬚ [Hz]
- Planned motor capacity, P_M = ⬚ [kW] ⬚ [P]
  number of poles used
- Speed range of the motor $N1$ = ⬚ to $N2$ = ⬚ [r/min]
- Output frequency range $f1$ = ⬚ to $f2$ = ⬚ [Hz]
  of the inverter
- Required power P_L = ⬚ [kW]
- Load torque (T_L) T_{Lmax} = ⬚ [N•m] T_{Lmin} = ⬚ [N•m]
  (converted into the equivalent (maximum) (minimum)
  value at the motor shaft)
- Load starting torque T_{LS} = ⬚ [N•m]
- Load GD^2_L GD^2_L = ⬚ [kgf•m^2]
  (converted into the equivalent
  value at the motor shaft)
- Planned acceleration/ deceleration time,

  ta = acceleration time ⬚ [s]
  td = deceleration time ⬚ [s]

<Calculation>

Temporary selection of motor capacity and inverter capacity

- Motor capacity Required power P_L ⇒ P_M = ⬚ [kW]
  - Rated motor speed N_M = ⬚ [r/min]

        Note: 1. Operable frequency ranges of standard motor and constant-torque motor:
                 Technical Note No. 22 (Appendices)
              2. Operable frequency range of geared motor:
                 Technical Note No. 22 (Appendices)

  - Rated motor torque

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

- Motor GD^2_M ⬚ [kgf•m^2]

        Note: 1. Motor GD^2_M includes that of the electromagnetic brake portion.
              2. Mitsubishi standard motor: Technical Note No. 22 (Chapter 4 Motor and Brake
                 Characteristics)
              3. NB electromagnetic brake: Technical Note No. 22 (Chapter 4 Motor and Brake
                 Characteristics)

- Inverter capacity Motor capacity P_M ⇒ Inverter type ⬚

Whether the motor can be started or not	Technical Note No. 22

• Maximum starting torque (T_{MS})
 	
$T_{MS} = T_M \times \alpha s \times \sigma =$ [ ] $\times$ [ ] $\times$ [ ]
 	
$\quad =$ [ ] [N•m]
 	
  • Judgment condition $\quad T_{MS} =$ [ ] $> T_{LS} =$ [ ]
 	
          Note: When the judgment condition is not satisfied;
              1) Increase the torque boost or set advanced magnetic flux vector control (or general-purpose magnetic flux vector control).
              2) Increase the inverter capacity.
              3) Increase the motor capacity and inverter capacity.
	αs: Maximum starting torque coefficient (Chapter 2 Driving Capability Data)
	σ: Heat coefficient (Chapter 1 How to Use the Data Collection)

Whether continuous operation can be performed or not	

• Continuous operation torque of motor (T_{MC})
 	
$T_{MC} = T_M \times \alpha c =$ [ ] $\times$ [ ] $=$ [ ] [N•m]
• Load torque factor (TF)
 	
$TF = T_L/T_M =$ [ ] $/$ [ ] $=$ [ ]
 	
  • Judgment condition $\quad T_{MC} =$ [ ] $> T_L =$ [ ]
 	
  (or $\alpha c =$ [ ] $> TF =$ [ ])
 	
          Note: When the judgment condition is not satisfied:
              1) Increase the motor capacity and inverter capacity.
              2) Use an inverter-dedicated motor (constant-torque motor).
              3) For 1.5kW or less, set advanced magnetic flux vector control (or general-purpose magnetic flux vector control).
                 In this case, the Mitsubishi standard motor must be used.
              4) Change the reduction ratio of the mechanism.
	αc: Continuous operation torque coefficient Chapter 2 Driving Capability Data Standard motor Chapter 2 Driving Capability Data Constant-torque motor

Shortest acceleration/deceleration time	

• Shortest acceleration time (tas)
 	
$tas = \dfrac{(GD^2_L + GD^2_M) \times N}{38.2 \times (T_M \times \alpha h - T_L max)}$
 	
$\quad = \dfrac{([\;] + [\;]) \times [\;]}{38.2 \times ([\;] \times [\;] - [\;])} =$ [ ] [N•m]
 	
  • Judgment condition
    Planned acceleration time (ta) = [ ] $>$ tas = [ ]
 	
• Shortest deceleration time tds
 	
$tds = \dfrac{(GD^2_L + GD^2_M) \times N}{38.2 \times (T_M \times \beta + T_L min)}$
 	
$\quad = \dfrac{([\;] + [\;]) \times [\;]}{38.2 \times ([\;] \times [\;] + [\;])} =$ [ ] [N•m]
 	
  • Judgment condition
    Planned deceleration time (td) = [ ] $>$ tds = [ ]
	αh: Non-linear acceleration torque coefficient Chapter 2 Driving Capability Data
	
	β: Deceleration torque coefficient Chapter 3 Braking Capability Data

<For SI Systems of Units>

Regenerative power handling capability	Technical Note No. 22

- Deceleration torque (Td)

$$Td = \frac{(GD^2{}_L + GD^2{}_M) \times N}{38.2 \times td}$$

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

- Power returned from the machine (W$_{MECH}$)

$W_{MECH} = 0.1047 \times (Td - T_Lmin) \times N/2$

$= 0.1047 \times (\boxed{} - \boxed{}) \times \boxed{} /2 = \boxed{} \ [\text{W}]$

- Power absorbed by the motor (W$_M$)

$W_M = k \times P_L = \boxed{} \times \boxed{} = \boxed{} \ [\text{W}]$

                                    k: Conversion coefficient
                                        Chapter 3 Braking
                                        Capability Data

- Power returned to the inverter (W$_{INV}$)

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

- Judgment condition
  Short-time permissible power of the braking (W$_{RS}$)

  $= \boxed{} > W_{INV} = \boxed{}$

  Braking unit   ☐ Built-in brake
                          ☐ External brake resistor
                          ☐ Brake unit
                          ☐ Power return converter

W$_{RS}$: Short-time permissible power[W]
        Chapter 3 Braking
        Capability Data

APPENDICES

Calculation Sheets <For Gravitational Systems of Units>

< Load/operation specifications>

- Power supply voltage, frequency [   ] [V]   [   ] [Hz]
- Planned motor capacity, $P_M =$ [   ] [kW]   [   ] [P]
  number of poles used
- Speed range of the motor $N1 =$ [   ] to N2= [   ] [rpm]
- Output frequency range $f1 =$ [   ] to f2= [   ] [Hz]
  of the inverter
- Required power $P_L =$ [   ] [kW]
- Load torque (T_L) $T_{Lmax} =$ [   ] [N•m] $T_{Lmin} =$ [   ] [kgf•m]
  (converted into the equivalent (maximum)   (minimum)
  value at the motor shaft)
- Load starting torque $T_{LS} =$ [   ] [kgf•m]
- Load GD^2_L $GD^2_L =$ [   ] [kgf•m^2]
  (converted into the equivalent
  value at the motor shaft)
- Planned acceleration/deceleration time,

    ta = acceleration time [   ] [s]
    td = deceleration time [   ] [s]

<Calculation>

Temporary selection of motor capacity and inverter capacity

- Motor capacity   Required power $P_L \Rightarrow P_M =$ [   ] [kW]
- Rated motor speed $N_M =$ [   ] [rpm]

> Note: 1. Operable frequency ranges of standard motor and constant-torque motor:
>   Technical Note No. 22 (Appendices)
>   2. Operable frequency range of geared motor:
>   Technical Note No. 22 (Appendices)

- Rated motor torque

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

- Motor GD^2_M [   ] [kgf•m^2]

> Note: 1. Motor GD^2_M includes that of the electromagnetic brake portion.
>   2. Mitsubishi standard motor: Technical Note No. 22 (Chapter 4 Motor and Brake Characteristics)
>   3. NB electromagnetic brake: Technical Note No. 22 (Chapter 4 Motor and Brake Characteristics)

- Inverter capacity   Motor capacity $P_M \Rightarrow$ Inverter type [   ]

< For Gravitational Systems of Units >

Whether the motor can be started or not	Technical Note No. 22

- Maximum starting torque (T$_{MS}$)

$T_{MS} = T_M \times \alpha s \times \sigma =$ ☐ $\times$ ☐ $\times$ ☐

= ☐ [kgf•m]

- Judgment condition $T_{MS} =$ ☐ $> T_{LS} =$ ☐

Note: When the judgment condition is not satisfied;
1) Increase the torque boost or set advanced magnetic flux vector control (or general-purpose magnetic flux vector control).
2) Increase the inverter capacity.
3) Increase the motor capacity and inverter capacity.

αs: Maximum starting torque coefficient (Chapter 2 Driving Capability Data)
σ: Heat coefficient (page 1-4)

Whether continuous operation can be performed or not	

- Continuous operation torque of motor (T$_{MC}$)

$T_{MC} = T_M \times \alpha c =$ ☐ $\times$ ☐ $=$ ☐ [kgf•m]

- Load torque factor (TF)

$TF = T_L/T_M =$ ☐ / ☐ = ☐

- Judgment condition $T_{MC} =$ ☐ $> T_L =$ ☐

(or αc = ☐ > TF = ☐)

Note: When the judgment condition is not satisfied:
1) Increase the motor capacity and inverter capacity.
2) Use an inverter-dedicated motor (constant-torque motor).
3) For 1.5kW or less, set advanced magnetic flux vector control (or general-purpose magnetic flux vector control). In this case, the Mitsubishi standard motor must be used.
4) Change the reduction ratio of the mechanism.

αc: Continuous operation torque coefficient Chapter 2 Driving Capability Data Standard motor Chapter 2 Driving Capability Data Constant-torque motor

Shortest acceleration/deceleration time	

- Shortest acceleration time (tas)

$$tas = \frac{(GD^2_L + GD^2_M) \times N}{375 \times (T_M \times \alpha h - T_L max)}$$

$$= \frac{(☐ + ☐) \times ☐}{375 \times (☐ \times ☐ - ☐)} = ☐ \text{ [kgf•m]}$$

- Judgment condition

Planned acceleration time (ta) = ☐ $>$ tas = ☐

- Shortest deceleration time (tds)

$$tds = \frac{(GD^2_L + GD^2_M) \times N}{375 \times (T_M \times \beta + T_L min)}$$

$$= \frac{(☐ + ☐) \times ☐}{375 \times (☐ \times ☐ + ☐)} = ☐ \text{ [kgf•m]}$$

- Judgment condition

Planned deceleration time (td) = ☐ $>$ tds = ☐

αh: Non-linear acceleration torque coefficient Chapter 2 Driving Capability Data

β: Deceleration torque coefficient Chapter 3 Braking Capability Data

< For Gravitational Systems of Units >

Regenerative power handling capability	Technical Note No. 22

- Deceleration torque (Td)

$$Td = \frac{(GD^2_L + GD^2_M) \times N}{375 \times td}$$

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

- Power returned from the machine (W_{MECH})

$W_{MECH} = 1.027 \times (Td - T_Lmin) \times N/2$

$= 1.027 \times (\boxed{} - \boxed{}) \times \boxed{} /2 = \boxed{}$ [W]

- Power absorbed by the motor (W_M)

$W_M = k \times P_M = \boxed{} \times \boxed{} = \boxed{}$ [W]

k: Conversion coefficient
Chapter 3 Braking
Capability Data

- Power returned to the inverter (W_{INV})

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

- Judgment condition
  Short-time permissible power of the braking unit (W_{RS})

  $= \boxed{} > W_{INV} = \boxed{}$

  W_{RS}: Short-time permissible power[W]
  Chapter 3 Braking
  Capability Data

  Braking unit ☐ Built-in brake
  ☐ External brake resistor
  ☐ Brake unit
  ☐ Power return converter