1 BASICS OF MOTOR

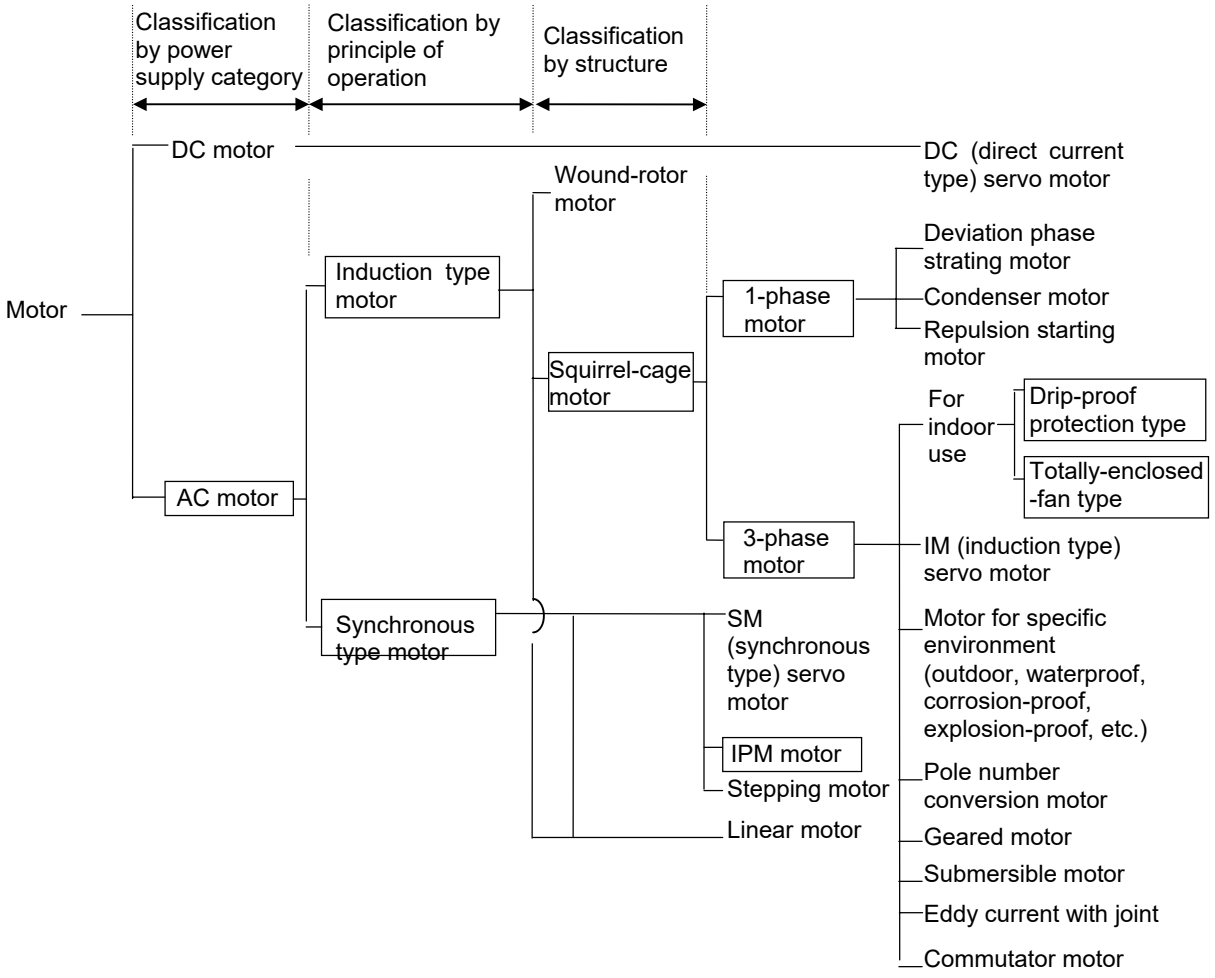
1.1 Type of Motor

1.1.1 Overview

A motor is a device which converts the electrical energy to the rotating mechanical energy. Many motors are used for various industrial machines to home appliances or bicycle in daily use.

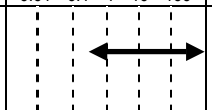
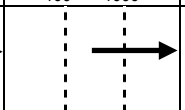
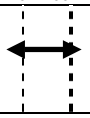
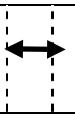
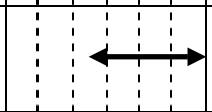
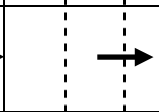
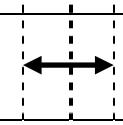
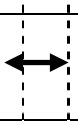
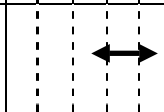
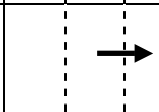
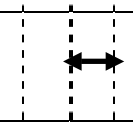
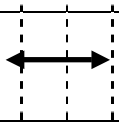
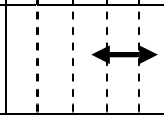
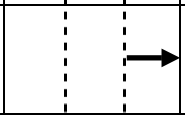
The types of motors can be classified by the performance, usage environmental condition, applications, etc. These are shown below.

The motor driven by the inverter is a mainly three-phase squirrel-cage motor, and the motor driven by the vector inverter is three-phase type motor with encoder which detects a position and speed. In addition, there is an energy-saving drive high-efficiency magnetic motor (IPM) for further energy saving.



1.1.2 Classification of motor

The following table shows the values for when a motor is used in combination with a controller which can adjust the speed of a motor.

Motor types	Rated output range (kW) 0.01 0.1 1 10 100	Maximum motor speed (r/min) 100 1000	Variable speed range (with inverter) 1:□ 10 100 1000	Encoder	Availability of torque control	Positioning accuracy (guide) (mm) 1/1000 1/100 1/10 1 10
General-purpose three-phase motor				Without	Not available*	Use the limit switch. 
General-purpose three-phase motor with encoder				With	Not available*	
Vector inverter dedicated motor				With	Available	
IPM motor				Without	Not available	Use the limit switch. 

* Available for FREQROL-A700 series.

1.2 Principle of Motor Operation

1.2.1 Overview

The principle of operation is same for all motors regardless of the size, and a torque is occurred according to the "Fleming's left-hand rule" by which the current is applied to a conductor in a magnetic field and a force acts to the conductor.

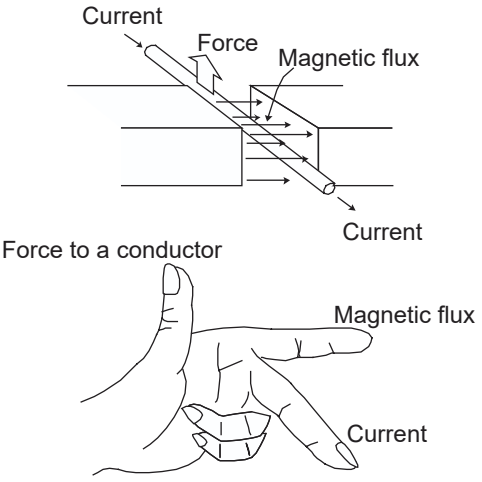


Fig. 1.1 Fleming's left-hand rule

The principle of induction motor operation is as below.
If the magnet is moved in the A direction when not touched with the disk, the disk also turns in the same direction.
At the same time as the movement of magnet, the electromotive force is induced in the disk, and the eddy current (induced current) is applied. The relationship between the eddy current induced in the disk and the magnetic flux by the magnet (Fleming's left-hand rule) causes an electromagnetic power, and the disk is turned in the arrow f direction.

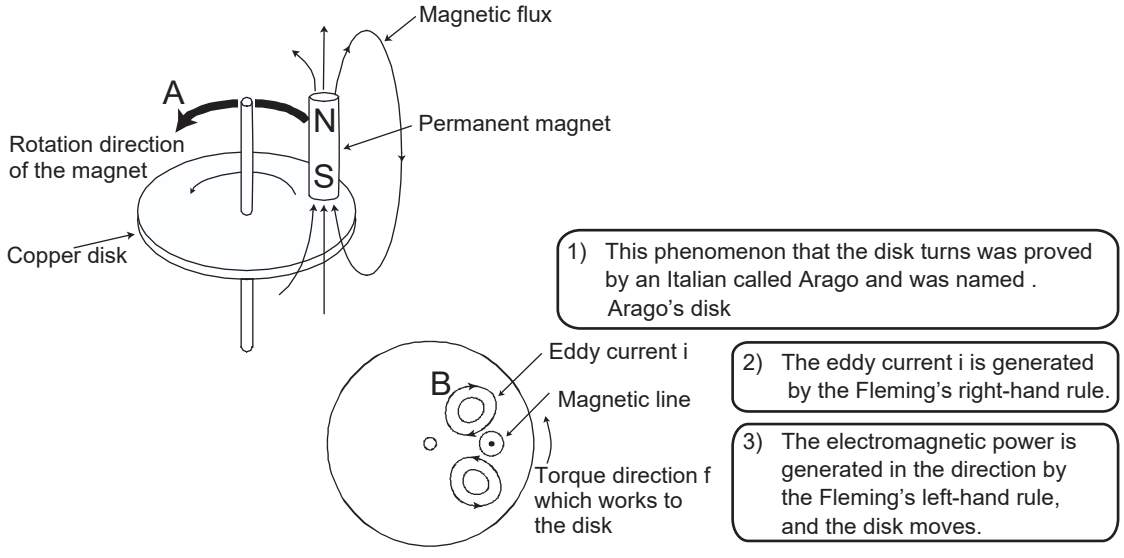


Fig. 1.2 Arago's disk

1.2.2 Three-phase motor (induction type)

The cross section view of the three-phase motor (induction type) is shown on the right.
It consists of stator core, stator winding, gap and rotor core.
The current is applied to the winding part, and the rotating magnetic field is generated. This rotating magnetic field is equivalent of Fig. 1.2. For this vector inverter dedicated motor used with the three-phase motor, the method, in which the current creating a magnetic field with the current applied to the stator winding (current for magnetic field) and the orthogonal current generating a torque (current for torque) are electrically controlled, is used. The control performance equivalent to a direct-current machine is ensured in principle. In addition, the vector inverter dedicated motor is widely used because of its constant torque control from low speed to high speed and good response.

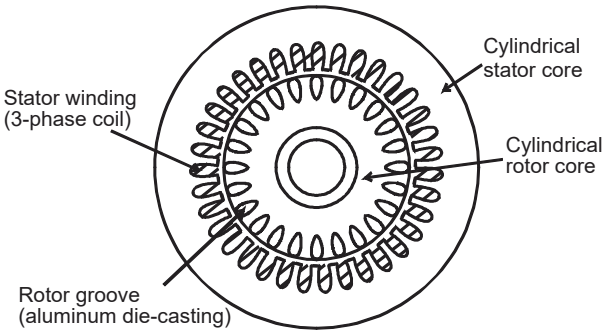


Fig. 1.3 Cross section of 3-phase motor (induction type)

1.2.3 IPM motor (synchronous type)

The rotor of the IPM motor (synchronous type) has permanent magnets embedded, and the stator consists of the winding which applies the current. The cross section view is shown in Fig. 1.4. The current according to the movement of the rotor is applied to the stator winding.
By detecting the magnet position at a start, the magnetic flux of these rotor magnets and the current applied to the stator winding are controlled at right angles to each other.

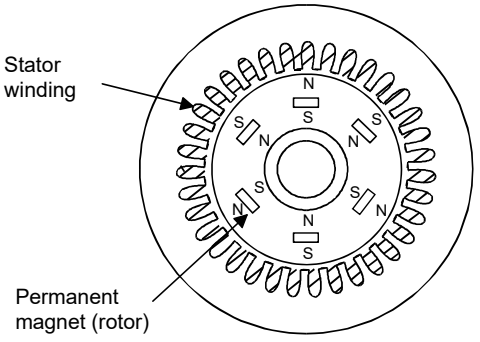


Fig. 1.4 Cross section of PM motor

1.3 Performance of Motor

1.3.1 Heat-resistant classes and temperature rise

Various insulants with high heat resistance are used for general-purpose motors due to the significant development of insulating materials to be used.
Currently, the motors have four types of heat-resistant class, E, B, F and H, and each maximum permissible temperature is as shown in Table 1.1. The rise of temperature severely shortens the life of motor.

It is necessary to set as (Ambient temperature + Motor temperature rise limit) < Maximum permissible temperature.
Motors are designed for the ambient temperature of 40℃.
For example, the motor temperature is designed to fit into the temperature rise limit standardized in Table 1.1 when the motor is operated with the rated torque in the rated voltage of 50Hz.

Table 1.1 Heat-resistant class, maximum permissible temperature and temperature rise limit

Heat-resistant class	**Maximum permissible temperature**	**Temperature rise limit**
E	120℃	75K
B	125℃	80K
F	155℃	105K
H	180℃	125K

Example In the case of E type
40℃(ambient temperature) + 75K (motor temperature rise limit)
< 120℃ (maximum permissible temperature)
155℃ < 120℃

* The temperature rise of insulants is measured in a resistance method.

1.3.2 Rated torque

The values of guaranteed output limit and designated voltage, current (torque), motor speed, frequency, ambient temperature, etc. by the motor manufacturer are collectively called a rating. These data are called rated output, rated current (rated torque), rated motor speed and so on. For the rating of output, there are constant rating, short-time rating and repeat rating (duty rating).

The constant rating is a constant output which can output continuously for a long time.

For the short-time rating, one hour rating, for instance, is a constant output which continuously outputs only for one hour after a motor is cooled down.

The repeat rating (duty operation) indicates the output at the load if the load changes periodically.

$$\text{Rated torque } T_M = 9550 \times \frac{\text{Motor rated output P [kW]}}{\text{Rated motor speed N [r/min]}} \quad [\text{N} \cdot \text{m}] \qquad \cdots\cdots \text{(Formula 1.1)}$$

These values are indicated on the name plates of motors or in test reports.

Example

What is the rated torque of 3.7kW 4P rated motor speed 1730 [r/min]?

$$\text{Rated torque } T_M = 9550 \times \frac{3.7 \text{ [kW]}}{1730 \text{[r/min]}} = 20.4 \quad [\text{N} \cdot \text{m}]$$

1.3.3 Relationship between motor speed and generated torque

The torque characteristics are shown in Fig. 1.5 and the current characteristics in Fig. 1.6 when a three-phase squirrel-cage motor is directly started.

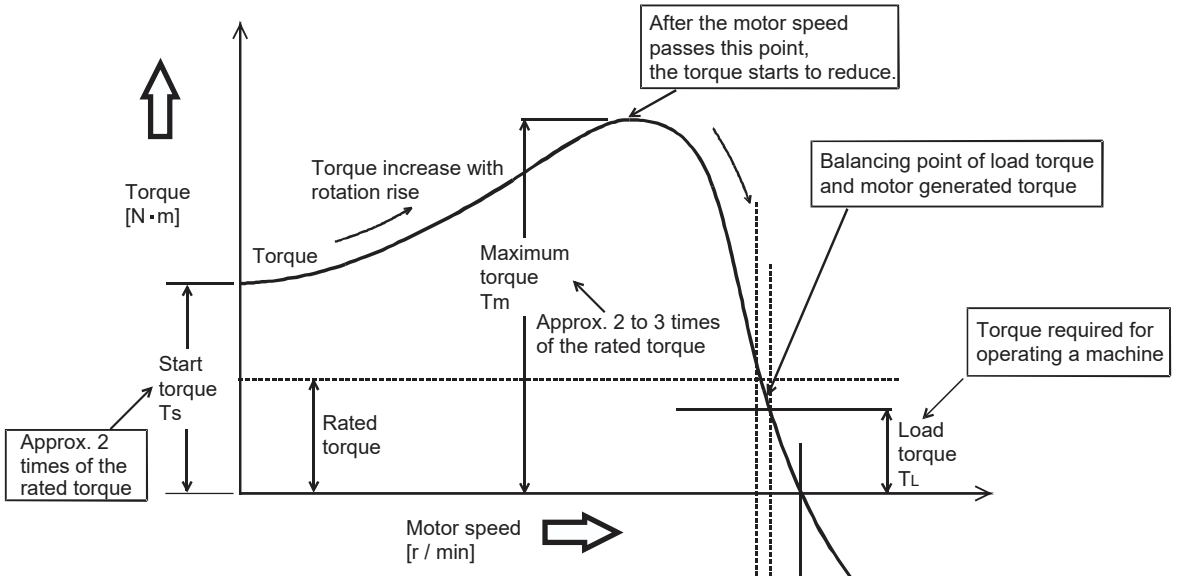


Fig. 1.5 Relationship of motor speed and torque

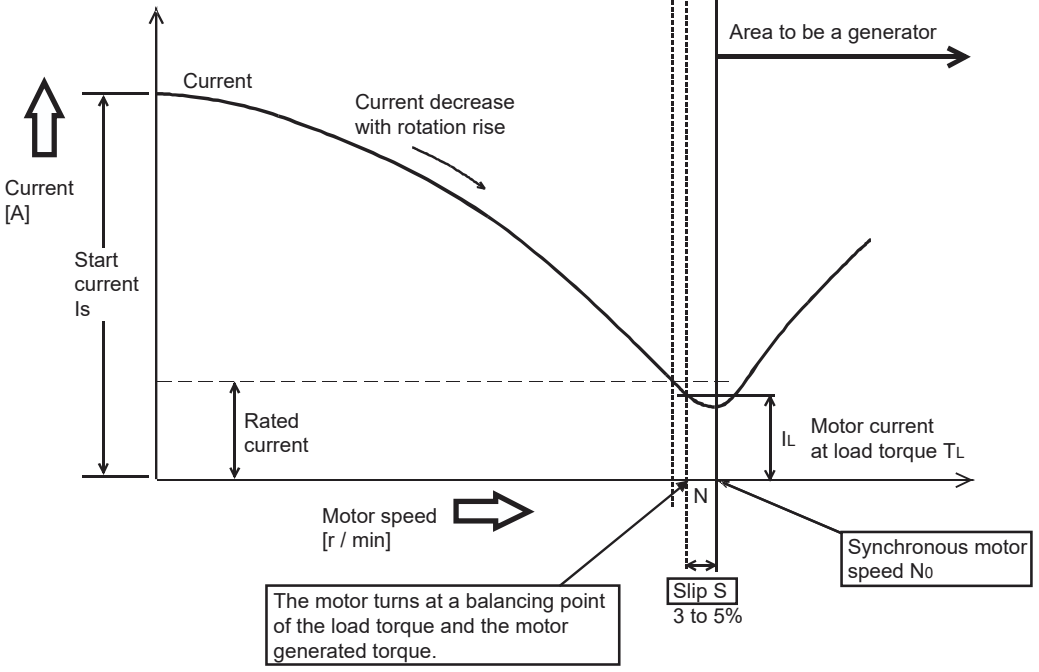


Fig. 1.6 Relationship of motor speed and current

Here, the motor speed is determined by the relationship between the load torque T_L and the motor generated torque according to the figure on the previous page, it can be expressed with the following formula.

$$\text{Motor speed} = \frac{120 \times \text{Frequency f (Hz)}}{\text{Pole number P}} \times (1 - S) \quad [\text{r/min}] \quad \cdots\cdots \quad \text{(Formula 1.2)}$$

Determined by the specification of the motor. This magnitude is called Synchronous speed N_0.

Determined by the magnitude of the load (load torque).

The control with an inverter is widely used in a method which changes this frequency f as a control of the motor speed.

1.3.4 Slip

The motor speed becomes a speed mismatched with the synchronous speed when the load is applied as shown in Fig. 1.5 and 1.6. The indicated degree of the gap with the synchronous speed is called "Slip".

The slip is derived by the following formula.

$$\text{Slip } S = \frac{\text{Synchronous motor speed } N_0 \quad - \text{Motor speed } N}{\text{Motor speed } N_0} \quad \cdots\cdots \quad \text{(Formula 1.3)}$$

At a start, the "slip" is 100% since the motor speed is 0.

When operating in the rated torque, the "slip" is generally 3 to 5%.

When the load torque increases, the motor speed slows down, the "slip" increases and the motor current also increases.

In the case of the rotation linked with outside, the motor speed becomes faster than the synchronous speed and the slip will be a minus value.

1.4 Installation

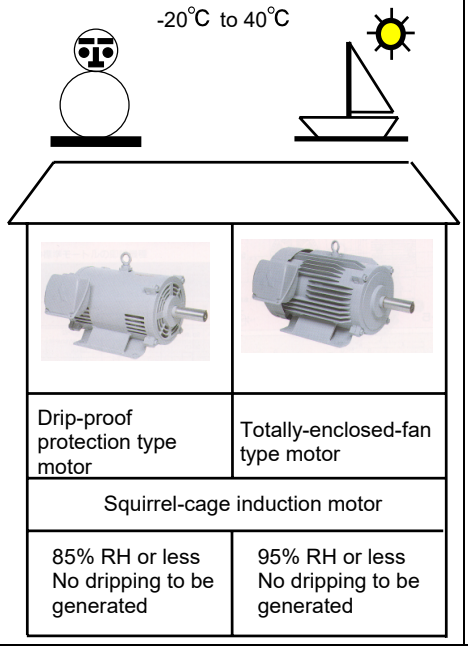
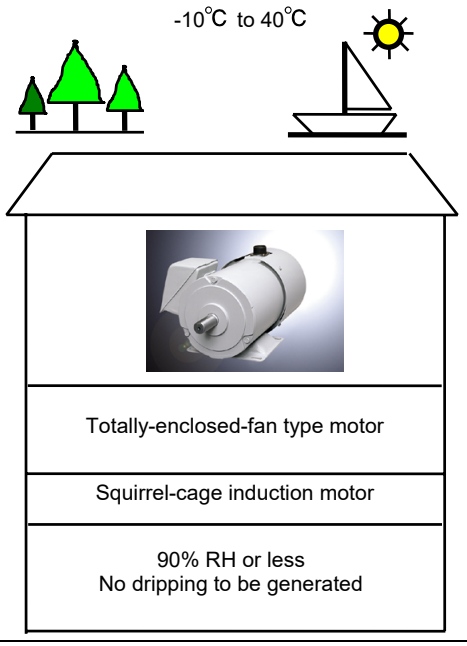
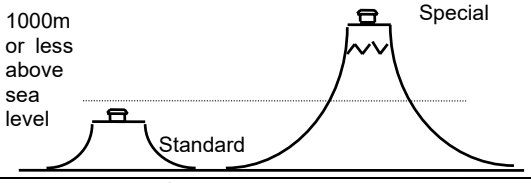
1.4.1 Installation environment

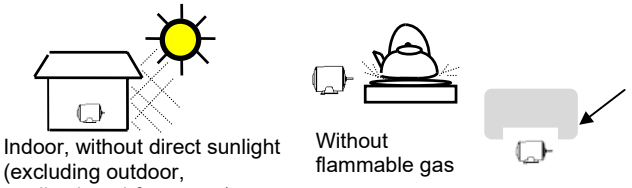
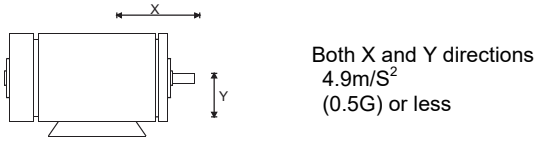
The motor driven with a general-purpose inverter is a general-purpose motor which does not generally operate a feedback control.

On the contrary, the motor driven with a vector inverter requires the feedback control and has a built-in encoder (sensor) behind the motor. For the encoder, a semiconductor and electronic components are installed.

In addition, there are restrictions in the motor such as the environment and the lives of internal winding insulating material, bearing material, grease material inside the bearing and so on. The following environmental conditions are mainly defined.

<table>
<tr><th>Environment</th><th>General-purpose inverter motor</th><th>Vector inverter dedicated motor</th></tr>
<tr><td>Ambient temperature

Ambient humidity</td><td> 
</td><td> 
</td></tr>
<tr><td>Elevation</td><td colspan="2"> 

The installation height of a motor is 1000m or less above sea level. If the atmospherical pressure is low, the heat dissipation gets worse.
The motor temperature, insulation, grease life, etc. during the operation cannot be guaranteed if the elevation is over 1000m, a special dealing is required.</td></tr>
<tr><td>Ambiance</td><td colspan="2"> 
</td></tr>
<tr><td>Vibration resistance</td><td colspan="2">Restrictions of the vibration passed on to the motor during the operation
 
</td></tr>
</table>

・The motors are designed with reference to the above environmental conditions.

1.4.2 Outer sheath form of motor

An outer sheath form for motor must be selected according to the installation condition and environment. Selecting an inappropriate motor may cause a trouble or shorten the motor life. Although the outer sheath forms (protection forms) are commonly classified into the classification by JIS, the motors expressed in the classification by the international standard IEC are recently manufactured as well. The classifications by JIS and IEC are as below.

(1) Classification by JIS

Symbols for the protection forms of motors are indicated by putting the first and second reference numbers corresponding to the following table after JP.

Example) JP 4 4

Second reference number

First reference number

(2) Classification by IEC

Symbols for the protection types of motors are indicated by putting the first and second reference numbers corresponding to the following table after IP.

Example) IP 6 5

Second reference number

First reference number

First reference number: Grade for the solid foreign matter entrance protection

Upper: Classification by JIS
Lower: Classification by IEC

are indicated.

0	Nonprotected type Unprotected	3	Protection to avoid the entrance of solid foreign matter of diameter 2.5mm or more such as an edge of tool or a wire	6	Absolute dust-proof structure, totally free from the entrance of powder dust
1	Half-protected type Protection to avoid the entrance of solid foreign matter of 50mm or more such as a hand	4	Totally-enclosed type Protection to avoid the entrance of solid foreign matter of diameter 1.0mm or more such as a cable or a flake		
2	Protected type Protection to avoid the entrance of solid foreign matter of diameter 12mm or more such as a one-yen coin	5	Dust-proof type Protection from powder dust, no entrance of the powder dust that disturbs a normal operation		

Second reference number: Grade for the water entrance related protection

Upper: Classification by JIS
Lower: Classification by IEC

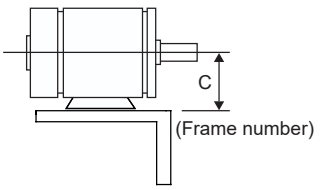
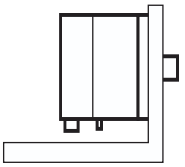
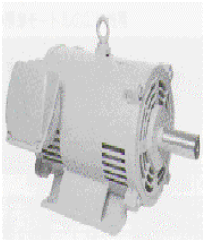
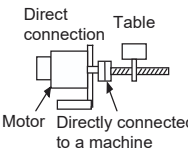
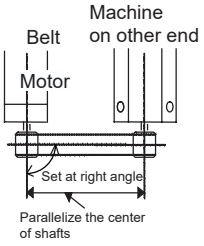
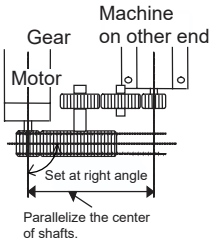
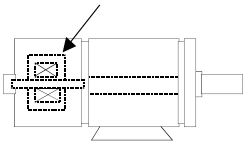
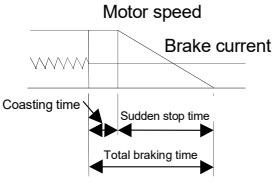
are indicated.

0	Nonprotected type Unprotected	3	Rainproof type Protection against the water spray within the range of 60° from the perpendicular	6	Ocean waves protection type Protection against strong jet water as ocean waves, no water immersion which disturbs a normal operation
1	Protection against the dripping that vertically drops such as condensed water	4	Splash-proof type Protection against the splash from all directions	7	Immersion protection type No water immersion which disturbs a normal operation even if submerged in 150mm to 1m
2	Drip-proof type Protection against the dripping within the range of 15° from the perpendicular	5	Jetproof type Protection against the jet water from all directions	8	Underwater type Usable in water, usable for a long time below water

1.4.3 Mechanical specifications of main motors

Generally, for general-purpose inverters and vector inverter motors, leg installed type (with legs) motors are used in relatively large numbers.

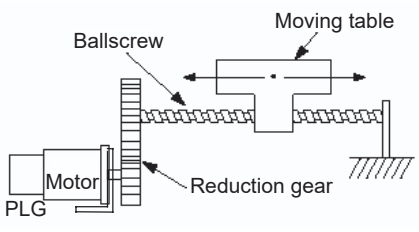
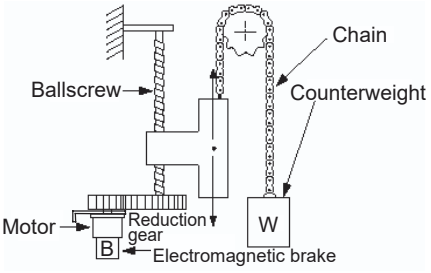
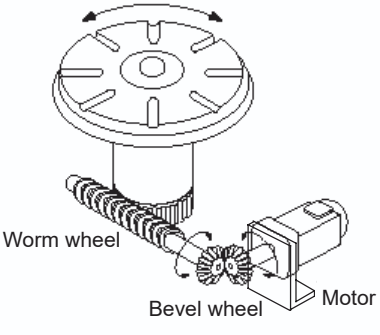
The following shows the point for the main mechanical specifications of these motors.

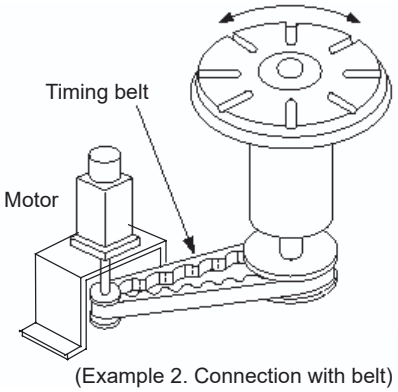
<table>
<tr>
<td>Installation method
Leg installed type
Frame number
Flange installed type</td>
<td>Leg installed type
 
</td>
<td>Flange installed type
  </td>
</tr>
<tr>
<td>Cooling method
Open type
Standard type
Totally-enclosed type
Suitable for adverse environment with dust, dirt, humidity, etc.
Separate-cooling type
Adopted with large capacity in a forced cooling system</td>
<td>Open type
  </td>
<td>Totally-enclosed type
  </td>
<td>Separate-cooling type
  </td>
</tr>
<tr>
<td>Power transmission
Direct connection driving
Belt driving
Gear driving</td>
<td> 
</td>
<td> 
</td>
<td> 
</td>
</tr>
<tr>
<td>Brake
Safety brake
Excitation open brake
Non-safety brake
Excitation brake</td>
<td colspan="3">Excitation open brake
Brake installation position for the inverter motor
 
 

When turning the brake power off separately</td>
</tr>
</table>

1.4.4 Movement direction of motor load

There are many types of mechanical drive systems by motors, and they can be used depending on the purpose (such as desired accuracy, positioning accuracy, travel distance and details of machine operation at work). For classifying these drive system mechanical sections and considering the relationship with the motor, the following indicates the categories of the mechanical movement directions. "mm" is used for the linear motion as a command unit, and an angle or the number of partitions is used for the rotational motion.

<table>
<tr><td></td><td colspan="2">Category of movement direction</td></tr>
<tr><td></td><td>Horizontal direction</td><td>Vertical direction (ascent and descent)</td></tr>
<tr><td rowspan="2">Linear motion</td><td> 
</td><td> 
</td></tr>
<tr><td>• Most common drive pattern which is used for a table feed of each machine or a transfer machine with a ballscrew, rack & pinion, belt, etc.</td><td>• Drive pattern which is used for a lifting shaft of transfer machine or a robot up-and-down shaft. As shown in the figure, the counter weight for a load balance is often mounted, and the motor with the electromagnetic brake is used for avoiding a slip down at a power failure.</td></tr>
<tr><td rowspan="2">Rotational motion</td><td colspan="2"> 

(Example 1. Connection with gear)


(Example 2. Connection with belt)</td></tr>
<tr><td colspan="2">• Drive pattern which is used for a rotary shaft of the index table, etc.
The motor speed of load shaft (table rotary shaft) is generally slow and often used by being reduced the speed according to the teeth number ratio of a gear or pulley.</td></tr>
</table>

Types of motor direction