FREQROL

MITSUBISHI ELECTRIC

INVERTER

TECHNICAL NOTE

No. 32

IPM TECHNICAL NOTE

MITSUBISHI

CONTENTS

CHAPTER 1 HISTORY AND TREND

1.1 History and trend of IPM motors

The progress of synchronous motors has been fueled by the advancement of permanent magnets and development of variable-speed controllers.

Synchronous permanent magnet motors were commercialized around the time when alnico magnets were invented. However, use of alnico magnets was limited for small-capacity motors because alnico magnets were poor in coercivity and had little demagnetization resistance. At that time, variable-speed controllers like inverters were not commercialized yet, and motors were directly connected to the DC power supply, and their rotors had to be equipped with damper coil for start-ups. Thus, excellent characteristics of synchronous motors were not fully exhibited, and synchronous permanent magnet motors were only available for special applications.

In the 1950's, ferrite magnets and rare earth magnets such as and neodymium magnets were invented, and those magnets with stronger magnetic force became commercialized. Variable-speed controllers were also commercialized around this time by the appearance of self-arc-extinguishing element with higher performance, such as the insulated gate bipolar transistor (IGBT). These advancements significantly improved synchronous permanent magnet motors and brought them to be high-performance high-efficiency motors.

In recent years, advancement of the computation ability and control technology of micro computers enabled the development of the IPM motor, which has a rotor with embedded permanent magnets that uses reluctance torque besides magnetic torque. This type of IPM motor is highly efficient and provides variable-speed operation for a wide range.

The rotor structure of an IPM motor can be flexible, and various characteristics can be exhibited by adjusting the control method. IPM motors can be used for various applications where high-speed and high-efficiency operation is required in a wide range such as a compressor motor for an air conditioner, and where robust low-speed ripples are required at low-speed operation such as the main shaft of a machine tool.

In the future, IPM motors will be employed in a wider range of diversified applications due to improvements in materials such as permanent magnets and electromagnetic steel sheets, advancement of work technology such as stamping technology, development of new power elements, and advancement of variable-speed controllers with improved control technology.

1.2 Market trend—Growing demand to cut greenhouse gas (CO_2) emission to stop global warming

In December 1997, "Kyoto Protocol" was adopted in the United Nations Framework Convention on Climate Change, which was held in Kyoto, Japan. In February 2005, the protocol was enforced, and the world started to focus on greenhouse gas emission reduction. Between 2008 and 2012, Japan is obligated to cut greenhouse gas emission by 6% of the 1990 emission level. Under such circumstances, Law Concerning Rational Use of Energy and the Law Concerning the Promotion of the Measures to Cope with Global Warming were reformed and became effective in April 2006. Under the new Law Concerning Rational Use of Energy, specified energy-treating plants must manage their thermal and electric energies together and meet the stricter regulations. Under the new Law Concerning the Promotion of the Measures to Cope with Global Warming, businesses of a certain size are required to calculate and report their greenhouse gas emissions, and the reports are disclosed by the government. Businesses and plants are under pressure to cut greenhouse gas emissions and to manage thermal and electric energies together to meet the regulations and to do so voluntarily.

An effective method to cut greenhouse gas is to cut power consumption. In Japan, 50% of the consumed power is reported to be used to drive motors. IPM motors, which are more efficient than induction motors, are receiving much attention as the means to cut power consumption of motors.

1.3 Mitsubishi IPM motors

Mitsubishi offers two series of IPM motors: the MELIPM series and the FR-FP series.
This TECHNICAL NOTE mainly presents descriptions about the FR-FP series.

1) Energy saving drive FR-FP series

(a) FR-FP700 series (b) FR-FP500J series (c) MM-EF series

Figure 1.1 FR-FP series

The FR-FP series was released in January 2005 to meet the increasing energy-saving demand to cut greenhouse gas emissions. This FR-FP series is specialized for energy-saving applications.
The FR-FP series consists of two types of drive units and the MM-EF series motors. The two types of drive units are high-performance type (FR-FP700 series) and compact type for general purposes (FR-FP500J series). The MM-EF series motors are designed to be highly efficient and can replace induction motors.

2) Magnet motor drive MELIPM series
The MELIPM series was released in February 2001 for general industrial applications.
The MELIPM series IPM motor has the totally-enclosed self-cooling structure.
The lineup offers two types: low-speed type (maximum speed of 3000r/min) and high-speed type (maximum speed of 7200r/min and 10000r/min).

CHAPTER 2 MOTOR TYPES AND STRUCTURES (CHARACTERISTICS OF IPM MOTORS)

2.1 Motor types

Motors can be categorized in many ways. The following diagram shows categorization of motors by their operation principles and structures.

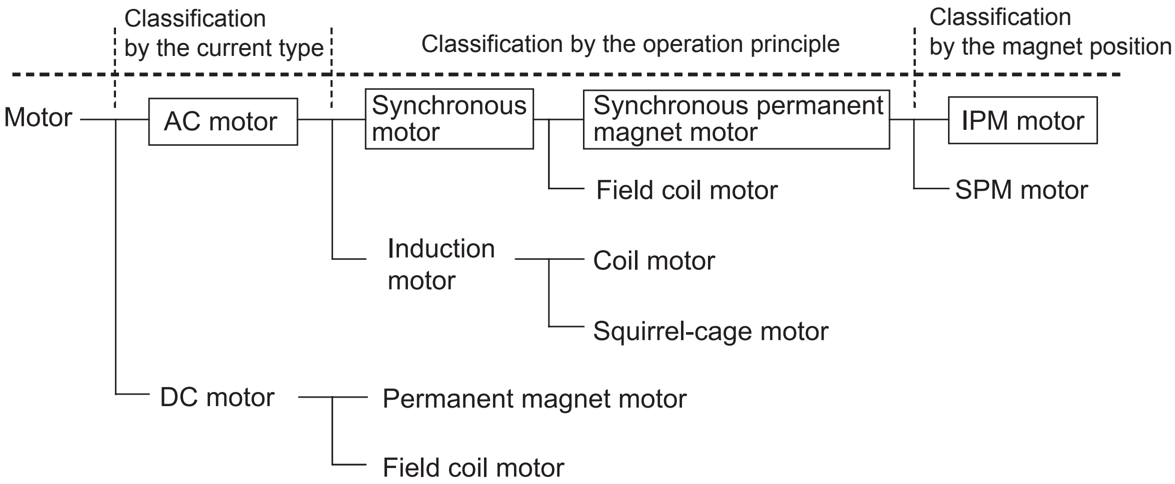


Figure 2.1 Motor types

2.1.1 DC motor

DC motors are driven by the DC power supply. DC motors are categorized into permanent magnet motors and field coil motors by their magnetic pole types. Permanent magnet motors have permanent magnets in their motor poles, and field coil motors have coils.

2.1.2 AC motor

AC motors obtain torque from the revolving magnetic field generated by the AC power supply.
AC motors are categorized into induction motors and synchronous motors. Induction motors use induced current, which is generated at their rotors, to generate torque.
Synchronous motors generate torque when the rotors are attracted to the revolving magnetic field.
Induction motors are further categorized into coil motors and squirrel cage motors by their rotor structures. A squirrel cage motor has several pole-shape conductors whose ends are shorted with short-circuit rings in their rotor slots. Coil motors have coil-shape rotors, which contain insulated wires in their rotor slots. Squirrel cage motors are commonly used today.
Synchronous motors are further categorized into synchronous permanent magnet motors and field coil motors by their rotor structures. Permanent magnet motors have permanent magnets in their rotors and are rotated by attraction/repelling force between the stator coils and the rotors. Field coil motors use coils for their rotors. A rotor acts as an electromagnet when the stator coil is excited, thus revolving magnetic field arises when a three-phase AC voltage is applied to the stator. The attraction/repelling force between the revolving magnetic field and the stator rotates the motor.
Permanent magnet motors are further categorized into interior permanent magnet (IPM) motors and surface permanent magnet (SPM) motors by their rotor structures and permanent magnet positions. Permanent magnets of an IPM motor are embedded inside a rotor, and permanent magnets of a SPM motor are attached on the rotor surface.

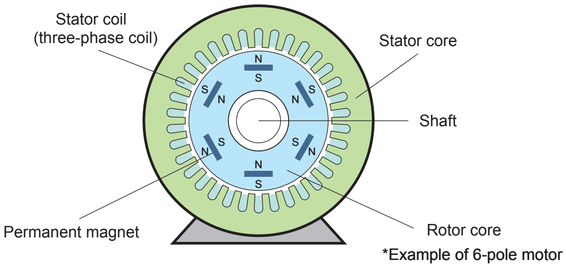
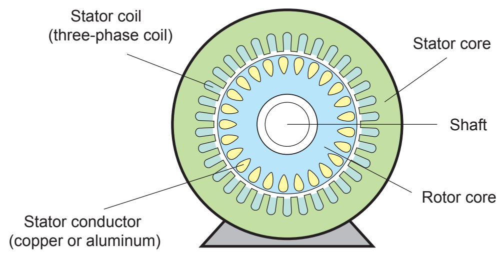
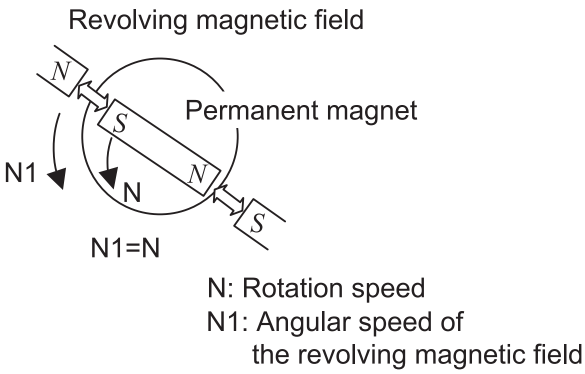
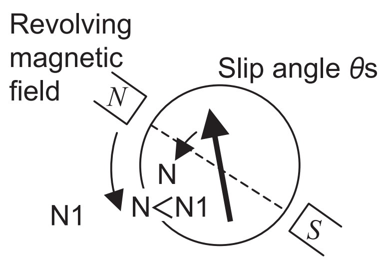
* Excitation means generating magnetic flux by feeding current to electromagnet coils.

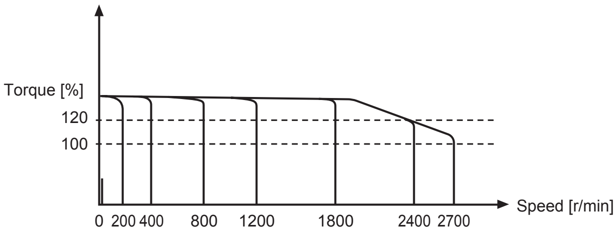
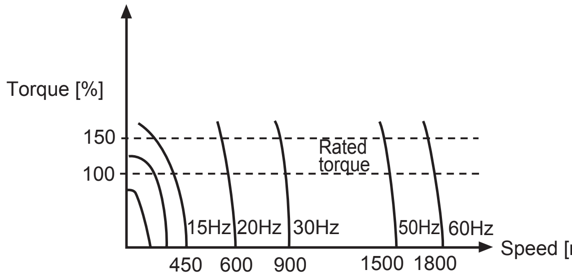
2.2 Differences between induction motors and synchronous motors

A motor mainly consists of a stator and a rotor. Whether in induction motors or in synchronous motors, a stator consists of a primary coil and a stator core, and its basic structure is the same. Rotor structures are different between induction motors and synchronous motors. In induction motors, a rotor consists of electromagnets that are excited by a separate power source. In synchronous motors, a rotor consists of permanent magnets.

Table 2.1 shows the differences between an IPM motor (a type of synchronous motor) and a squirrel-cage induction motor (a typical induction motor).

Table 2.1 Differences between IPM motor and squirrel-cage induction motor

	IPM motor	Squirrel-cage induction motor
Motor structure (section view)	 Permanent magnets are embedded in the rotor.	 The rotor is made of copper or aluminum. No magnets are used.
Magnetic flux generation method	Magnetic flux is generated by the magnets embedded in the rotor. At no-load (torque=0), no current is required to generate torque. No current flows to the stator, so no power is lost by the coil resistance. ⇒Highly efficient because no excitation current is required.	Magnetic flux is generated by flowing excitation current. Current flows even at no-load (torque=0), so some power is lost by the coil resistance.
Torque generation method	Torque is generated by the attraction force between permanent magnets and the revolving magnetic field, which is generated by a voltage input. IPM motors also use reluctance torque, which is generated from the magnetic resistance differences that arise from the embedded magnets. (Refer to Chapter 3) 	Torque is generated from the induced electromotive force and the electromagnetic force. Electromotive force is induced because of a slip, and electromagnetic force is produced from the revolving magnetic field that is generated by a voltage input. 

<table>
<tr>
<td>Speed – torque curve</td>
<td>No slip occurs, so the speed does not fluctuate when a load is applied.

</td>
<td>Slip occurs, so the speed fluctuates when a load is applied.

</td>
</tr>
<tr>
<td>Speed</td>
<td>$N = \frac{120f}{p}$ [r/min]
f: Output frequency
p: Number of motor poles

Motor rotates in synchronization with the frequency of the voltage input to the motor (with no slip).</td>
<td>$N = \frac{120f}{p} \cdot (1-s)$ [r/min]
s: Slip

Motor rotates at the speed slightly slower than the frequency of the voltage input to the motor (with slip)</td>
</tr>
</table>

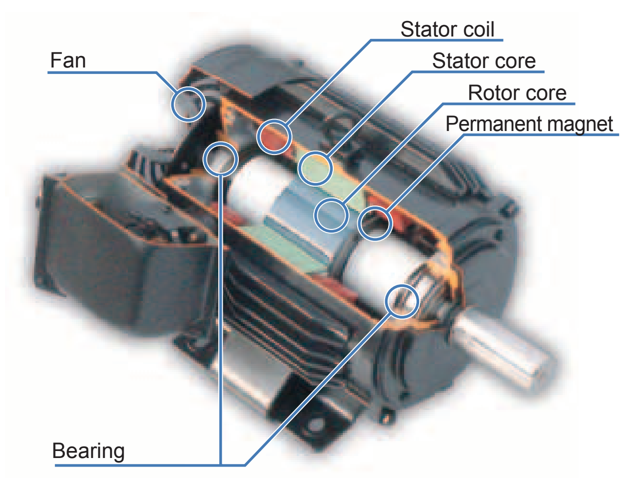


Figure 2.2 Structure of IPM motor (MM-EF series)

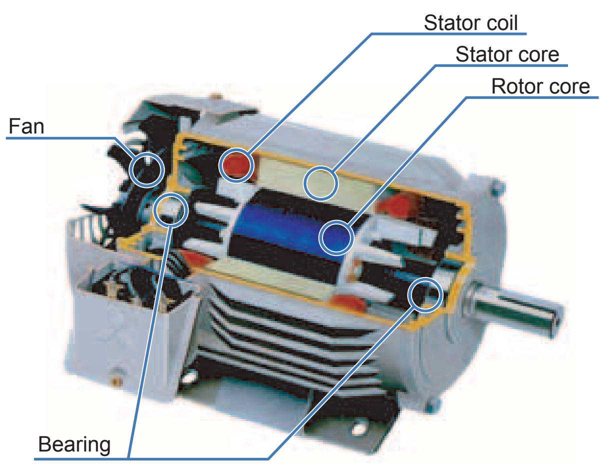


Figure 2.3 Structure of squirrel-cage induction motor (SF-JR series)

2.3 Characteristics of IPM motors

As mentioned in Chapter 2.2, IPM motors have the following characteristics compared to induction motors.

1) Highly efficient
   No current flows to the rotor, so no power is lost at the rotor (secondary side). This makes an IPM motor more efficient than an induction motor.

2) Compact
   Smaller power loss in an IPM motor means that the required heat capacity is lower. The rotor is also downsized by employing high density magnets such as rare earth magnets. With low heat capacity and high density magnets, the motor has become compact.

3) Improved speed-control accuracy

Unlike induction motors, an IPM motor rotates in synchronization with the revolving magnetic field without a slip. The speed does not fluctuate even when a load is applied. Thus, the speed is controlled more accurately.

4) Prolonged bearing grease life

No current flows to the rotor, so the rotor does not heat up. As a result, bearing grease lasts longer.

2.4 Differences between IPM motors and brushless DC motors (commutatorless motors)

Brushless DC motors, which are widely used for household appliances nowadays, are one example of DC motors. Magnets are used for the rotor, and the coil circuits are used for the stator. Brushless DC motors have almost the same structure as that of synchronous permanent magnet motors such as an IPM motor.

First difference with an IPM motor is that DC flows to the coil circuit in a brushless DC motor. In brushless DC motors, DC is commutated to the detected angle to correspond with the magnetic pole of the rotor. (Refer to Chapter 4).

Another difference is that a brushless DC motor needs a detector, such as a Hall effect sensor, to detect the angle of rotation, whereas such a detector is not required to control an IPM motor. As an IPM motor consists of fewer electronic circuits, it is less vulnerable to the environment change such as change in surrounding air temperature. Thus, an IPM motor is a reliable motor.

2.5 Fundamental parts of IPM motors

1) Permanent magnets

Permanent magnets determine the characteristics of synchronous permanent magnet motors such as an IPM motor. Typical examples of permanent magnets used for IPM motors are "ferrite magnets" and "neodymium magnets."

"Ferrite magnets"

Ferrite magnets are relatively inexpensive and are used in different fields of technology. The magnetic force is weak compared to neodymium magnets, and its magnetic characteristic is largely affected by the temperature.

"Neodymium magnets"

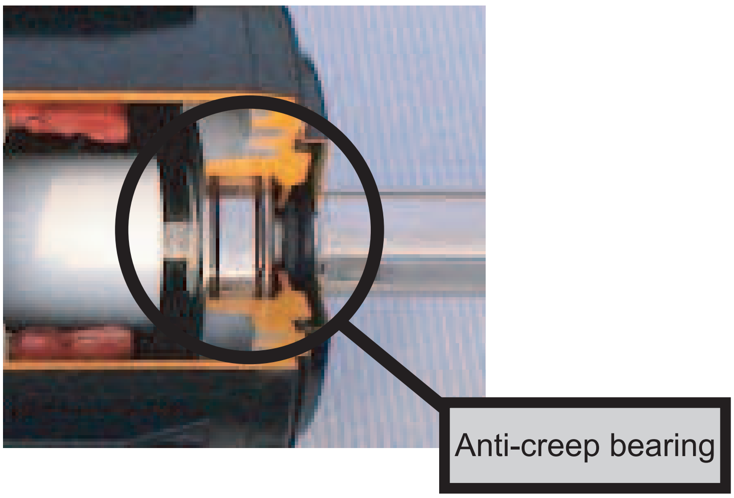
Neodymium magnets are one example of rare earth magnets, and their main components are neodymium, iron and boron. Neodymium magnets are expensive as they use rare earth components but emit the strongest magnetic force among all the commercially available magnets today. This strong magnetic force enables downsizing of the motor. Neodymium magnets are used for the MM-EF series IPM motors and the general-purpose servo motors of Mitsubishi.

2) Bearing

The MM-EF series IPM motors are equipped with anti-creep bearings as a standard.

Slip (called creep) sometimes occurs between the bearing and housing when an unbalanced load is applied to the bearing of fan motors and pumps. Friction by this creep may lower the service life of the bearing. Anti-creep bearing has two O-rings at its outer ring to protect the bearing from a creep.

The most commonly-used ball bearing called a deep groove ball bearing is employed. A deep groove ball bearing generates little friction torque and is suitable for a fast-rotating part or for an application that requires low noise and vibration. A shielded bearing, which contains grease filled in a sealed format, is employed.



CHAPTER 3 OPERATION PRINCIPLES AND TECHNIQUES OF IPM MOTORS

3.1 Operation principles of IPM motors

Interior Permanent Magnet (IPM) motors are synchronous motors with permanent magnets embedded in their rotors. Figure 3.1 shows the diagram of an IPM motor that has permanent magnets embedded in its rotor.

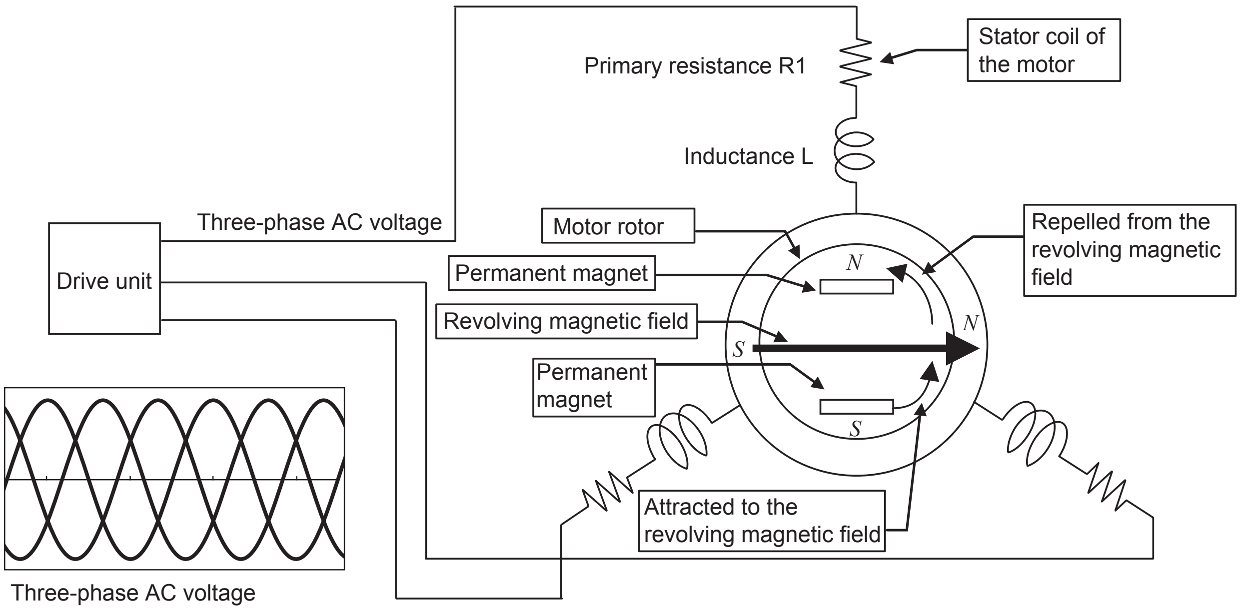


Figure 3.1 Diagram of an IPM motor

When a three-phase AC voltage is applied to the IPM motor above inductance at the rotor coil produces revolving magnetic field inside the motor.

This revolving magnetic field travels from one pole to another in one frequency cycle of the three-phase AC voltage. When a frequency of the three-phase AC voltage increases, traveling speed of the revolving magnetic field also increases.

When a three-phase AC voltage is applied to an IPM motor, which has permanent magnets in its rotor, attraction/repelling force rises between the permanent magnets in the rotor and the revolving magnetic field generated by the three-phase AC voltage. When this happens, the rotor of the motor rotates in synchronization with the traveling speed of the revolving magnetic field.

In induction motors, conductor coils are used for the rotors instead of magnets. Like for an IPM motor, a three-phase AC voltage is applied to the stator of an induction motor to generate revolving magnetic field. In induction motor, however, current must be also fed to the secondary-side coil to provide magnetic force to the revolving magnetic field, which is generated at the stator. Because of this, current flows even at no load.

Amount of the torque generated by an induction motor is determined by the secondary current that flows through the rotor. The secondary current flows into the rotor by the following mechanism. First, slip (difference) is created between the actual rotor (motor shaft) speed and the traveling speed of the revolving magnetic field, which is created at the stator. Then, the path where the magnetic flux travels through the rotor coil is alternated to produce induced voltage at the rotor.

When load torque increases, rotor slip increases. Thus, the motor rotates at the speed slightly lower than the frequency of the applied AC voltage.

3.2 Saliency of IPM motors

Because magnets are embedded inside a rotor of an IPM motor, inductance at the stator coil changes with the magnet positions in the rotor. This characteristic is called saliency of an IPM motor, and it is an important characteristic to generate reluctance torque and to detect magnetic pole positions. (Further explanation is given on reluctance torque in later chapters.)

· Saliency: Characteristic defined by the inductance at the stator coil which changes with the position of the magnets embedded in the rotor.

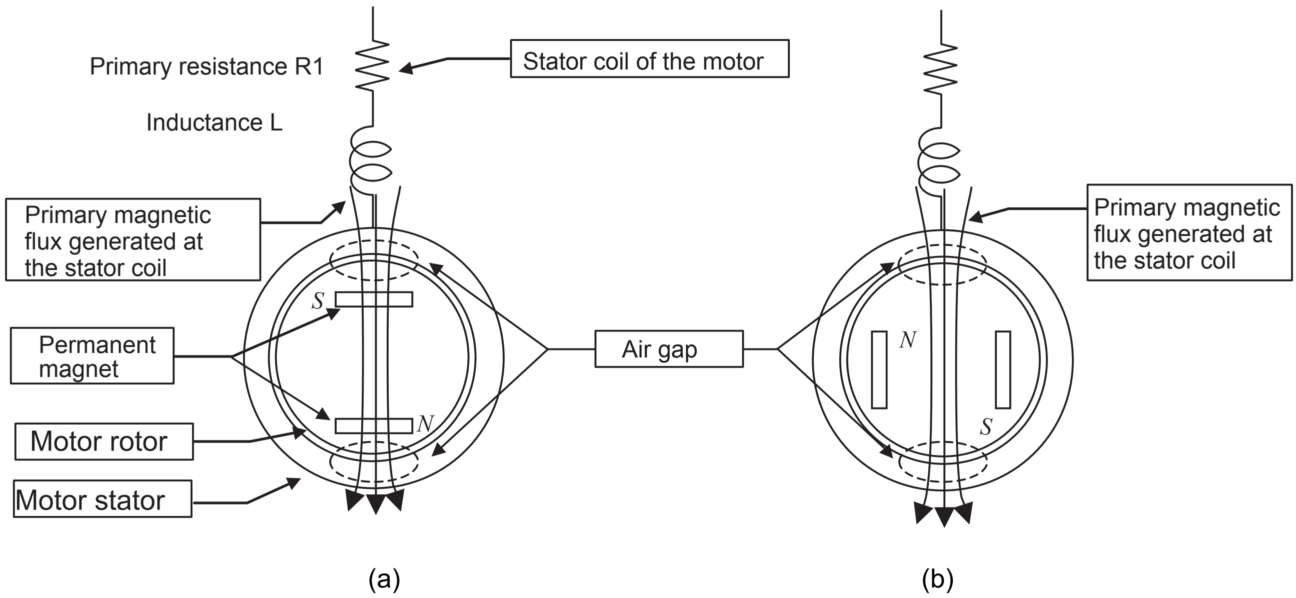


Figure 3.2 Saliency

When current flows through a motor, magnetic flux is generated by the inductance at the stator. In Figure 3.2 (a), the magnetic flux travels through the two air gaps (each air gap between the stator and the rotor) and two permanent magnets. In Figure (b), the magnetic flux only travels through two air gaps. Assuming the magnetic permeability of air gaps and permanent magnets are comparably low, magnetic flux is less likely to be generated in Figure (a) and more likely to be generated in Figure (b).

The magnetic flux generated by inductance has the characteristic that "when inductance L is large, magnetic flux is more likely to be generated, and when L is small, magnetic flux is less likely to be generated."

Because an IPM motor has the characteristic that its inductance L changes with its rotor position, the inductance L at the stator coil is the smallest in Figure 3.2 (a) and the largest in Figure (b). This characteristic is called saliency.

3.3 The torque generated in IPM motors

Generated torque in an IPM motor is the total of magnet torque and reluctance torque. Magnet torque is determined by the revolving magnetic field size, and reluctance torque is determined by the saliency of the IPM motor. (Refer to Chapter 3.2).

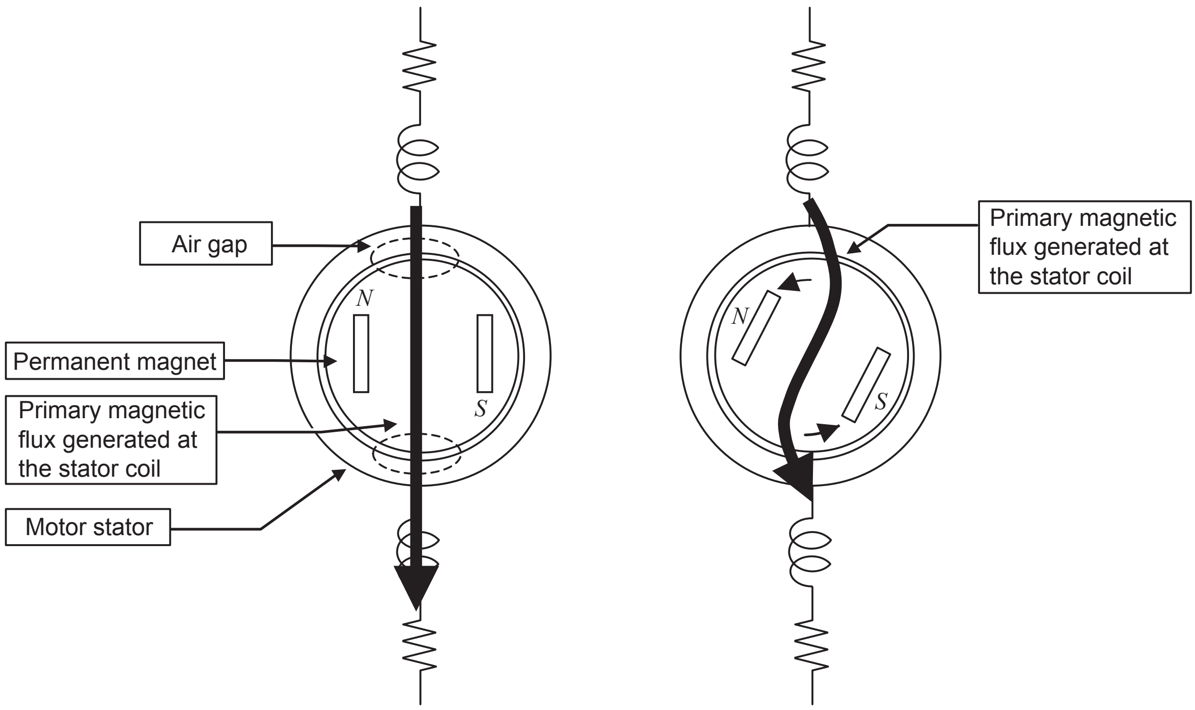
1) Magnet torque

Magnetic flux is generated inside a motor by the inductance at the stator when a current flows to the motor stator. (Refer to Chapter 3.1.) Magnet torque is generated from the attraction/repelling force between this magnetic flux and the magnets embedded in the rotor.

As magnet torque is proportional to the magnetic flux size that is generated at the stator, the magnet torque is also proportional to the motor current.

2) Reluctance torque

Reluctance torque is generated due to the saliency unique to IPM motors.



When the rotor is at this position, the magnetic flux only travels through two air gaps, so the permeability of the magnetic flux is the highest.

When the rotor is at this position, the magnetic flux flows to the path with the shortest distance as it is the easiest to travel. Then, the torque that pushes back the rotor to the (A) position generates.

(A) (B)

Figure 3.3 Reluctance torque

Because of its rotor structure, generatability and permeability of magnetic flux differs depending on the rotor position in an IPM motor. The position shown in Figure 3.3 (A) is the most permeable position for the magnetic flux. When the generated magnetic flux tries to travel through in the position in Figure 3.3 (B), the magnetic flux flows to where it can travel easiest, so the magnetic flux generated at the stator travels as shown in Figure 3.3 (B). As the magnetic flux tries to travel the path with the shortest distance, the force that pushes back the rotor to the 3.3 (A) position is generated. This force is called reluctance torque.

The torque of an IPM motors is expressed by the following formula.

Torque = magnet torque + reluctance torque

The first term indicates the torque generated by the magnetic flux of permanent magnets (magnet torque). The second term indicates the reluctance torque generated by the saliency when the inductance differences exist in certain rotor positions. Total of magnet torque and reluctance torque is the torque of an IPM motor. Under the vector control of an IPM motor, motor current is divided into the torque current Iq, which is used to generate torque, and the excitation current Id, which is used to control the magnetic flux. (Refer to Chapter 4.) When current is fed to use the reluctance torque wisely, the reluctance torque amount is gained as shown in Figure 3.4.

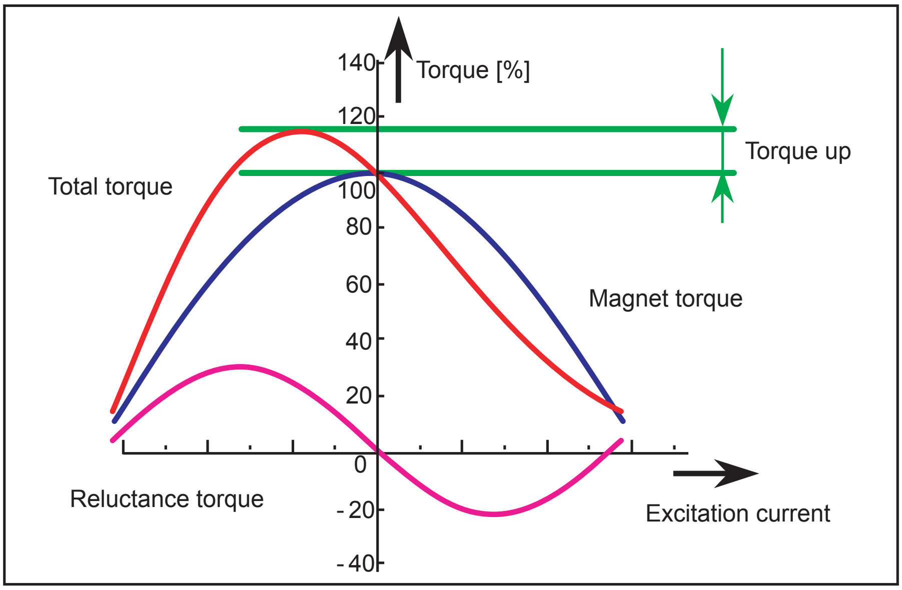


Figure 3.4 Change in torque by the excitation current Id at constant motor current

CHAPTER 4 CONTROL METHOD OF IPM MOTORS

As explained in Chapter 3, when a three-phase AC voltage is applied to an IPM motor with embedded permanent magnets at its rotor, attraction/repelling force rises between the permanent magnets in the rotor and the revolving magnetic field generated by the three-phase AC.
In order to rotate a motor smoothly, attraction/repelling force between permanent magnets and the rotor must be applied to the direction where the motor rotates to. Thus, a voltage must be applied to the motor so that the revolving magnetic field travels to the 90° angle from the magnetic flux at the rotor.

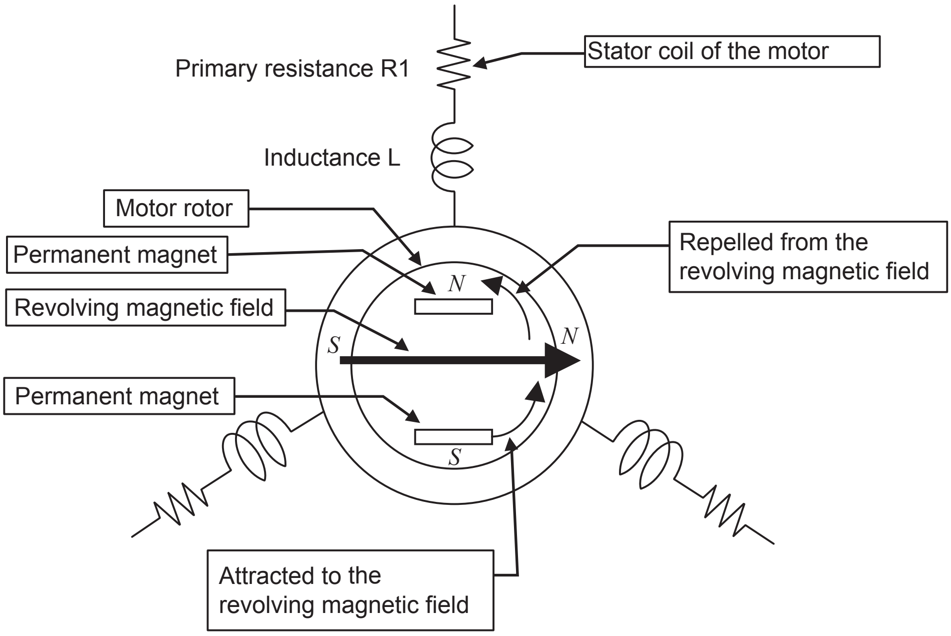


Figure 4.1 Diagram of an IPM motor

An induction motor, which is one type of AC motor, produces enough torque under V/f control when it is driven by a general-purpose inverter. Under V/f control, however, magnetic pole positions in the rotor cannot be controlled. If an IPM motor is driven under V/f control, revolving magnetic field is generated without consideration of permanent magnet positions in the rotor. In that case, attraction/repelling force between the permanent magnets and the revolving magnetic field may not be applied properly and may fail to rotate the motor. This status is called loss of synchronism.

In rare cases, the motor rotates as the attraction/repelling force coincidentally applied in the same direction with the rotating direction. However, the magnetic pole position in the rotor and the revolving magnetic field position become misaligned in the following cases, and loss of synchronism occurs.

1) Motor speed fluctuates as an impact load is applied.
2) A sudden deceleration has been commanded by an inverter, but the command is not tracked by the motor rotor.

Thus, simply applying a voltage does not enable the IPM motor operation. To drive an IPM motor, its magnetic pole positions must be detected.
Synchronous motors usually use detectors to detect magnetic pole positions in the rotor. IPM motors, however, do not use such position detectors and detect magnetic pole positions prior to the operation.
To drive an IPM motor efficiently, the magnetic flux generated at the stator must be treated accurately. This is why vector control is used to drive an IPM motor.

This chapter presents explanations about magnetic pole position detection and vector control.

4.1 Initial magnetic pole detection

As mentioned in the previous section, magnetic pole positions in the rotor must be detected prior to IPM motor operation. Synchronous motors are usually equipped with position detectors like an encoder to detect magnetic pole positions.
When a detector is equipped, accurate speed control and positioning can be performed like for a servo motor. However, it also brings challenges such as necessities of increased wiring and reliability assurance and higher detector cost.
An IPM motor can be driven without a detector and can be used for the applications that do not require accuracy like for a servo motor.
A drive unit connected with an IPM performs initial magnetic pole detection and estimates the magnetic pole positions in the rotor. For this initial magnetic pole detection, the drive unit detects magnetic pole positions in the rotor using saliency and magnetic saturation characteristic of the IPM motor.

1) Saliency
   Characteristic defined by the inductance at the stator coil which changes with the position of the magnets embedded in the rotor. (Refer to Chapter 3.2 Saliency of IPM motors)
   While a rotor makes one rotation in a motor, the magnetic flux of the rotor comes parallel to the primary magnetic flux of the stator twice, and it comes vertical to the primary magnetic flux of the stator twice. This means that there are two high-inductance positions and two low-inductance positions in a motor. When an inductance changes, the current that flows through the primary coil (output current to the drive unit) also changes. The drive unit detects this change in current and estimates the magnetic pole positions.

2) Magnetic saturation characteristic (characteristic defined by the magnetic flux size which changes with the position of the magnets embedded in the rotor)
   As a current flows through the motor stator, magnetic flux is generated at the stator. When this magnetic flux generated at the stator and the magnetic flux of the permanent magnets balance each other out, their total magnetic flux size decreases, and it becomes difficult for a current to flow.
   On the contrary, when the magnetic flux at the stator adds up to the magnetic flux of the permanent magnets, it becomes easy for a current to flow.
   While the rotor makes one rotation in a motor, there is one area where the magnetic flux size becomes largest and one area where the magnetic flux size becomes smallest. Where the magnetic flux size is small, small current flows to the coil. Where the magnetic flux size is large, large current flows. The drive unit detects this change in current and estimates magnetic pole positions.

4.2 IPM motor control

IPM motors are controlled based on the initial magnetic pole detection, which is explained in the previous section.
As shown in Figure 4.2, a drive unit divides a three-phase AC into torque current and excitation current and controls both currents to their optimum. Torque current is used to generate torque in a motor, and the excitation current is used to generate magnetic flux in a motor. This control method is called vector control. Figure 4.3 shows the control method in a block diagram.

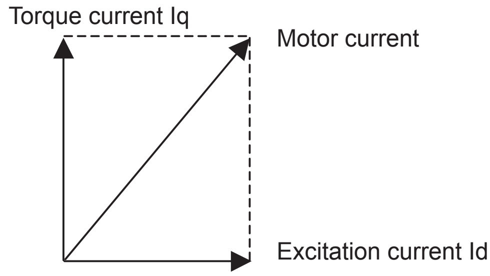


Figure 4.2

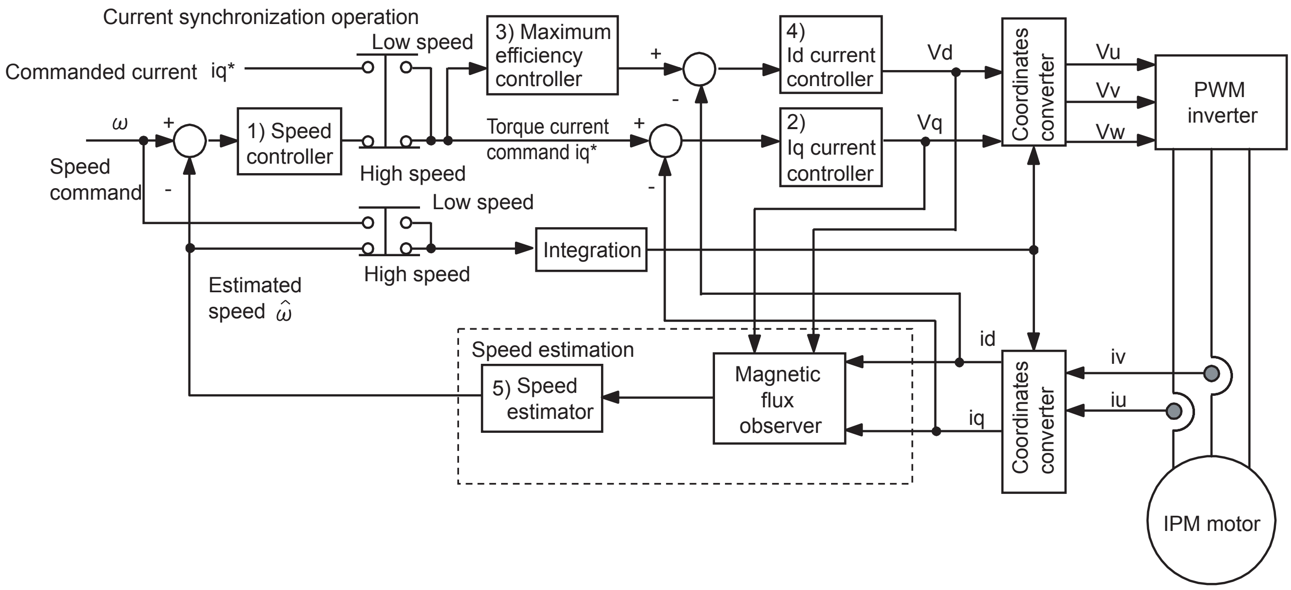


Figure 4.3 Vector control shown as a block diagram

Under vector control, motor position is normally detected using an encoder to perform speed feedback and phase detection. An IPM motor, however, does not use an encoder, so the speed feedback and phase detection must be performed without an encoder.
In today's IPM motor control, speed feedback and phase detection are performed using a mathematic model instead of a sensor. The values obtained using the mathematic model are used to estimate the motor speed and to perform vector control. This control method is called sensorless vector control.
As shown above, the following elements are used for vector control of an IPM motor: 1) Speed controller, 2) Iq current (torque current) controller, 3) Maximum efficiency controller, 4) Id current (excitation current) controller), and 5) Speed estimator (including a Magnetic flux observer). Functions of those elements are explained below.

1) Speed controller
This controller operates to diminish the difference between the speed command ω and the estimated speed $\hat{\omega}$. In other words, it operates to match the speed command to the motor speed. In order to match the speeds, the motor load at a particular timing is calculated from the difference between the speed command ω and estimated speed $\hat{\omega}$, and the required torque for the timing (torque current command Iq*) is transmitted to the Iq current (torque current) controller.

2) Iq current (torque current) controller

This controller calculates voltage Vq to feed the same amount of torque current as the torque current command Iq*, which was obtained by the Speed controller.

3) Maximum efficiency controller

As explained in Chapter 3, reluctance torque is generated in an IPM motor besides the torque generated by the permanent magnets in the rotor. When this reluctance torque is used, the required torque is generated with the least current. This controller calculates the excitation current command Id*, which is required to generate the reluctance torque, and transmits the value to the Id current (excitation current) controller.

4) Id current (excitation current) controller

This controller calculates voltage Vd to feed the same amount of excitation current as the excitation current command Id*, which was obtained by the Maximum efficiency controller.

5) Speed estimator

In the drive unit connected to an IPM motor, Magnetic flux observer is used to estimate the IPM motor speed.

Magnetic flux observer formulates the motor as a mathematical model inside the drive unit by using electric characteristics (motor constants) of the IPM motor.

The output voltage to the IPM motor and the amount of current flows in the motor are already identified by the drive unit, so the drive unit estimates the magnetic flux size generated in the motor and the required current for the magnetic flux using the mathematic model.

The estimated current and the actual current are compared, and the motor speed is obtained by a calculation using the mathematic model.

4.3 Operation method at low-speed range

The output voltage during an IPM motor operation is almost proportional to the motor speed.
The actual voltage applied to the motor is slightly different from the output voltage commanded by the inverter because of a voltage drop at wiring resistance and inside the inverter.
When the speed is sufficiently high, the slight voltage difference to the output voltage is negligible and does not affect the Magnetic flux observer explained in Chapter 4.2. 5). However, when the speed is low, ratio of the slight voltage difference to the output voltage becomes large, so the difference does affect the Magnetic flux observer considerably, making it difficult for an accurate speed estimation.
To avoid this, Magnetic flux observer does not estimate the speed in the low-speed range, and the revolving magnetic field of the motor is controlled to travel at constant speed in response to the speed command. This control method is called current synchronization operation.
In this current synchronization operation, constant level of current flows regardless of the load condition of the motor so that the revolving magnetic field travels at a constant speed. This enables motor operation under light load without loss in synchronism.

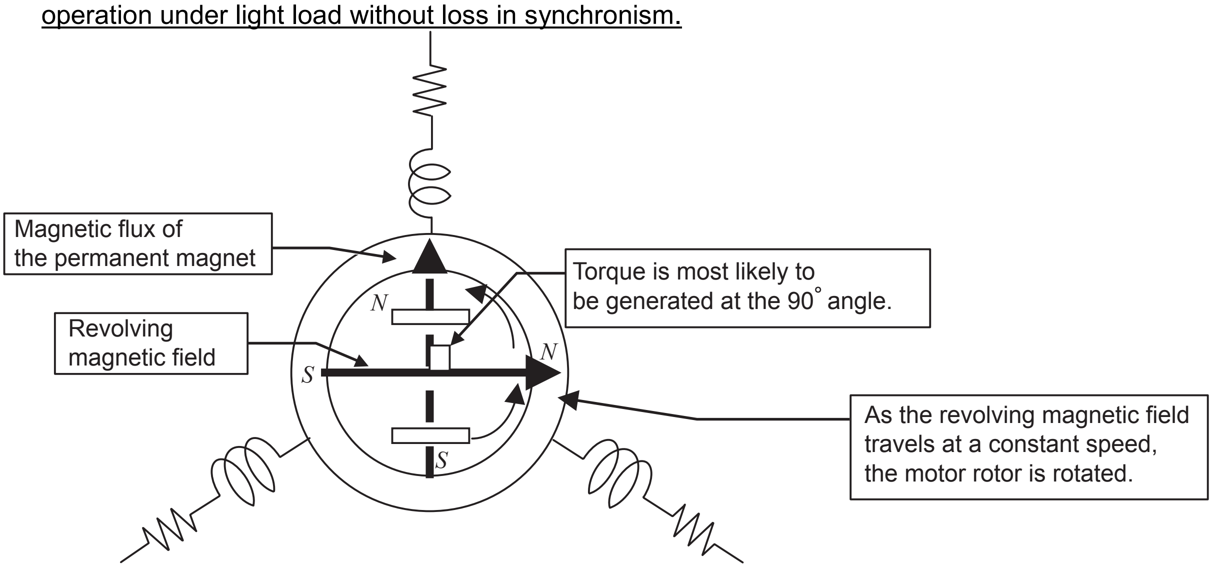


Figure 4.4

In an IPM motor, largest torque is produced when the revolving magnetic field is generated at the 90° angle from the magnetic flux of a rotor magnet. During the current synchronization operation, however, the actual rotation speed of the rotor is not estimated, so the angle between the magnetic flux of the permanent magnets and the revolving magnetic field deviates from 90° when a load is applied as shown in the below diagram. In that condition, torque is less likely to be generated.
From this reason, about 50% of the rated torque is generated in the low-speed operation range with the current synchronization operation.

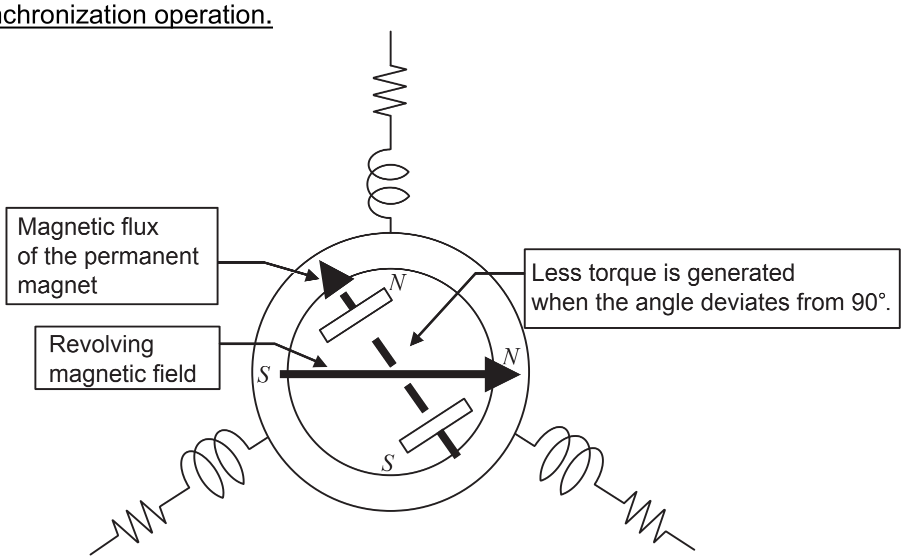


Figure 4.5

CHAPTER 5 DIFFERENCES BETWEEN INDUCTION MOTORS AND IPM MOTORS

There are many differences between an induction motor and an IPM motor due to their rotor structures. This chapter presents those differences.

5.1 Voltage generation during coasting of a motor

An IPM motor coasts when it is driven fast by a device other than the drive unit while no voltage is output from the drive unit, or when drive unit output is shut off while the IPM motor is running. Voltage is generated in the motor while the permanent magnets in the rotor rotate inside the stator coil at such instances. The voltage generated here is called induced voltage of IPM motor.

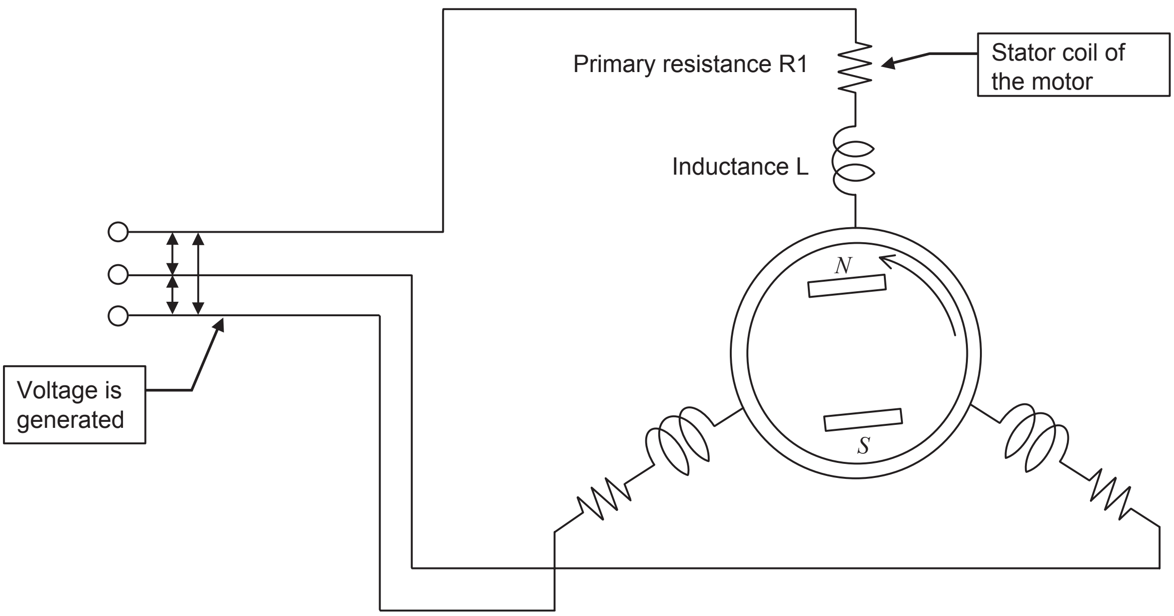


Figure 5.1

Higher induced voltage is generated when the coasting speed of the motor is faster.
On the other hand, voltage is never generated in an induction motor no matter how fast the motor coasts because the rotor does not have magnets.

Note: Do not touch the IPM motor terminals while the motor is coasting.

5.2 Dynamic brake

Voltage is generated when a rotor rotates in an IPM motor as explained in Chapter 5.1. This section explains about the operation when the outputs of an IPM motor are shorted as shown below.
When an external force is applied to rotate a rotor while three phases connected to the motor are shorted, induced voltage is generated in the IPM as explained in Chapter 5.1.
This induced voltage leads a current to flows through the IPM motor, and that flow of current produces a force against the external force trying to rotate the motor in the IPM motor.
As a result, a brake is applied to the motor rotation, and this is called dynamic brake.
In inductions motors, dynamic brake is not available as no induced voltage is generated.

Note: Do not short the IPM motor terminals to apply dynamic brake while the IPM motor is coasting. Doing so causes excessive current to flow into the motor and may damage the motor.

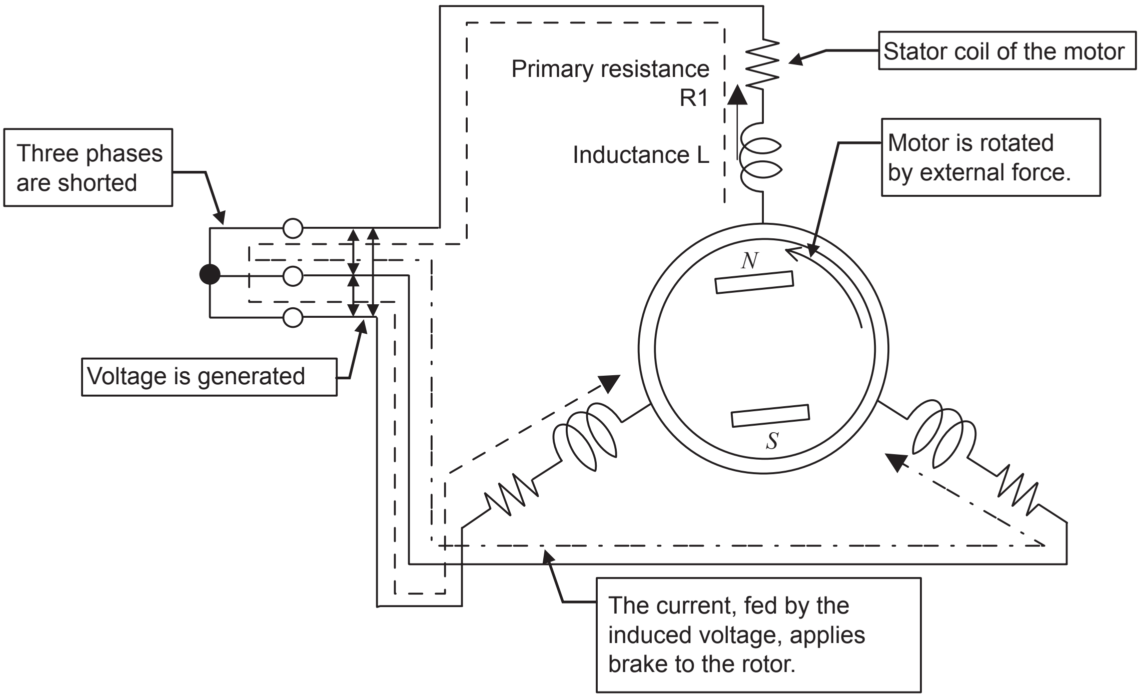


Figure 5.2

5.3 Voltage from the drive unit

As explained in Chapter 5.1, induced voltage is generated in an IPM motor. The diagram below shows the equivalent circuit for an IPM motor.

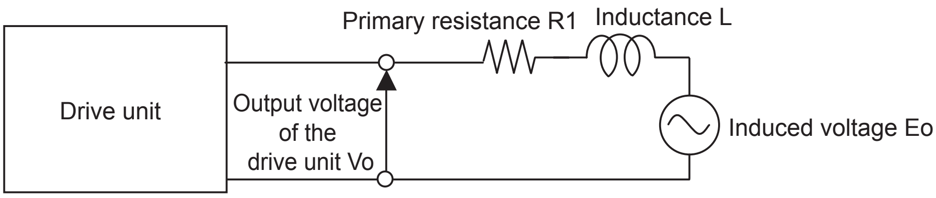


Figure 5.3 Equivalent circuit of an IPM motor

When driving an IPM motor with no load, voltage from the drive unit must be adjusted so that "the output voltage of the drive unit Vo" is equal to "the induced voltage Eo". As explained in Chapter 4, the output voltage of the drive unit is automatically adjusted to be equal to the induced voltage of the IPM motor under vector control. The following figure shows the motor speed and the output voltage of the drive unit when the voltage is adjusted.

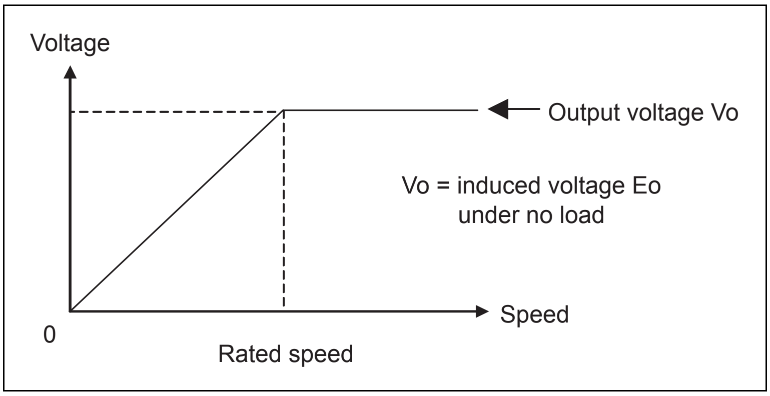


Figure 5.4

Thus, IPM motors have the following characteristics, which are different from induction motors.

1) The following equation is satisfied when no load is applied: "output voltage from the drive unit Vo = induced voltage E0". Thus, electric potential differences between the drive unit and the IPM motor diminish, and the no-load current becomes almost 0A.
2) A voltage must be applied according to the speed to satisfy the equation "output voltage from the drive unit Vo = induced voltage Eo". This means IPM motors cannot be operated with a commercial power supply because it will burn the IPM motor.
3) Applied voltage must be adjusted according to the load. Because of this, only one IPM motor can be driven by each drive unit.
   Driving several IPM motors with one drive unit causes loss in synchronism in IPM motors and a trip in the drive unit.

5.4 Start operation of IPM motors

Start operation of an IPM motor is different from that of an induction motor in the following ways.

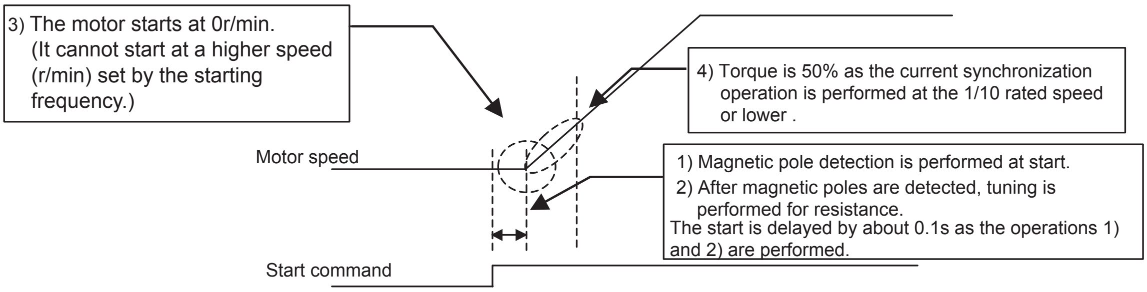


Figure 5.5

1) Magnetic pole positions must be detected accurately prior to the IPM motor operation. To do so, magnetic pole detection must be always performed at start. (Refer to Chapter 4.1.)
2) Motor constants must be identified to formulate a mathematical model of the IPM motor inside the drive unit. For this purpose, tuning must be performed at start for the resistance of the IPM motor including the primary resistance and wiring. (Motor constants include inductance L besides the primary resistance, but only the constants affected by the motor temperature and wiring length are considered as the resistance. Tuning is performed at start only for the resistance.
3) An IPM motor must start running from 0r/min to avoid loss in synchronism. (Unlike for an induction motor under V/f control, an IPM motor cannot start running at a speed other than 0r/min, such as 10r/min.)
4) When an IPM motor runs at low speed (1/10 or slower of the rated speed), current synchronization operation is performed, outputting 50% of the rated motor torque. To use the IPM motor for an application with large inertia, such as a fan, adjust the Pr.791 Acceleration time in low-speed range setting.

5.5 Stop operation of IPM motors

When a general-purpose inverter stops an induction motor, DC brake is applied while the motor is still running. If DC brake is applied in the same manner for an IPM motor, brake torque is generated suddenly, giving a considerable amount of shock to the motor at stop as shown below.

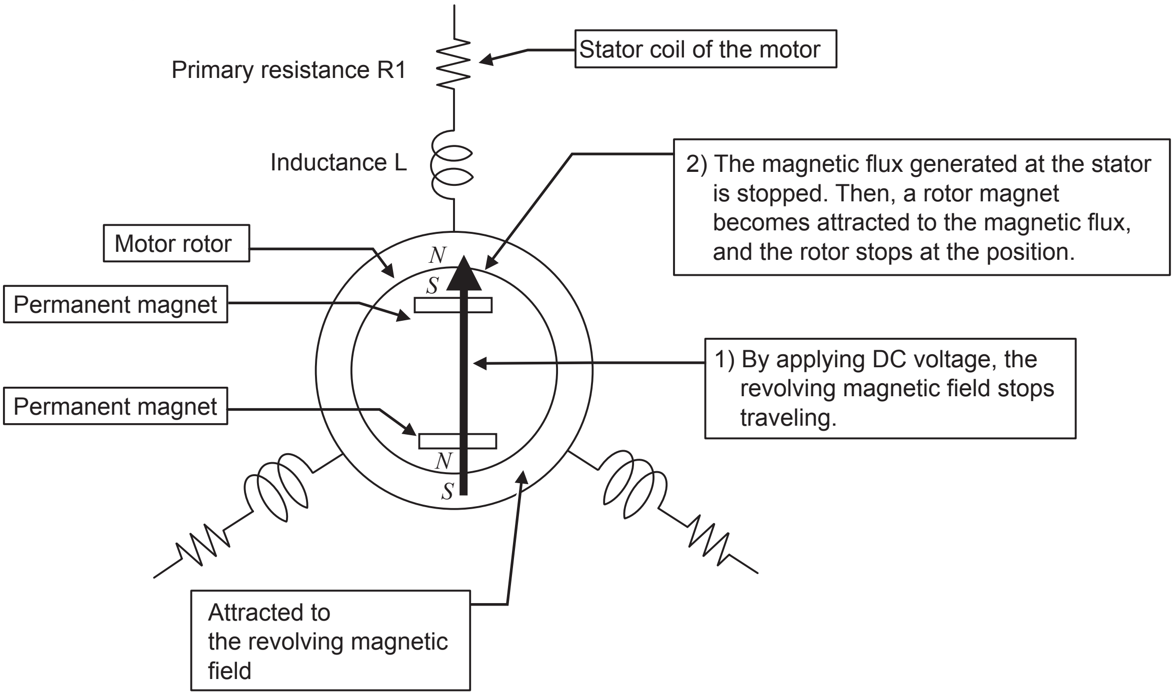


Figure 5.6 Diagram of an IPM motor

For this reason, stop operation for an IPM motor is different from that for an induction motor in the following ways.

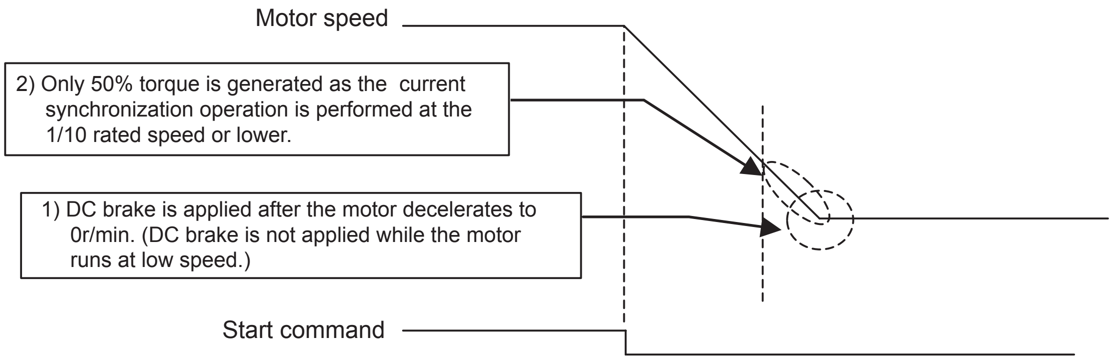


Figure 5.7

1) To lighten the shock at a stop, an IPM motor is decelerated to 0r/min before DC brake is applied. (DC brake is used for the low speed operation in an induction motor under V/f control, but such operation is not available for IPM motors.)
2) When an IPM motor runs at low speed (1/10 or slower of the rated speed), current synchronization operation is performed, outputting only 50% of the rated motor torque. To use the IPM motor for an application with large inertia, such as a fan, adjust the Pr.792 Deceleration time in low-speed range setting.

CHAPTER 6 CHARACTERISTICS

6.1 Motor torque characteristics

The MM-EF series motors are designed to achieve the best efficiency in the applications with the variable-torque characteristic, such as fans and pumps, in order to save energy and to cut CO_2 emission. As shown in Figure 6.1, 100% of the continuous operation torque is assured within the rated speed to meet the variable-torque characteristic, and the variable-torque characteristic is applicable within the speed control range of 10:1. Because fans and pumps do not require large overload tolerance, 120% short-time torque with 180r/min or higher is assured. In the low-speed range of 180r/min or lower, the maximum torque is 50% because the current synchronization operation is performed.

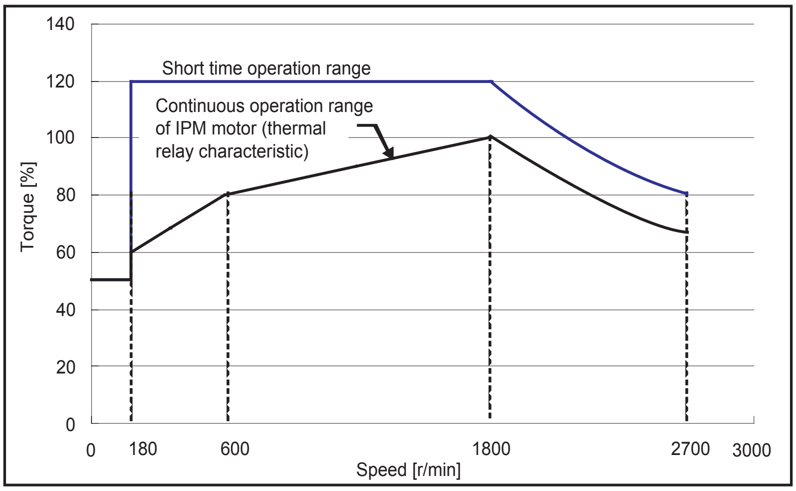
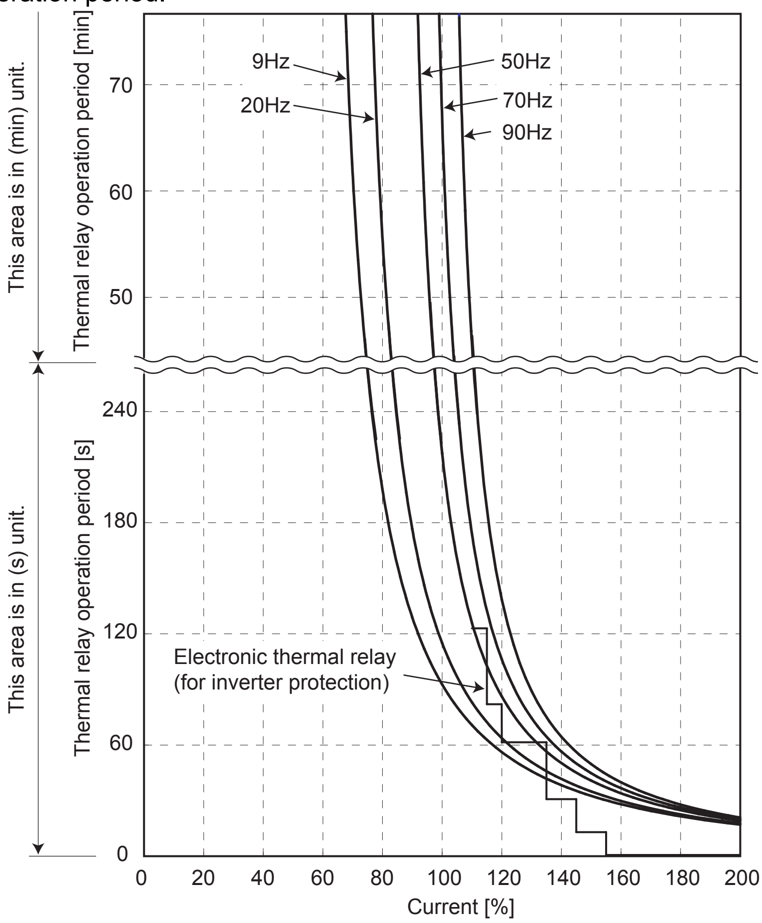


Figure 6.1 Torque characteristics of MM-EF series motors

Figure 6.2 shows operation time characteristics with the motor load factor and the electronic thermal relay operation period.



FR-FP740-3.7K
Carrier frequency: 2kHz

Figure 6.2 Motor load factor and operation time characteristics of the electronic thermal relay

Figure 6.3 shows the measured torque characteristics at different IPM motor speeds. Because an IPM motor is a synchronous motor, a slip does not occur as it does for an induction motor. An IPM motor rotates at the command speed even when the torque increases. The IPM motor outputs the maximum torque of 120% within the speed control range of 10:1.

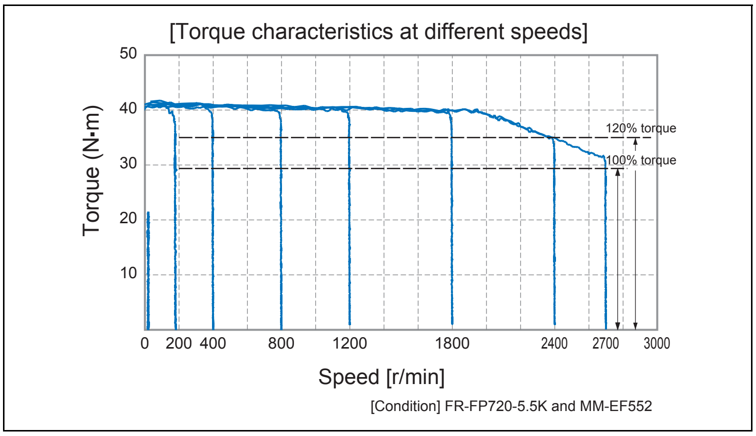


Figure 6.3 Torque characteristics at different speeds

6.2 Braking torque

Because an IPM motor is more efficient than an induction motor, its ability to consume the regenerative power generated at braking is smaller than that of an induction motor. For this reason, the braking torque of an IPM motor is smaller than that of an induction motor, and the average short-time braking torque during deceleration is about 5%. (10% for 1.5kW or less)

Large braking torque can be obtained by adding an external brake unit.

6.3 Frame number, total length, and mass of the motor

Because permanent magnets are used and power loss is minimal in an IPM motor, the motor size can be downsized. Considering the compatibility between an IPM motor and an induction motor, frame numbers of most MM-EF series are smaller by one capacity size than that of induction motors.

As one frame number goes down, the total motor length becomes shorter by 26% at maximum, and the motor mass becomes lighter by 50% at maximum.

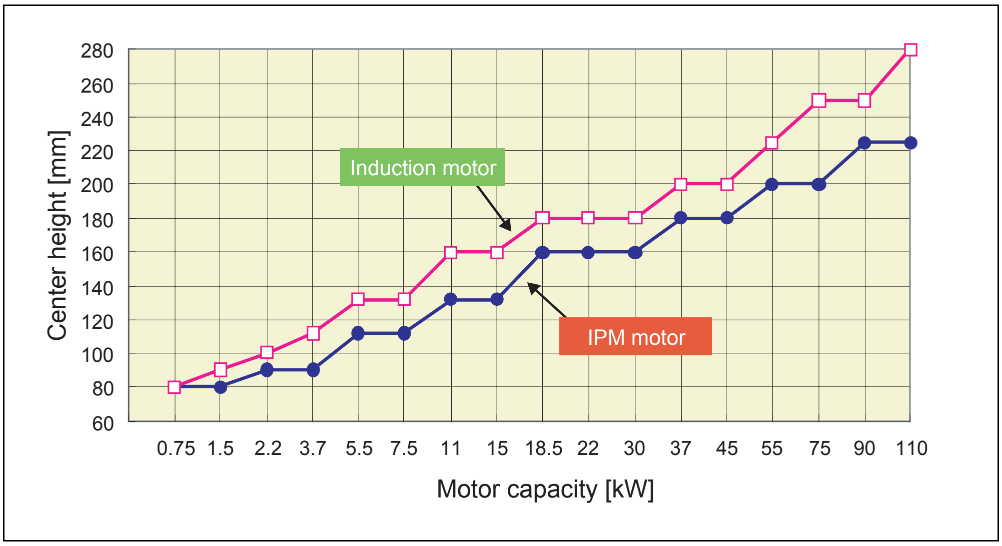


Figure 6.4 Frame numbers of motors

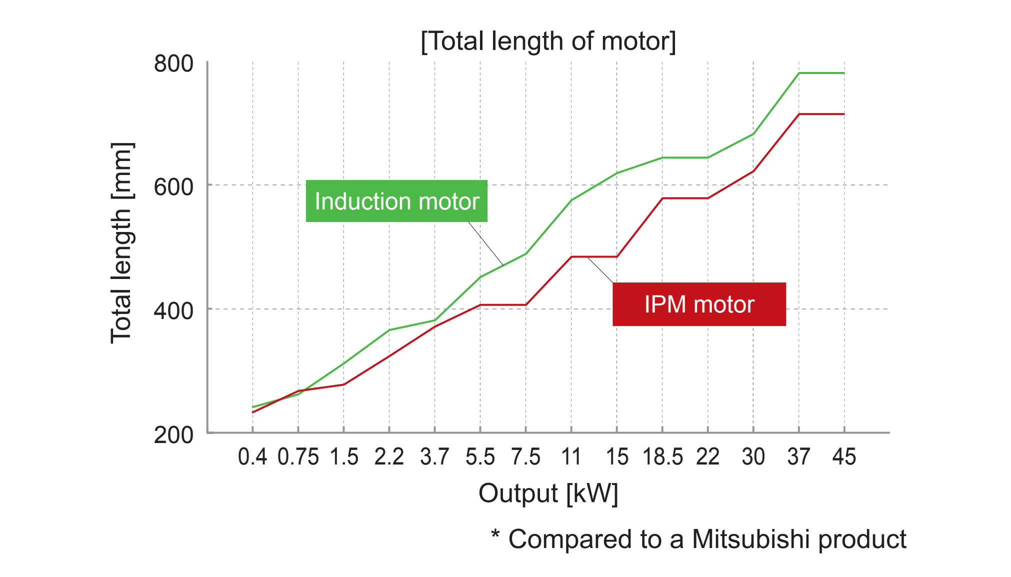


Figure 6.5 Total lengths of motors

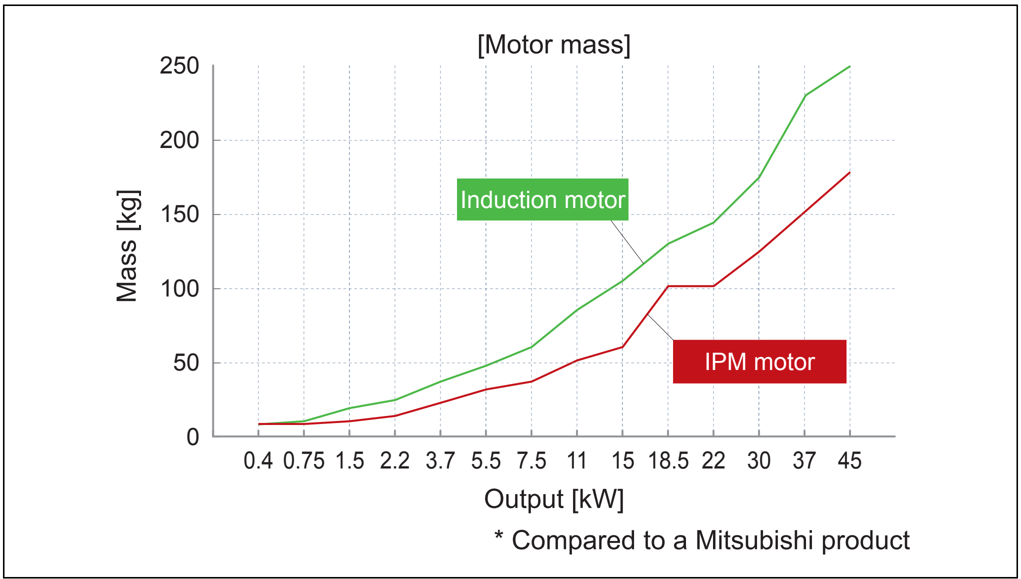


Figure 6.6 Mass of motors

6.4 Grease life

Because an IPM motor has less power loss, the bearing temperature is lower than that of an induction motor. This extends the service life of the grease to about seven years (60,000 hours)*, which is twice as long as the grease life of a Mitsubishi induction motor.

As the replacement interval of the bearing is extended, the operation rate improves, and the maintenance cost is reduced.

* Calculation conditions: Rated load, 1800r/min, surrounding air temperature of 40°C

Note: For the replacement of bearings, contact your nearest Mitsubishi FA Center.

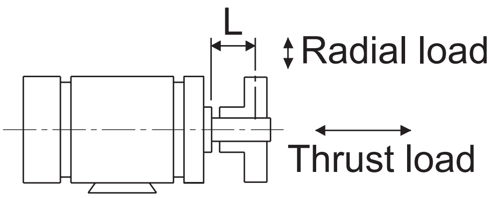
6.5 Permissible load of an axis

The following table shows the permissible radial/thrust load for the MM-EF series.

Table 6.1

Motor model (standard model)	**MM-EF□2(4)**	**4**	**7**	**15**	**22**	**37**	**55**	**75**	**11K**	**15K**	**18K**	**22K**	**30K**	**37K**	**45K**
Motor model (waterproof model)	**MM-EF□2(4)P2**	**4**	**7**	**15**	**22**	**37**	**55**	**75**	**11K**	**15K**	**18K**	**22K**	**30K**	**37K**	**45K**
L[mm] (Note 1)		30	40	50	60		80		110		110			140	
Permissible radial load [N]		392	539	580	830	1070	1710		2150		2940		3230	4900	
Permissible thrust load [N]		294	470	500	690	900	1420		1810		2350		2740	2940	

Note 1. See the following figure for the abbreviation used in the table.



Note 2. The permissible radial load and the permissible thrust load are the permissible values when they are applied individually.

* Precautions for installation of a motor

(1) Use a flexible coupling to keep the misalignment of the shaft center within the permissible radial load value.

(2) When using a pulley, sprocket or timing belt, select it by keeping its radial load value within the permissible radial load value.

(3) Do not use a rigid coupling because it applies excessive bending force to the shaft and may break the shaft.

6.6 IPM motor characteristics (efficiency and loss)

The following table shows IPM motor characteristics at the rated speed (1800r/min) with the rated load torque.

Table 6.2

	Capacity (kW)	Motor model	Drive unit	Efficiency		Loss		
				Motor efficiency (%)	Total efficiency (%)	Motor loss (W)	Inverter loss (W)	Total loss (W)
200V	0.4	MM-EF42	FR-FP520J-0.4K	88.4	84.6	52	21	73
	0.75	MM-EF72	FR-FP520J-0.75K	87.0	84.9	112	21	133
	1.5	MM-EF152	FR-FP520J-1.5K	90.6	88.2	156	45	201
	2.2	MM-EF222	FR-FP520J-2.2K	90.6	88.3	228	64	292
	3.7	MM-EF372	FR-FP520J-3.7K	91.2	89.3	357	86	443
	5.5	MM-EF552	FR-FP520J-5.5K	92.1	90.5	472	105	577
	7.5	MM-EF752	FR-FP520J-7.5K	93.3	90.8	539	221	760
	11	MM-EF11K2	FR-FP520J-11K	93.0	90.0	828	394	1222
	15	MM-EF15K2	FR-FP520J-15K	94.1	91.1	940	525	1465
	18.5	MM-EF18K2	FR-FP720-18.5K	93.5	90.4	1286	679	1965
	22	MM-EF22K2	FR-FP720-22K	93.3	90.3	1580	783	2363
	30	MM-EF30K2	FR-FP720-30K	94.7	91.4	1679	1144	2823
	37	MM-EF37K2	FR-FP720-37K	95.0	92.0	1947	1270	3217
	45	MM-EF45K2	FR-FP720-45K	95.7	92.5	2022	1627	3649
400V	0.4	MM-EF424	FR-FP540J-0.4K	88.4	84.9	52	19	71
	0.75	MM-EF724	FR-FP540J-0.75K	86.7	85.1	115	16	131
	1.5	MM-EF1524	FR-FP540J-1.5K	90.4	88.0	159	46	205
	2.2	MM-EF2224	FR-FP540J-2.2K	90.9	88.9	220	55	275
	3.7	MM-EF3724	FR-FP540J-3.7K	91.4	89.6	348	81	429
	5.5	MM-EF5524	FR-FP540J-5.5K	93.3	91.3	395	129	524
	7.5	MM-EF7524	FR-FP540J-7.5K	94.0	92.0	479	173	652
	11	MM-EF11K24	FR-FP540J-11K	93.6	91.7	752	244	996
	15	MM-EF15K24	FR-FP540J-15K	94.0	92.0	957	347	1304
	18.5	MM-EF18K24	FR-FP740-18.5K	93.7	92.4	1244	278	1522
	22	MM-EF22K24	FR-FP740-22K	93.7	91.8	1479	486	1965
	30	MM-EF30K24	FR-FP740-30K	94.0	92.3	1915	588	2503
	37	MM-EF37K24	FR-FP740-37K	95.1	92.9	1906	922	2828
	45	MM-EF45K24	FR-FP740-45K	95.6	93.1	2071	1264	3335

Measurement condition (drive unit carrier frequency of 2kHz)

CHAPTER 7 ENERGY SAVING EFFECT, CO_2 EMISSION CALCULATION METHOD, AND LIFE CYCLE COST

7.1 Energy saving effect (power loss comparison)

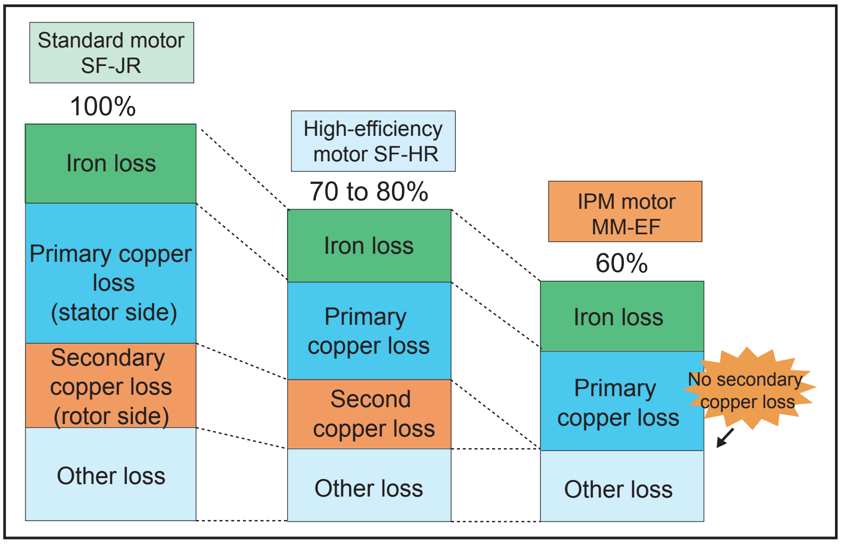


Figure 7.1 Comparison of power loss at motors (example of 22kW motors)

Compared to a standard motor (SF-JR), the winding method and slot shape of a high-efficiency motor (SF-HR) are highly optimized. As a result, primary and secondary copper losses are reduced, and iron loss is also reduced by employing the low-loss magnetic steel sheet. Therefore, a fan could be downsized with that amount of power loss, which also contributes to the reduction of loss in the fan. In total, a 22kW high-efficiency motor has 20% to 30% lower power loss than that of a 22kW standard motor.

Because no current flows to the rotor in an IPM motor compared to a high-efficiency motor, no secondary copper loss occurs at the rotor side. For this reason, an IPM motor is more efficient than a high-efficiency motor. Power loss in a 22kW IPM motor is 40% lower than that of a 22kW standard motor, and the energy from that power loss can be saved.

Figure 7.2 shows the total efficiency of standard, high-efficiency and IPM motors in different capacities when they are driven by inverters. (IPM motors are driven by dedicated drive units.)
The order of total efficiency of the motors can be indicated as: Standard motor < High-efficiency motor < IPM motor. Efficiency differences among the motors are more significant when their capacities are small. For example, a 3.7kW IPM motor is about 10% more efficient than a 3.7kW standard motor, and about 7% more efficient than a 3.7 high-efficiency motor.

Note): Total efficiency

Total efficiency (%) = Output / (Output + Inverter loss + Motor loss) ×100

The total efficiency is expressed by the formula above and shows how efficiently the electricity is converted to power. Total efficiency is better when less power is lost in the inverter and the motor.

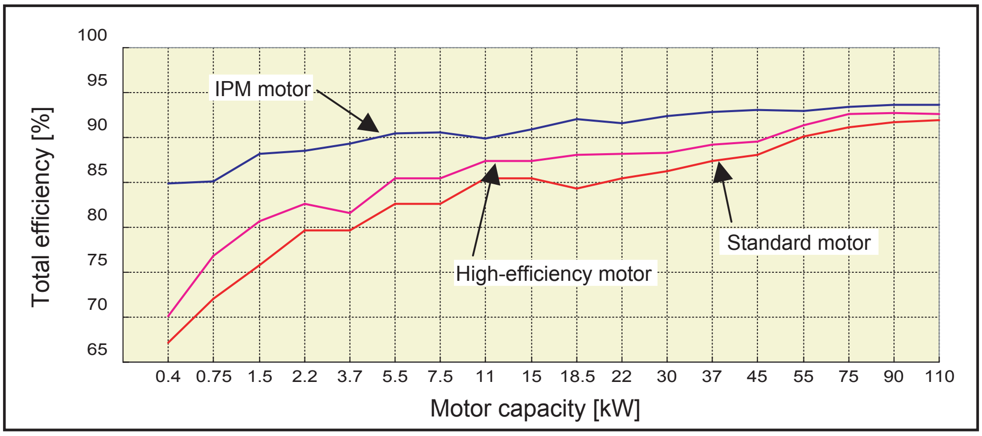


Figure 7.2 Comparison of total efficiency

Figure 7.3 shows the total loss (inverter loss + motor loss) in standard, high-efficiency, and IPM motors in different capacities when they are driven by inverters. (IPM motors are driven by dedicated drive units.) Power loss of a 3.7kW IPM motor is 0.37kW lower than that of a 3.7kW standard motor, and 0.26kW lower than that of a 3.7kW high-efficiency motor. Additionally, power loss of a 110kW IPM motor is 1.65kW lower than that of a 110kW standard motor, and 1.1kW lower than that of a 110kW high-efficiency motor. Thus, energy saving effect is notable. Figure 7.2 shows less significant total efficiency differences among the high-capacity motors. However, Figure 7.3 shows that a large amount of power is still saved in a high-capacity IPM motor.

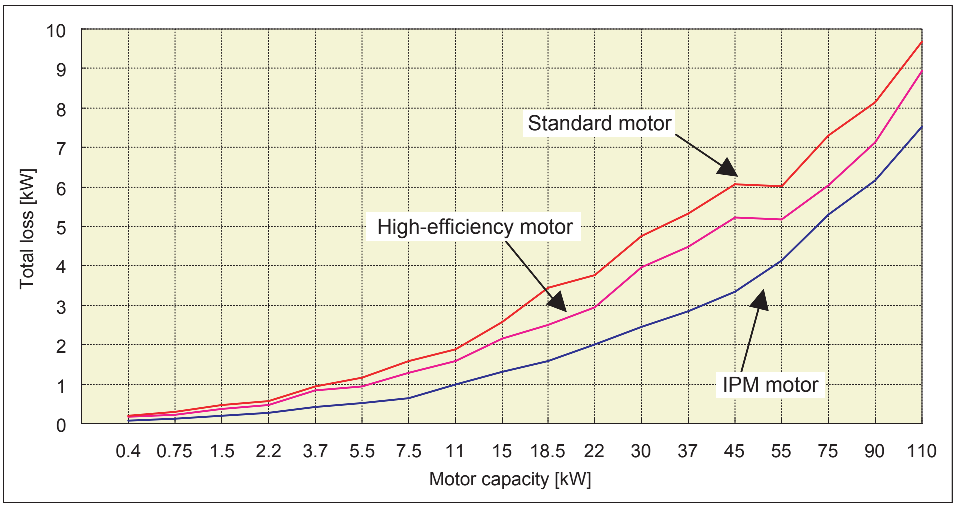


Figure 7.3 Comparison of total losses

When an induction motor is driven by an inverter with the speed control method, the total power loss usually becomes higher for the amount of the inverter loss than the power loss in the same speed operation with the commercial power supply. However, when a small or medium size IPM motor is driven by a drive unit, the total power loss (IPM motor loss + drive unit loss) is less than the power loss at the same speed operation of a standard motor with the commercial power supply. For small capacities, power loss is less when an IPM motor is driven by the drive unit compared to when a high-efficiency motor is driven by the commercial power supply. Replacing a motor with an IPM motor saves energy in the capacities where the total loss of the IPM motor and the drive unit are less than the total loss of the standard/high-efficiency motor driven by the commercial power supply, without performing variable-speed operation.

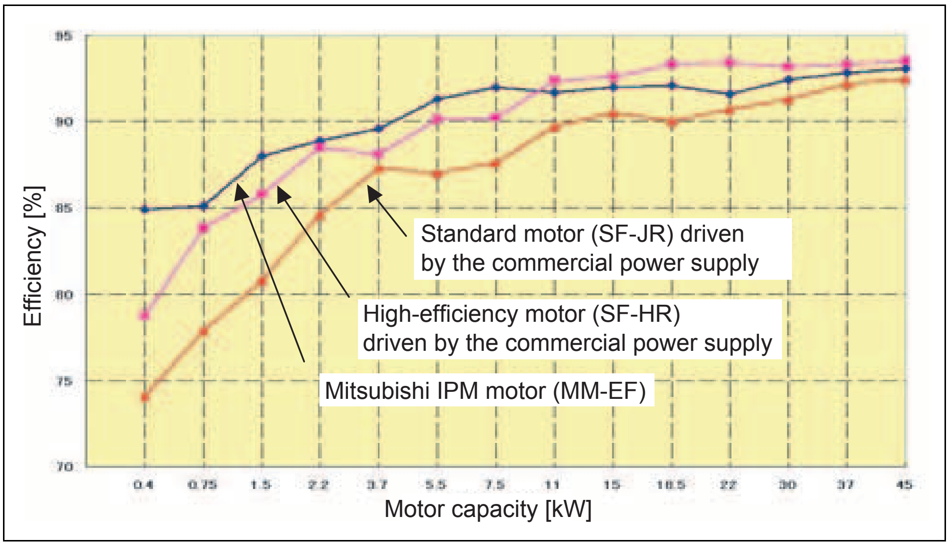


Figure 7.4 Comparison with a standard motor (SF-JR) driven by the commercial power supply

*Efficiency: Total efficiency of the IPM motor efficiency and the inverter efficiency at the rated speed and with the rated load.
For a standard/high-efficiency motor, it is the efficiency during the commercial power supply operation (220V and 60Hz).

7.2 CO_2 emission calculation method

To convert the power consumption to the amount of CO_2 emission, use the following formula and the CO_2 emission factor.

$$\text{Amount of } CO_2 \text{ emission [ton]} = \text{Consumed power [kWh]} \times CO_2 \text{ emission factor}$$

For the CO_2 emission factor, the default value of "0.000555t - CO_2/kWh" is usually used. This default value is specified by the ministerial ordinance (2006, the Ministry of Economy, Trade and Industry and the Ministry of the Environment in Japan) as the CO_2 emission factor to calculate the greenhouse gas emissions associated with business activities by specified emission generators.
Instead of the default value, the emission factors specific to general electricity businesses and specified-scale electricity businesses (abbreviated as "emission factor by the electricity business" hereafter) can be also used. The emission factor by the electricity business is published by the government after the Ministry of Economy, Trade and Industry and the Ministry of the Environment confirms the value is lower than the default value. The following table shows the emission factors based on the actual emissions in the 2007 fiscal year, which are reported by the electricity businesses (posted in the official report in December 19, 2008) By using the emission factor of the contracted electricity business, more accurate CO_2 emission amount can be calculated.

Figure 7.1

Electric Power Supplier	**Emission coefficient (t-CO_2/kWh)**
Hokkaido Electric Power Co., Inc.	0.000517
Tohoku Electric Power Co., Inc.	0.000473
Tokyo Electric Power Co., Inc.	0.000425
Chubu Electric Power Co., Inc.	0.000470
Kansai Electric Power Co., Inc.	0.000366
Shikoku Electric Power Co., Inc.	0.000392
Kyushu Electric Power Co., Inc.	0.000387

7.3 Life cycle cost calculation

Life cycle cost means the total cost incurred in one life cycle of a product from the purchase and installation to the disposal. The price of most IPM motors is higher than induction motors as they employ powerful magnets, so their initial costs are more expensive. However, the power cost and maintenance cost of an IPM motor is less expensive than that of an induction motor. This makes the total cost of an IPM motor less expensive than that of an induction motor. The following diagram shows the details of life cycle costs of an induction motor driven by a general-purpose inverter and an IPM motor driven by a dedicated drive unit.

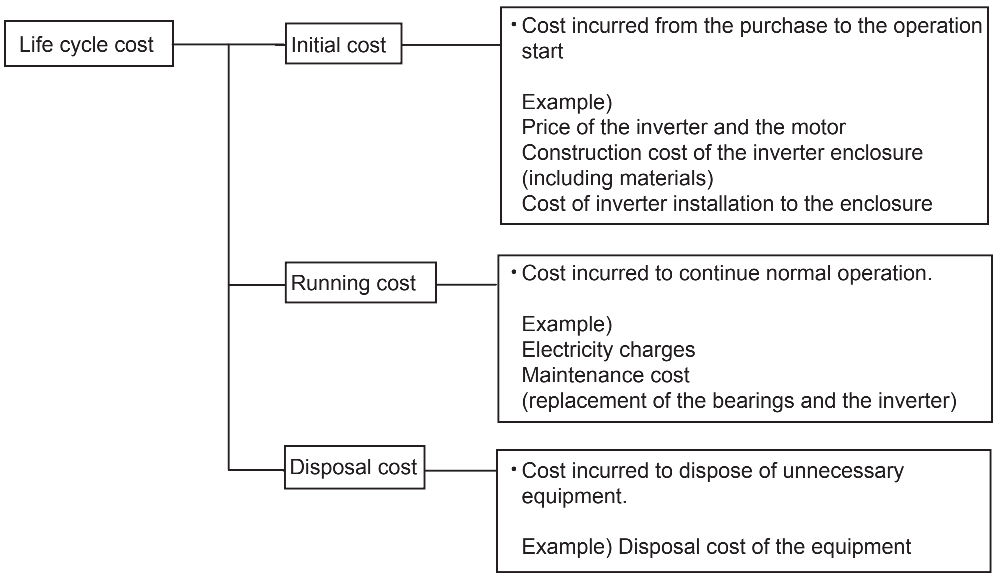


Figure 7.5 Life cycle cost

- Initial cost — Cost of developing a machine design, purchasing of devices such as a fan and motor, construction of an enclosure, installation of the machine, and the start-up.
- Running cost — Cost incurred during the operation of the equipment. This includes costs of power consumption and maintenance cost to continue normal operation.
- Disposal cost — Cost to dispose of unnecessary equipment. Some of unnecessary items may be sold.

●Example of life cycle cost calculation

The table below shows incurred life cycle costs (LCC) in the following operation methods when a fan in an air conditioner is operated: when a standard motor is driven under damper control with the commercial power supply, when a standard motor is driven by a general-purpose inverter, and when an IPM motor is driven by the dedicated drive unit.

Conditions

Motor capacity: 15kW

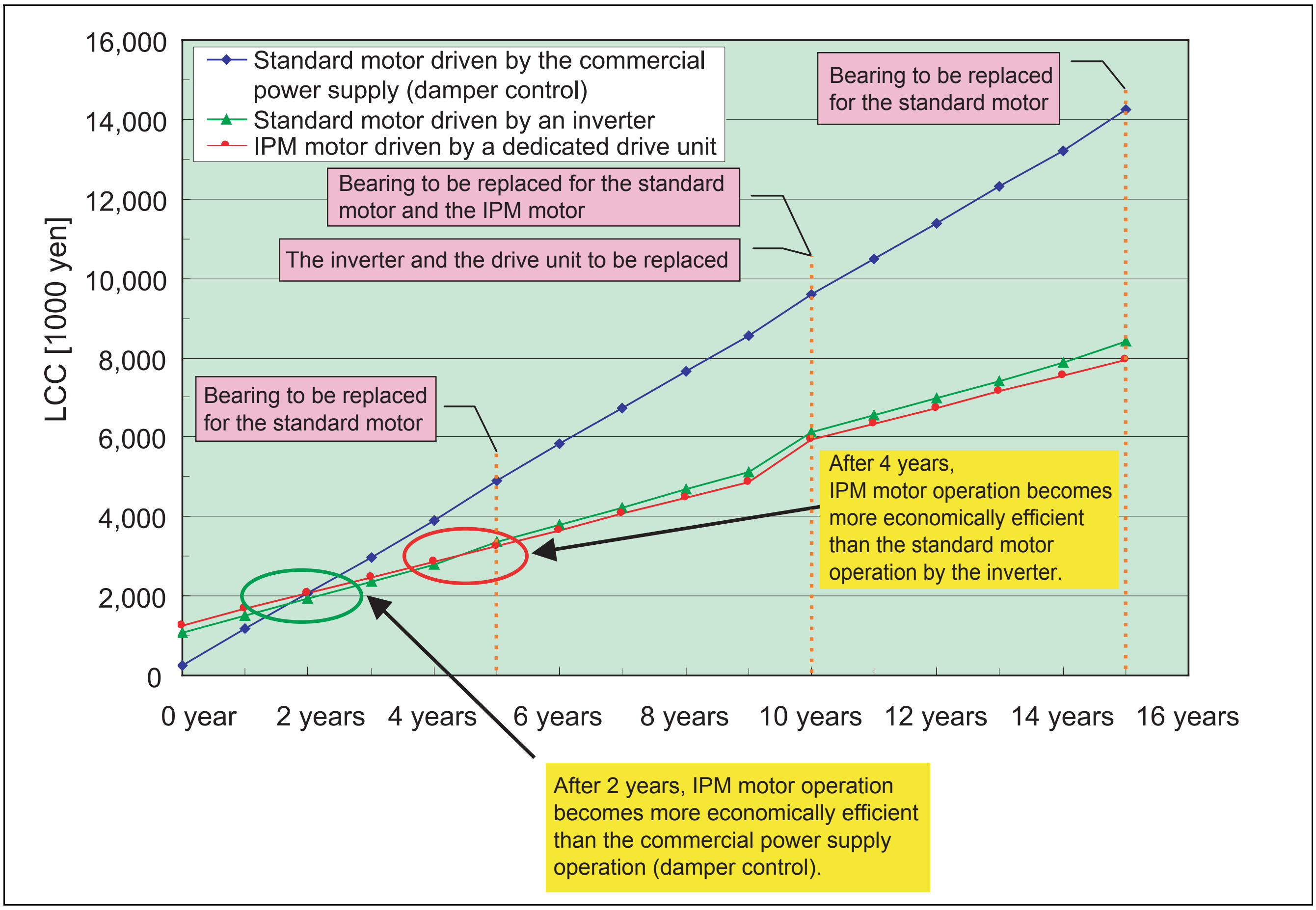
Operation time: 16 hours/day × 250 days/year = 4000 hours/year

Power cost: 14 yen/kWh

CO_2 emission factor: 0.000555t - CO_2/kWh

Table 7.2

	Standard motor driven by the commercial power supply (damper control)	Standard motor driven by an inverter	IPM motor driven by a drive unit	Remarks
Motor capacity	15kW			The initial cost of the damper control is the standard price of a standard motor. The initial costs of a standard motor driven by an inverter and an IPM motor driven by a drive unit include the standard price of the inverter and the motor, and the installation cost ((motor + inverter) × 0.5).
Inverter model	None	FR-F720-15K	FR-FP720-15K	
Initial cost	¥265,200	¥1,056,300	¥1,267,500	
Air volume %	75 %	75 %	75 %	
Consumed power per year (kWh)	64,800 kWh	31,233 kWh	28,582 kWh	
Power cost per year	¥907,200	¥437,262	¥400,148	¥14/kWh
Bearing replacing cost	¥120,000	¥120,000	¥150,000	The cost changes according to the circumstances.
Bearing replacing interval	5 years	5 years	10 years	
Inverter replacing interval		10 years	10 years	
Power cost difference with IPM	¥507,052	¥37,144		
CO_2 emission reduction difference with IPM (ton)	20.10 ton	1.47 ton		Effect of applying an IPM per year (1,000kWh ≒ 0.555ton-CO_2)
LCC (1,000 yen)	14,233	8,414	7,947	LCC for 15 years



16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
LCC [1000 yen]
Standard motor driven by the commercial power supply (damper control)
Standard motor driven by an inverter
IPM motor driven by a dedicated drive unit
Bearing to be replaced for the standard motor
Bearing to be replaced for the standard motor and the IPM motor
The inverter and the drive unit to be replaced
Bearing to be replaced for the standard motor
After 4 years, IPM motor operation becomes more economically efficient than the standard motor operation by the inverter.
0 year
2 years
4 years
6 years
8 years
10 years
12 years
14 years
16 years
After 2 years, IPM motor operation becomes more economically efficient than the commercial power supply operation (damper control).

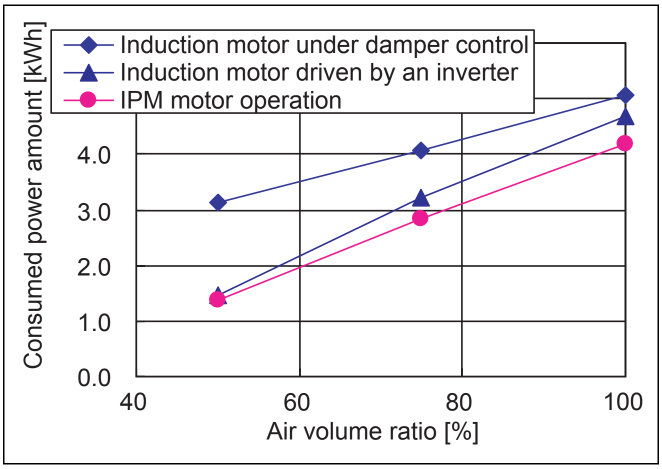
Figure 7.6

CHAPTER 8 ACTUAL DATA

This chapter presents actual measured data of an IPM motor to support logical explanations given in the previous chapters.

8.1 Consumed power amount

With the cooperation of a user, load factors of a fan in an air conditioner were measured in a commercial building in Tokyo. IPM motor operation exhibits significant energy savings compared to the induction motor operation with the commercial power supply (damper control). Consumed power of the IPM motor operation is equivalent or lower than that of the induction motor operation with an inverter.



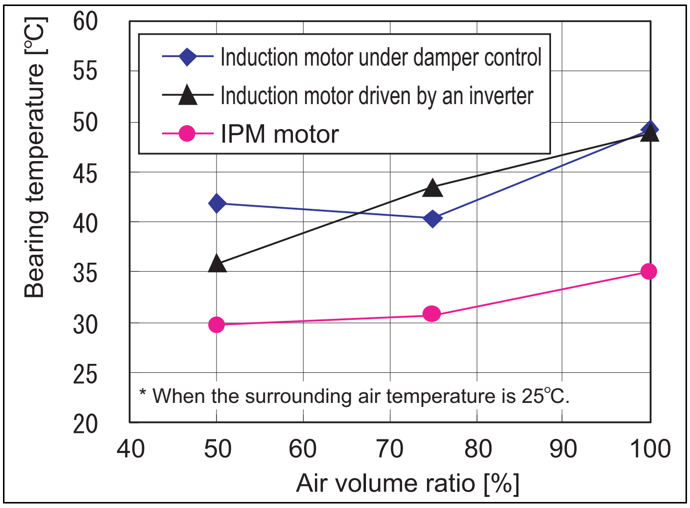
* Inverter : FR-F520J-5.5K
Induction motor : SF-JR 4P 5.5K
Drive unit : FR-FP520J-5.5K
IPM motor : MM-EF552

Figure 8.1 Comparison of input power to an air conditioner

8.2 Bearing temperature of the motors

When the consumed power at Chapter 8.1 was measured, the bearing temperature of the motors were also measured. It is clear that the bearing temperature of the IPM motor is lower than that of the induction motor by 10 to 15°C under the same load.

In general, the service life of electronic components becomes twice as long when the temperature drops by 10°C. This measurement result indicates that the grease life of the bearing in an IPM motor is longer than that of an induction motor.



* Inverter : FR-F520J-5.5K
Induction motor : SF-JR 4P 5.5K
Drive unit : FR-FP520J-5.5K
IPM motor : MM-EF552

Figure 8.2 Comparison of bearing temperatures

8.3 Acceleration characteristics

The following data, which was measured in a Mitsubishi laboratory, shows the acceleration characteristic of an IPM motor. Even when a sudden acceleration is commanded, the motor accelerates smoothly with the high-speed stall prevention function. Note that it takes about 0.1s to detect the magnetic pole positions at start.

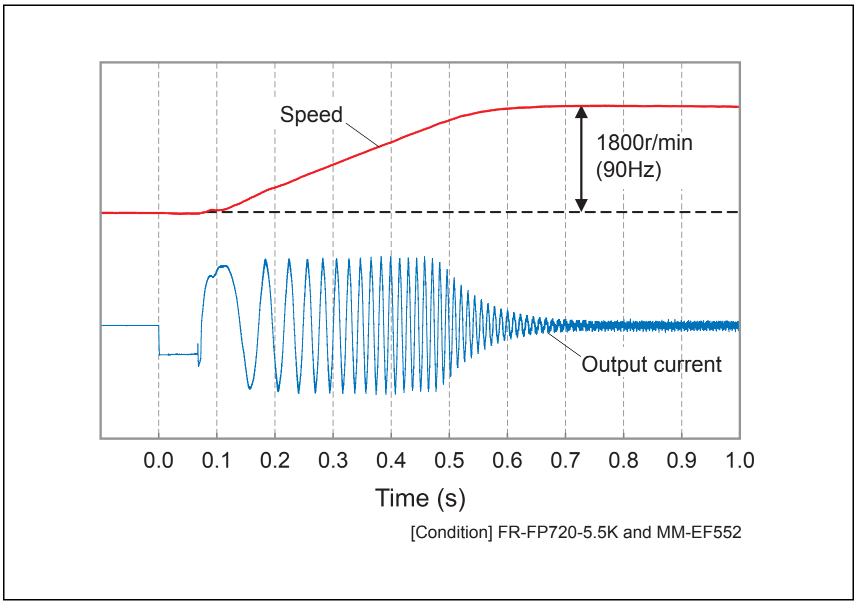


Figure 8.3 Acceleration characteristics

8.4 Impact load characteristics

When a 100% impact load is applied, the speed fluctuates temporarily, but the IPM motor runs smoothly without having loss in synchronism.

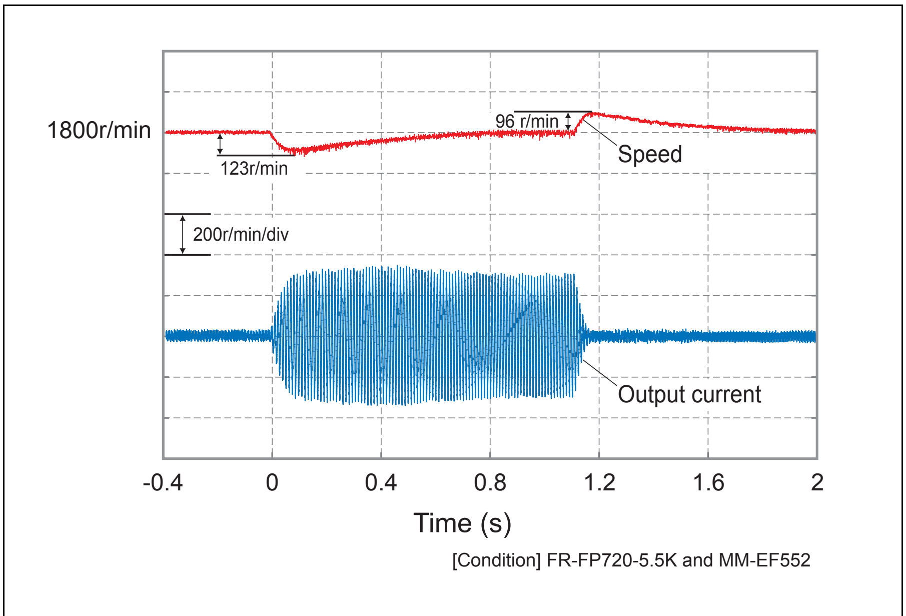


Figure 8.4 Impact load characteristics

8.5 Restart after an instantaneous power failure

For equipment like an air conditioner, an inverter is required to drive the motor continuously even at power restoration after a power failure. This function is called the automatic restart after instantaneous power failure function.

Magnetic pole positions in the motor rotor must be detected accurately in an IPM motor, so a sensorless IPM drive unit performs the magnetic pole detection at start of motor running. When a motor coasts at restart after an instantaneous power failure, its running speed, running direction, and magnetic pole positions during coasting must be separately detected.

These factors are identified by the following mechanism. First, the circuit of a drive unit is controlled to supply a power instantaneously when an IPM motor restarts from coasting. From the motor power at this timing, the drive unit detects coasting status of the motor. This mechanism is applied to the coasting status detection function of the FR-FP series to provide smooth restart at power restoration after a power failure.

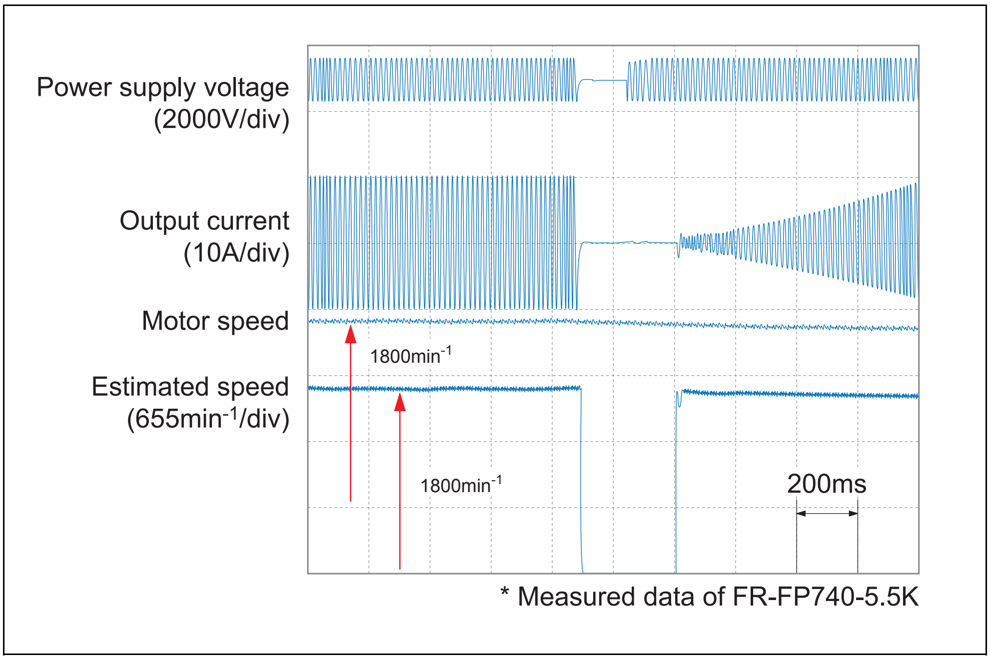


Figure 8.5 Automatic restart after instantaneous power failure function

CHAPTER 9 TECHNICAL LIMITATIONS

9.1 Commercial power supply operation

As explained in Chapter 4, an IPM motor requires a voltage input to generate the revolving magnetic field at the stator according to the magnetic pole positions of the rotor. During the commercial power supply operation, an IPM motor cannot be driven by the commercial power supply because the revolving magnetic field is generated without consideration of the magnetic pole positions in the rotor.
For the equipment that needs to be operated continuously at a drive unit failure, duplicate the drive unit to continue the motor operation.
By duplicating drive units, operation can be performed alternately between the main drive unit and the spare drive unit. This provides advantages such as omission of replacement time to another drive unit and availability of operation check using the duplicated unit.

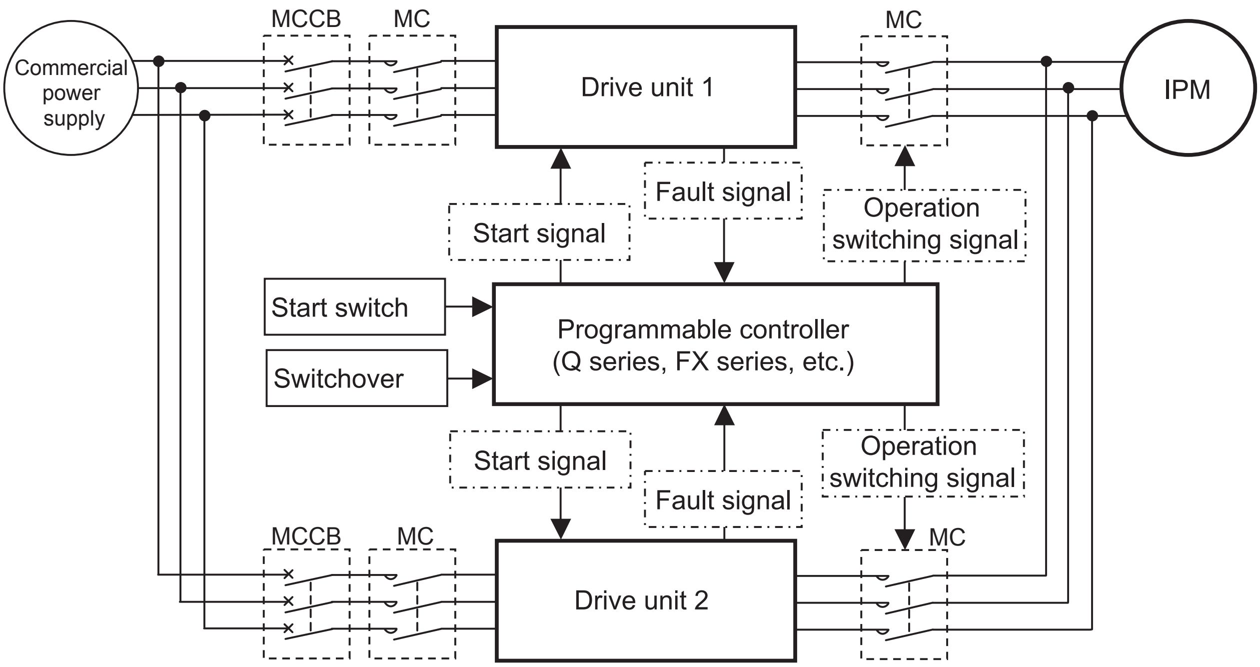


Figure 9.1

9.2 High-speed operation

Induced voltage is generated in proportion to the speed in an IPM motor. High-speed operation must be limited at the rated speed or higher so that the voltage induced during coasting does not exceed the permissible voltage of the conductor elements, which are used in the drive unit. Because of this, the operatable high-speed range, which is the rated speed or higher, may be narrower than that of an induction motor.
To use an IPM motor for high-speed operation, appropriate motor specifications must be selected to generate the rated torque at high speed.

9.3 Multiple operation

Because a drive unit needs to detect the magnetic pole positions of the IPM motor and to control the voltage according to the load, one drive unit can drive only one IPM motor.

9.4 Starting delay

In an IPM motor, initial magnetic pole position detection must be performed at start. When a start signal is input to the drive unit, the actual running start of the motor is delayed for the time of the initial magnetic pole detection (about 0.1s with the FR-FP series). Because of this, an IPM motor is not appropriate for the applications that start/stop frequently in a short period of time.

CHAPTER 10 APPLICATION EXAMPLE

10.1 Appropriate applications for the FR-FP series

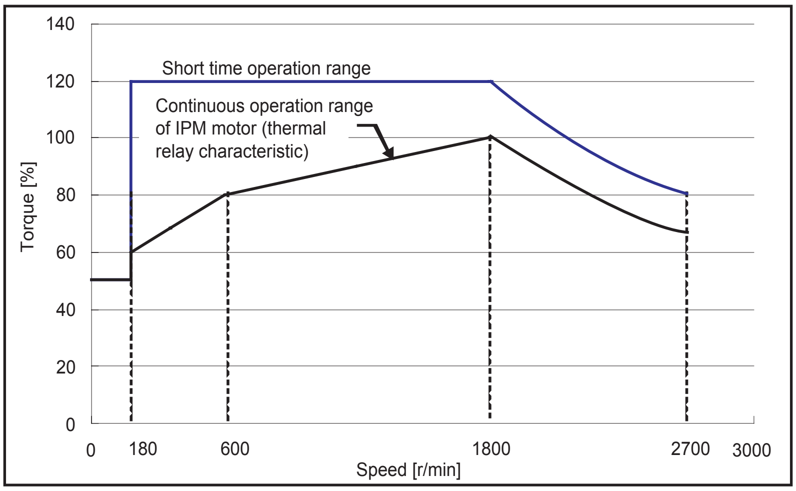
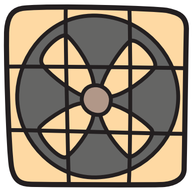
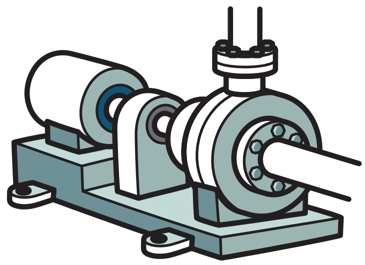


Figure 10.1 Torque characteristics of the MM-EF series motors



(Example: Air conditioning fan)



(Example: Pump)

●Air conditioner / pump

Advantages:

(1) With the efficient operation of an IPM motor, more energy is saved than the induction motor operation by the inverter.

(2) Size and weight of the air conditioner are reduced by employing the smaller and lighter motor.

(3) Maintenance cost is reduced by employing the longer-lasting motor

Precautions:

(1) An IPM motor always needs a dedicated drive unit. The backup operation with the commercial power supply is not available. (Duplicate the drive unit instead. (Refer to Chapter 9.))

(2) Choose the motor with appropriate speed according to the specifications of the application. (Unlike an induction motor, an IPM motor cannot be used for both 50Hz and 60Hz.)

(3) To replace an induction motor with an IPM motor, use the same height of the IPM motor. (Contact your sales representative for the replacement attachments for the MM-EF series motors.)

(4) An IPM motor cannot be used for a pump that requires high starting torque.

●Conveyor

Advantages:

(1) Because an IPM motor is a synchronous motor, it runs at the set speed without slip.

(2) Equipment size can be reduced by employing the smaller and lighter motor.

(3) Because of its high efficiency, more energy is saved than the operation with an induction motor

Precautions:

(1) An IPM motor cannot be used for a conveyor that requires high starting torque.

10.2 Inappropriate applications for an IPM motor

- Lift: Because high torque is required in the low-speed range.
- Positioning: A position cannot be detected because an IPM motor does not have an encoder.

CHAPTER 11 Q&A

No.	Question (Q)	Answer (A)
1	About IPM motor	
1-1	What is an IPM motor?	IPM is short for “Interior Permanent Magnet”.
1-2	What are the differences between an IPM motor and a servo motor (=SPM motor)?	In a servo motor, magnets are attached on the surface of the motor rotor. In an IPM motor, magnets are embedded inside the rotor. Reluctance torque can be efficiently used in an IPM motor. Additionally, Mitsubishi IPM motors are operatable without encoders.
1-3	Is it possible to drive an IPM motor with the commercial power supply?	Do not drive an IPM motor with the commercial power supply. Doing so will damage the IPM motor. For an application, which needs to be switched to the commercial power supply, use an induction motor and a general-purpose inverter.
1-4	What are the precautions when switching from the commercial power supply operation?	When switching from the commercial power supply operation, take caution for the starting torque.
1-5	What are the precautions when switching from the inverter operation?	The motor also needs to be switched.
1-6	What happens if an IPM motor is connected to a general-purpose inverter by mistake?	Because a general-purpose inverter does not detect the magnetic pole positions, a loss of synchronism may occur and cause overload shutoff. Make sure to use an IPM motor with the dedicated FR-FP series drive unit.
1-7	Is it possible to use a one-rank-higher drive unit than an IPM motor capacity?	It is not possible. Use a motor and a drive unit of the same capacity. Failure to do so may cause a loss of synchronism and overload shutoff.
1-8	Is it possible for one drive unit to operate two or more IPM motors?	It is not possible. The ratio must be "Drive unit: IPM motor = 1: 1". (If used otherwise, correct magnetic pole positions cannot be detected.)
1-9	How are the effect of noise, leakage current and power supply harmonics compared to an inverter? Any countermeasures? How is a drive unit treated for the harmonic suppression guideline issued by the Japanese government?	Same as for the general-purpose inverter.
1-10	How different are the vibration and noise of an IPM motor compared to that of an induction motor (IM)?	Almost the same.
1-11	Does the rotation by external force generate voltage?	Even at power-OFF, rotating an IPM motor by external force generates voltage at output terminals. Be careful of an electric shock.
1-12	Why is the motor, which has been just purchased and taken out from the package, too heavy to be rotated by hand?	Check if the power supply lead cables, which are located inside the terminal block, are shorted. After the three lead cables are opened, the motor rotates smoothly. However, do not touch the shaft when the motor is directly connected to a machine or a drive unit. Do not touch the key groove of the shaft with bare hands. Doing so will cause an injury and an electric shock.
2	Features of the FR-FP (MM-EF) series	
2-1	For what applications can the FR-FP (MM-EF) series be used?	For the energy saving applications of fans or pumps, etc.

No.	Question (Q)	Answer (A)
2-2	What are the key differences between the MELIPM series and the FR-FP (MM-EF) series?	The MELIPM series are for the applications with constant-torque load and high-speed operation. The FR-FP (MM-EF) series are for an application with variable-torque load.
2-3	What features does the FR-FP series (IPM motor) have?	The FR-FP series is highly efficient, small, and light (compared to an induction motor). In addition, it can be driven without a sensor and has the automatic restart after instantaneous power failure function.
2-4	How much energy (%, and W) is saved compared to the optimum excitation control of a standard/high-efficiency motor?	One example is a 3.7kW IPM motor which is about 10% more efficient than the standard motor, and about 7% more efficient than the high-efficiency motor. When an IPM motor is driven at 100% load, about 200W is saved.
3	Functions and characteristics of the FR-FP series	
3-1	How slow can the FR-FP series motors run?	Down to 180r/min
3-2	Is it possible for the FR-FP series to perform regenerative operation?	An option brake unit, a resistor, etc. needs to be connected. Because the FR-FP series are highly efficient, higher regenerative power can be obtained than in a general-purpose motor.
3-3	When using the FR-FP series, how much torque can be generated in the continuous operation at low speed?	The torque is about 50% at 180r/min.
3-4	What is the selection method for the FR-FP series?	It is fundamentally the same as for the general-purpose inverters.
3-5	What are the hardware differences between the FR-FP series and the general-purpose inverters?	Outline dimensions and installation dimensions are different in some capacities.
3-6	How are the wave patterns of the output voltage and output current of a drive unit?	Same wave patterns as for a general-purpose inverter.
3-7	What parameter differences exist between the FR-FP series and the general-purpose inverters?	The basic parameters are the same.
3-8	Is it possible to use the parameter unit of an inverter?	It is possible to use FR-PU04 and FR-PU07. (Some restrictions exist for FR-PU04 as well as for the general-purpose inverters.)
3-9	Is it possible to use the plug-in options of a general-purpose inverter?	It is possible.
3-10	Are the automatic restart after instantaneous power failure, continuous operation at an instantaneous power failure, and regenerative avoidance operations possible?	The automatic restart after instantaneous power failure function and the regenerative avoidance operation are available. The continuous operation at an instantaneous power failure function is available for FR-FP700, but not for FR-FP500J.
3-11	What are the carrier frequencies?	2kHz, 6kHz, 10kHz and 14kHz can be set. (Only 2kHz and 6kHz can be set for 75K or higher.)
4	About the MM-EF series IPM motors	
4-1	How many motor poles does it have?	0.4kW to 30kW have 6 poles, 37kW or higher have 8 poles.
4-2	The motor is equipped with key groove?	It is equipped as a standard.
4-3	How is the motor coated?	It is coated with acrylic-urethane modified alkyd resin.
4-4	Are there any restrictions with the installation direction of a motor?	All directions except on-the-axis are available.

No.	Question (Q)	Answer (A)
4-5	Is the protective structure of IP45 available even though the protective structure for standard models is IP44?	It is available. “P2” is added at the end of the model name for the standard model whose protective structure is IP45.
4-6	How much N are the permissible radial and thrust loads?	Refer to Chapter 6.5 in this TECHNICAL NOTE.
4-7	What is the shaft end size?	The shaft end size is the same for an IPM motor (MM-EF), a standard motor (SF-JR 4P), and a high-efficiency motor (SF-HR 4P) under the same output (kW).

APPENDIX CHARACTERISTIC DATA FOR THE MM-EF SERIES IPM MOTORS

(1)200V class

Model No.		Capacity		
MM-EF42		0.4kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	2.12N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP520J-0.4K	200 to 220V 50/60Hz	1.6A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
5.48Ω	91.8mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	19	57	166	213
	Current	(A)	0.32	0.27	0.24	0.76
	Power	(W)	4	10	27	34
	Drive unit Eff.	(%)	30.6	53.4	74.6	72.3
50%-Torque	Torque	(N•m)	0.64	0.85	1.06	0.71
	Voltage	(V)	22	60	168	208
	Current	(A)	0.51	0.67	0.82	1.09
	Power	(W)	18	68	234	262
	Motor Eff.	(%)	67.7	79.0	85.7	76.4
	Total Eff.	(%)	44.5	68.8	81.0	71.9
75%-Torque	Torque	(N•m)	0.96	1.27	1.59	1.06
	Voltage	(V)	23	62	171	208
	Current	(A)	0.72	0.95	1.18	1.28
	Power	(W)	26	98	342	364
	Motor Eff.	(%)	69.2	81.4	87.8	82.4
	Total Eff.	(%)	50.3	73.1	83.5	78.4
100%-Torque	Torque	(N•m)	1.27	1.70	2.12	1.42
	Voltage	(V)	24	64	175	207
	Current	(A)	0.93	1.23	1.54	1.52
	Power	(W)	35	130	453	470
	Motor Eff.	(%)	68.3	81.9	88.4	85.1
	Total Eff.	(%)	52.3	74.1	84.6	81.5

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	29.9	27.5	19.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks;

Model No.		Capacity		
MM-EF72		0.75kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	3.98N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP520J-0.75K	200 to 220V 50/60Hz	3.0A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
5.48Ω	91.5mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	19	57	166	224
	Current	(A)	0.19	0.15	0.19	0.55
	Power	(W)	3	11	33	67
	Drive unit Eff.	(%)	26.7	57.6	79.7	78.4
50%-Torque	Torque	(N•m)	1.19	1.59	1.99	1.33
	Voltage	(V)	23	62	169	200
	Current	(A)	0.88	1.17	1.46	1.57
	Power	(W)	32	123	426	450
	Motor Eff.	(%)	69.9	81.3	88.0	83.3
	Total Eff.	(%)	53.0	74.3	85.1	80.4
75%-Torque	Torque	(N•m)	1.79	2.39	2.99	1.99
	Voltage	(V)	26	66	178	200
	Current.	(A)	1.28	1.71	2.15	2.02
	Power	(W)	51	188	638	653
	Motor Eff.	(%)	65.7	79.9	88.3	86.2
	Total Eff.	(%)	53.2	74.3	85.9	83.7
100%-Torque	Torque	(N•m)	2.39	3.18	3.98	2.65
	Voltage	(V)	28	71	191	200
	Current	(A)	1.68	2.26	2.87	2.55
	Power	(W)	74	259	862	864
	Motor Eff.	(%)	61.2	77.4	87.0	86.8
	Total Eff.	(%)	51.6	72.7	84.9	84.7

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	36.9	28.5	18

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks;

Model No.		**Capacity**		
MM-EF152		1.5kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	7.96N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP520J-1.5K	200 to 220V 50/60Hz	5.9A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
1.60Ω	89.7mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	18	56	162	206
	Current	**(A)**	0.30	0.31	0.43	1.75
	Power	**(W)**	5	21	62	87
	Drive unit Eff.	**(%)**	29.0	63.3	82.7	82.5
50%-Torque	**Torque**	**(N•m)**	2.39	3.18	3.98	2.65
	Voltage	**(V)**	21	58	161	204
	Current	**(A)**	1.76	2.36	2.98	2.95
	Power	**(W)**	59	235	832	851
	Motor Eff.	**(%)**	76.9	85.0	90.2	88.0
	Total Eff.	**(%)**	60.2	78.5	87.4	84.7
75%-Torque	**Torque**	**(N•m)**	3.58	4.78	5.97	3.98
	Voltage	**(V)**	23	61	168	203
	Current	**(A)**	2.58	3.46	4.38	3.84
	Power	**(W)**	90	354	1236	1243
	Motor Eff.	**(%)**	74.7	84.8	91.1	90.5
	Total Eff.	**(%)**	61.4	79.2	88.4	87.7
100%-Torque	**Torque**	**(N•m)**	4.78	6.37	7.96	5.31
	Voltage	**(V)**	25	64	177	203
	Current	**(A)**	3.41	4.57	5.83	4.82
	Power	**(W)**	127	478	1656	1646
	Motor Eff.	**(%)**	71.2	83.7	90.6	91.2
	Total Eff.	**(%)**	59.9	78.5	88.2	88.5

Temperature Rise Test

100%-Torque	**Rev (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	49.1	40	26.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks;

Model No.		Capacity		
MM-EF222		2.2kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	11.7N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP520J-2.2K	200 to 220V 50/60Hz	8.7A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
1.13Ω	90.8mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	18	56	163	207
	Current	(A)	0.45	0.41	0.57	2.24
	Power	(W)	6	21	70	100
	Drive unit Eff.	(%)	31.5	64.8	85.2	81.0
50%-Torque	Torque	(N•m)	3.50	4.67	5.84	3.89
	Voltage	(V)	22	60	165	206
	Current	(A)	2.52	3.36	4.26	4.15
	Power	(W)	84	340	1211	1237
	Motor Eff.	(%)	78.6	86.3	90.9	88.9
	Total Eff.	(%)	63.6	80.7	88.5	86.3
75%-Torque	Torque	(N•m)	5.25	7.00	8.75	5.83
	Voltage	(V)	23	62	172	201
	Current	(A)	3.71	4.96	6.29	5.62
	Power	(W)	133	514	1806	1815
	Motor Eff.	(%)	74.6	85.6	91.3	90.8
	Total Eff.	(%)	63.2	80.6	88.9	88.3
100%-Torque	Torque	(N•m)	7.00	9.34	11.7	7.78
	Voltage	(V)	25	66	181	203
	Current	(A)	4.90	6.61	8.45	6.95
	Power	(W)	185	703	2427	2402
	Motor Eff.	(%)	71.5	83.4	90.6	91.6
	Total Eff.	(%)	61.4	78.9	88.3	89.3

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	61.3	49.5	28.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks;

Model No. MM-EF372		**Capacity** 3.7kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	19.6N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP520J-3.7K	200 to 220V 50/60Hz	14.4A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
0.59Ω	91.1 mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	18	57	166	210
	Current	**(A)**	0.58	0.94	1.06	3.78
	Power	**(W)**	10	38	110	172
	Drive unit Eff.	**(%)**	47.8	75.9	88.7	87.0
50%-Torque	**Torque**	**(N•m)**	5.89	7.85	9.82	6.54
	Voltage	**(V)**	21	60	168	206
	Current	**(A)**	4.23	5.57	7.05	6.71
	Power	**(W)**	139	562	2012	2053
	Motor Eff.	**(%)**	80.1	87.8	92.0	90.1
	Total Eff.	**(%)**	68.0	82.9	90.0	88.5
75%-Torque	**Torque**	**(N•m)**	8.83	11.8	14.7	9.81
	Voltage	**(V)**	23	63	175	204
	Current	**(A)**	6.21	8.31	10.5	8.98
	Power	**(W)**	215	853	3013	3016
	Motor Eff.	**(%)**	77.4	86.8	92.1	92.0
	Total Eff.	**(%)**	66.8	82.2	90.4	90.5
100%-Torque	**Torque**	**(N•m)**	11.8	15.7	19.6	13.1
	Voltage	**(V)**	24	66	185	200
	Current	**(A)**	8.25	11.1	14.2	11.8
	Power	**(W)**	303	1161	4057	4008
	Motor Eff.	**(%)**	73.4	85.0	91.2	92.4
	Total Eff.	**(%)**	64.0	80.5	89.3	90.8

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	54.7	31.0	18.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V …1 min. Good

Remarks;

Model No. MM-EF552		**Capacity** 5.5kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	29.2N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP520J-5.5K	200 to 220V 50/60Hz	22.0A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
0.317Ω	94.9mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	20	61	179	207
	Current	**(A)**	3.13	3.12	3.25	8.30
	Power	**(W)**	19	57	172	231
	Drive unit Eff.	**(%)**	41.8	68.9	86.9	84.9
50%-Torque	**Torque**	**(N•m)**	8.76	11.7	14.6	9.73
	Voltage	**(V)**	21	60	169	204
	Current	**(A)**	5.97	8.04	10.3	11.8
	Power	**(W)**	195	817	3004	3083
	Motor Eff.	**(%)**	84.8	89.8	91.6	89.2
	Total Eff.	**(%)**	71.5	84.9	90.2	87.6
75%-Torque	**Torque**	**(N•m)**	13.1	17.5	21.9	14.6
	Voltage	**(V)**	22	62	172	202
	Current	**(A)**	8.86	12.0	15.3	14.6
	Power	**(W)**	301	1235	4471	4525
	Motor Eff.	**(%)**	82.2	89.0	92.3	91.2
	Total Eff.	**(%)**	70.9	84.5	90.8	89.6
100%-Torque	**Torque**	**(N•m)**	17.5	23.3	29.2	19.5
	Voltage	**(V)**	24	64	180	202
	Current	**(A)**	11.9	15.9	20.3	17.9
	Power	**(W)**	421	1671	5970	5978
	Motor Eff.	**(%)**	78.3	87.8	92.1	92.0
	Total Eff.	**(%)**	68.4	83.4	90.5	90.5

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	43.5	26.0	21.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks;

Model No. MM-EF752		**Capacity** 7.5kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	39.8N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP520J-7.5K	200 to 220V 50/60Hz	29A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
0.190Ω	93.2mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	20	59	173	201
	Current	**(A)**	4.08	4.06	4.24	11.1
	Power	**(W)**	22	70	209	262
	Drive unit Eff.	**(%)**	44.7	72.6	88.9	79.8
50%-Torque	**Torque**	**(N•m)**	11.9	15.9	19.9	13.3
	Voltage	**(V)**	21	59	163	196
	Current	**(A)**	8.35	11.1	14.2	16.3
	Power	**(W)**	268	1113	4018	4098
	Motor Eff.	**(%)**	83.9	89.8	93.3	91.5
	Total Eff.	**(%)**	71.8	85.3	91.1	89.1
75%-Torque	**Torque**	**(N•m)**	17.9	23.9	29.8	19.9
	Voltage	**(V)**	22	60	168	195
	Current	**(A)**	12.4	16.6	21.0	20.4
	Power	**(W)**	415	1678	6009	6037
	Motor Eff.	**(%)**	81.3	89.4	93.6	93.2
	Total Eff.	**(%)**	70.8	85.0	91.3	90.8
100%-Torque	**Torque**	**(N•m)**	23.9	31.8	39.8	26.5
	Voltage	**(V)**	23	62	174	193
	Current	**(A)**	16.4	22.1	28.2	25.2
	Power	**(W)**	570	2278	8040	8014
	Motor Eff.	**(%)**	78.9	87.8	93.3	93.6
	Total Eff.	**(%)**	69.1	83.5	90.8	91.2

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	44.2	30.0	23.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks;

Model No. MM-EF11K2		Capacity 11kW		
Rating CONT	**Phases** 3	**Poles** 6	**r/min** 1800	**Torque** 58.4N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP520J-11K	200 to 220V 50/60Hz	43A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.151Ω	89.1mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	19	59	171	205
	Current	**(A)**	6.38	6.20	6.33	9.39
	Power	**(W)**	24	66	238	358
	Drive unit Eff.	**(%)**	37.9	63.0	85.5	86.0
50%-Torque	**Torque**	**(N•m)**	17.5	23.3	29.2	19.5
	Voltage	**(V)**	21	57	160	199
	Current	**(A)**	11.9	16.1	21.5	18.9
	Power	**(W)**	387	1611	5910	6001
	Motor Eff.	**(%)**	85.2	90.9	93.1	91.9
	Total Eff.	**(%)**	72.5	85.5	90.4	89.4
75%-Torque	**Torque**	**(N•m)**	26.3	35.0	43.8	29.2
	Voltage	**(V)**	22	60	169	197
	Current	**(A)**	17.7	23.8	30.1	25.9
	Power	**(W)**	604	2464	8832	8866
	Motor Eff.	**(%)**	82.1	89.3	93.4	93.1
	Total Eff.	**(%)**	70.8	84.3	90.6	90.6
100%-Torque	**Torque**	**(N•m)**	35.0	46.7	58.4	38.9
	Voltage	**(V)**	23	63	181	196
	Current	**(A)**	23.4	31.5	40.0	33.4
	Power	**(W)**	850	3340	11831	11770
	Motor Eff.	**(%)**	77.6	87.8	93.0	93.5
	Total Eff.	**(%)**	67.5	82.9	90.0	90.9

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	71.0	38.5	25.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks;

Model No.		Capacity		
MM-EF15K2		15kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	79.6N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP520J-15K	200 to 220V 50/60Hz	55A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
0.106Ω	93.1mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	20	61	178	210
	Current	**(A)**	8.35	7.98	8.19	13.2
	Power	**(W)**	30	82	289	421
	Drive unit Eff.	**(%)**	37.3	63.9	85.7	86.1
50%-Torque	**Torque**	**(N•m)**	23.9	31.8	39.8	26.5
	Voltage	**(V)**	21	59	165	200
	Current	**(A)**	16.8	22.2	28.0	27.0
	Power	**(W)**	522	2179	7947	8064
	Motor Eff.	**(%)**	86.3	91.7	94.4	92.9
	Total Eff.	**(%)**	73.7	86.7	91.7	90.3
75%-Torque	**Torque**	**(N•m)**	35.8	47.8	59.7	39.8
	Voltage	**(V)**	22	61	175	198
	Current	**(A)**	24.7	32.8	41.1	36.7
	Power	**(W)**	812	3308	11894	11948
	Motor Eff.	**(%)**	83.1	90.8	94.6	94.2
	Total Eff.	**(%)**	71.9	85.9	91.8	91.6
100%-Torque	**Torque**	**(N•m)**	47.8	63.7	79.6	53.1
	Voltage	**(V)**	24	65	186	197
	Current	**(A)**	32.7	43.6	54.9	47.1
	Power	**(W)**	1129	4497	15947	15901
	Motor Eff.	**(%)**	79.8	89.0	94.1	94.4
	Total Eff.	**(%)**	69.4	84.1	91.1	91.8

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	70.9	41.5	29.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks;

Model No.		Capacity	
MM-EF18K2		18.5kW	

Rating	Phases	Poles	r/min	Torque
CONT	3	6	1800	98.1N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP720-18.5K	200 to 220V 50/60Hz	70.5A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.066Ω	89.8mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	17	54	158	203
	Current	(A)	3.34	1.85	3.05	15.0
	Power	(W)	26	96	367	869
	Drive unit Eff.	(%)	44.4	74.4	90.1	90.7
50%-Torque	Torque	(N•m)	29.5	39.3	49.1	32.7
	Voltage	(V)	20	57	165	199
	Current	(A)	21.4	28.4	35.6	32.6
	Power	(W)	649	2719	9928	10370
	Motor Eff.	(%)	85.7	90.8	93.2	89.2
	Total Eff.	(%)	73.6	85.8	90.3	86.4
75%-Torque	Torque	(N•m)	44.2	58.9	73.6	49.1
	Voltage	(V)	22	61	176	197
	Current	(A)	31.5	41.8	52.6	45.0
	Power	(W)	992	4090	14832	15135
	Motor Eff.	(%)	84.0	90.5	93.5	91.7
	Total Eff.	(%)	72.8	85.4	90.5	89.0
100%-Torque	Torque	(N•m)	58.9	78.5	98.1	65.4
	Voltage	(V)	23	65	190	197
	Current	(A)	41.5	55.4	70.1	58.8
	Power	(W)	1356	5543	19779	19972
	Motor Eff.	(%)	81.9	89.0	93.5	92.6
	Total Eff.	(%)	71.0	84.0	90.4	89.7

Temperature Rise

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	65.6	36.5	29.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks; Carrier frequency 2kHz

Model No.		Capacity		
MM-EF22K2		22kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	117N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP720-22K	200 to 220V 50/60Hz	83.5A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.066Ω	89.8mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	17	53	157	204
	Current	**(A)**	2.01	1.83	3.12	14.7
	Power	**(W)**	22	93	400	880
	Drive unit Eff.	**(%)**	41.7	74.1	90.8	91.1
50%-Torque	**Torque**	**(N•m)**	35.0	46.7	58.4	38.9
	Voltage	**(V)**	21	59	170	199
	Current	**(A)**	25.2	33.2	41.6	37.2
	Power	**(W)**	794	3236	11748	12157
	Motor Eff.	**(%)**	83.1	90.7	93.7	90.5
	Total Eff.	**(%)**	72.4	85.9	91.1	88.0
75%-Torque	**Torque**	**(N•m)**	52.5	70.0	87.5	58.4
	Voltage	**(V)**	22	63	185	197
	Current	**(A)**	36.9	49.1	61.9	52.7
	Power	**(W)**	1205	4899	17621	17915
	Motor Eff.	**(%)**	82.1	89.8	93.6	92.2
	Total Eff.	**(%)**	71.9	85.0	90.8	89.6
100%-Torque	**Torque**	**(N•m)**	70.0	93.4	116.7	77.8
	Voltage	**(V)**	24	68	197	197
	Current	**(A)**	48.9	65.6	83.5	69.9
	Power	**(W)**	1667	6693	23588	23689
	Motor Eff.	**(%)**	79.2	87.7	93.3	92.9
	Total Eff.	**(%)**	69.4	83.0	90.3	90.2

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	96.0	50.5	31.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks; Carrier frequency 2kHz

Model No. MM-EF30K2		Capacity 30kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	159N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP720-30K	200 to 220V 50/60Hz	109A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.046Ω	92.8mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	18	56	165	206
	Current	**(A)**	1.31	2.52	3.88	22.3
	Power	**(W)**	27	115	506	983
	Drive unit Eff.	**(%)**	44.7	75.7	91.9	90.0
50%-Torque	**Torque**	**(N•m)**	47.7	63.7	79.6	53.1
	Voltage	**(V)**	21	61	175	201
	Current	**(A)**	31.7	42.5	53.8	49.0
	Power	**(W)**	1009	4263	15719	16028
	Motor Eff.	**(%)**	89.1	93.9	95.5	93.7
	Total Eff.	**(%)**	76.6	88.7	92.5	91.1
75%-Torque	**Torque**	**(N•m)**	71.6	95.5	119.4	79.6
	Voltage	**(V)**	23	65	189	198
	Current	**(A)**	47.5	63.4	80.2	70.4
	Power	**(W)**	1575	6526	23585	23880
	Motor Eff.	**(%)**	85.7	92.0	95.4	94.3
	Total Eff.	**(%)**	74.5	86.8	92.3	91.5
100%-Torque	**Torque**	**(N•m)**	95.5	127.3	159.2	106.1
	Voltage	**(V)**	25	70	196	197
	Current	**(A)**	63.2	84.9	109	94.1
	Power	**(W)**	2210	8879	31687	31840
	Motor Eff.	**(%)**	81.5	90.1	94.7	94.2
	Total Eff.	**(%)**	71.2	84.8	91.4	91.3

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	86.6	57.0	36.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks; Carrier frequency 2kHz

Model No.		Capacity	
MM-EF37K2		37 kW	

Rating	Phases	Poles	r/min	Torque
CONT	3	8	1800	196N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP720-37K	200 to 220V 50/60Hz	136A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.024Ω	91.8mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	18	55	161	200
	Current	(A)	1.67	5.01	8.34	41.6
	Power	(W)	38	167	781	1699
	Drive unit Eff.	(%)	44.7	72.3	89.8	92.1
50%-Torque	Torque	(N•m)	58.9	78.5	98.1	65.4
	Voltage	(V)	20	58	166	198
	Current	(A)	41.2	54.3	68.8	70.5
	Power	(W)	1241	5271	19528	20256
	Motor Eff.	(%)	89.5	93.6	94.7	91.3
	Total Eff.	(%)	76.6	88.3	91.9	88.8
75%-Torque	Torque	(N•m)	88.3	117.8	147.2	98.1
	Voltage	(V)	21	60	175	197
	Current	(A)	61.0	80.6	102	92.7
	Power	(W)	1902	7958	29204	29692
	Motor Eff.	(%)	87.5	93.0	95.0	93.4
	Total Eff.	(%)	75.4	87.7	92.1	90.7
100%-Torque	Torque	(N•m)	117.8	157.0	196.3	130.9
	Voltage	(V)	23	64	186	197
	Current	(A)	80.7	107	135	117
	Power	(W)	2588	10751	38950	39307
	Motor Eff.	(%)	85.8	91.8	95.0	94.2
	Total Eff.	(%)	73.9	86.5	92.0	91.4

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	61.5	36.5	25.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks; Carrier frequency 2kHz

Model No. MM-EF45K2		Capacity 45kW		
Rating CONT	**Phases** 3	**Poles** 8	**r/min** 1800	**Torque** 239N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP720-45K	200 to 220V 50/60Hz	162A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.020Ω	93.2mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	18	56	163	207
	Current	**(A)**	2.02	5.56	9.16	42.3
	Power	**(W)**	38	176	796	1668
	Drive unit Eff.	**(%)**	40.5	70.2	89.0	89.7
50%-Torque	**Torque**	**(N•m)**	71.6	95.5	119.4	79.6
	Voltage	**(V)**	20	59	169	200
	Current	**(A)**	49.1	65.5	82.4	80.7
	Power	**(W)**	1489	6419	23628	24289
	Motor Eff.	**(%)**	90.6	93.5	95.3	92.7
	Total Eff.	**(%)**	78.2	88.4	92.3	90.1
75%-Torque	**Torque**	**(N•m)**	107.4	143.2	179.0	119.4
	Voltage	**(V)**	22	62	180	200
	Current	**(A)**	72.9	96.9	122	108
	Power	**(W)**	2294	9645	35271	35851
	Motor Eff.	**(%)**	88.3	93.3	95.7	94.2
	Total Eff.	**(%)**	76.7	88.1	92.6	91.5
100%-Torque	**Torque**	**(N•m)**	143.2	191.0	238.7	159.1
	Voltage	**(V)**	23	66	193	197
	Current	**(A)**	96.5	129	163	140
	Power	**(W)**	3126	13049	47021	47484
	Motor Eff.	**(%)**	86.4	92.0	95.7	94.7
	Total Eff.	**(%)**	75.0	86.8	92.5	91.9

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	65.7	42.0	28.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 1500 V…1 min. Good

Remarks; Carrier frequency 2kHz

(2) 400V class

Model No.		Capacity		
MM-EF424		0.4kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	2.12N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP540J-0.4K	400 to 440V 50/60Hz	0.8A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
22.1Ω	183mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	36	114	332	427
	Current	(A)	0.12	0.09	0.11	0.36
	Power	(W)	4	12	32	63
	Drive unit Eff.	(%)	23.5	51.8	73.6	82.0
50%-Torque	Torque	(N•m)	0.64	0.85	1.06	0.71
	Voltage	(V)	41	119	337	430
	Current	(A)	0.25	0.33	0.41	0.48
	Power	(W)	18	69	236	256
	Motor Eff.	(%)	67.5	77.5	84.8	78.3
	Total Eff.	(%)	40.3	65.6	79.7	73.6
75%-Torque	Torque	(N•m)	0.96	1.27	1.59	1.06
	Voltage	(V)	44	123	342	429
	Current	(A)	0.36	0.47	0.59	0.58
	Power	(W)	26	100	343	360
	Motor Eff.	(%)	69.0	80.3	87.6	83.3
	Total Eff.	(%)	46.6	70.8	83.5	79.5
100%-Torque	Torque	(N•m)	1.27	1.70	2.12	1.42
	Voltage	(V)	46	126	349	427
	Current	(A)	0.46	0.62	0.77	0.71
	Power	(W)	35	132	453	466
	Motor Eff.	(%)	68.4	80.8	88.4	85.9
	Total Eff.	(%)	49.6	72.8	84.9	82.5

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	35.6	34.0	23.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks;

Model No.		Capacity	
MM-EF724		0.75kW	

Rating	Phases	Poles	r/min	Torque
CONT	3	6	1800	3.98N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP540J-0.75K	400 to 440V 50/60Hz	1.5A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
22.1Ω	182mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	36	113	331	429
	Current	(A)	0.11	0.10	0.12	0.33
	Power	(W)	3	11	34	61
	Drive unit Eff.	(%)	21.0	49.4	75.0	81.7
50%-Torque	Torque	(N•m)	1.19	1.59	1.99	1.33
	Voltage	(V)	45	124	342	425
	Current	(A)	0.43	0.58	0.73	0.67
	Power	(W)	32	123	426	443
	Motor Eff.	(%)	69.7	81.4	88.1	84.8
	Total Eff.	(%)	49.4	73.6	85.6	82.1
75%-Torque	Torque	(N•m)	1.79	2.39	2.99	1.99
	Voltage	(V)	50	131	359	418
	Current	(A)	0.64	0.85	1.08	0.92
	Power	(W)	52	188	638	644
	Motor Eff.	(%)	65.6	79.9	88.2	87.4
	Total Eff.	(%)	51.3	74.3	86.4	85.5
100%-Torque	Torque	(N•m)	2.39	3.18	3.98	2.65
	Voltage	(V)	55	140	383	417
	Current	(A)	0.84	1.14	1.45	1.20
	Power	(W)	74	260	866	854
	Motor Eff.	(%)	61.0	77.9	86.7	87.8
	Total Eff.	(%)	50.5	72.6	85.1	86.1

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	51.5	30.5	19.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks;

Model No. MM-EF1524		**Capacity** 1.5kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	7.95N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP540J-1.5K	400 to 440V 50/60Hz	3.0A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
6.33Ω	179mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	36	112	326	434
	Current	**(A)**	0.19	0.19	0.25	0.66
	Power	**(W)**	7	23	74	103
	Drive unit Eff.	**(%)**	31.0	59.3	81.9	82.8
50%-Torque	**Torque**	**(N•m)**	2.39	3.18	3.98	2.65
	Voltage	**(V)**	41	118	330	426
	Current	**(A)**	0.88	1.16	1.48	1.32
	Power	**(W)**	60	236	836	856
	Motor Eff.	**(%)**	75.5	84.9	89.7	87.5
	Total Eff.	**(%)**	57.4	78.1	86.6	84.6
75%-Torque	**Torque**	**(N•m)**	3.58	4.78	5.97	3.98
	Voltage	**(V)**	44	122	342	426
	Current	**(A)**	1.28	1.71	2.19	1.77
	Power	**(W)**	91	353	1239	1246
	Motor Eff.	**(%)**	74.5	85.2	90.9	90.3
	Total Eff.	**(%)**	60.2	79.6	88.2	88.0
100%-Torque	**Torque**	**(N•m)**	4.78	6.37	7.96	5.31
	Voltage	**(V)**	47	128	360	424
	Current	**(A)**	1.69	2.28	2.93	2.27
	Power	**(W)**	126	479	1659	1646
	Motor Eff.	**(%)**	71.5	83.6	90.4	91.2
	Total Eff.	**(%)**	59.7	78.9	88.0	89.2

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	49.6	38.5	24.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks;

Model No.		**Capacity**		
MM-EF2224		2.2kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	11.7N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP540J-2.2K	400 to 440V 50/60Hz	4.4A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
4.50Ω	182mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	36	113	331	417
	Current	**(A)**	0.30	0.25	0.32	1.20
	Power	**(W)**	6	22	69	116
	Drive unit Eff.	**(%)**	25.1	56.3	79.6	83.9
50%-Torque	**Torque**	**(N•m)**	3.50	4.67	5.84	3.89
	Voltage	**(V)**	42	119	338	428
	Current	**(A)**	1.25	1.67	2.11	1.88
	Power	**(W)**	84	338	1205	1231
	Motor Eff.	**(%)**	79.0	86.9	91.4	89.3
	Total Eff.	**(%)**	62.7	81.6	88.9	86.8
75%-Torque	**Torque**	**(N•m)**	5.25	7.00	8.75	5.83
	Voltage	**(V)**	45	124	351	427
	Current	**(A)**	1.85	2.48	3.16	2.54
	Power	**(W)**	130	510	1801	1802
	Motor Eff.	**(%)**	76.3	86.3	91.6	91.5
	Total Eff.	**(%)**	63.8	81.9	89.5	89.4
100%-Torque	**Torque**	**(N•m)**	7.00	9.34	11.7	7.78
	Voltage	**(V)**	48	131	370	419
	Current	**(A)**	2.46	3.33	4.26	3.34
	Power	**(W)**	182	698	2421	2387
	Motor Eff.	**(%)**	72.6	84.1	90.9	92.2
	Total Eff.	**(%)**	62.5	80.3	88.9	90.1

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	62.5	51.0	28.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks;

Model No.		**Capacity**		
MM-EF3724		3.7kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	19.6N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP540J-3.7K	400 to 440V 50/60Hz	7.2A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
2.39Ω	183mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	39	119	349	447
	Current	**(A)**	1.31	1.31	1.34	1.21
	Power	**(W)**	17	49	142	180
	Drive unit Eff.	**(%)**	42.3	68.9	86.7	87.8
50%-Torque	**Torque**	**(N•m)**	5.89	7.85	9.82	6.54
	Voltage	**(V)**	41	117	331	434
	Current	**(A)**	2.10	2.80	3.53	3.00
	Power	**(W)**	138	561	2009	2045
	Motor Eff.	**(%)**	80.7	87.9	92.1	90.4
	Total Eff.	**(%)**	66.8	83.1	90.0	88.3
75%-Torque	**Torque**	**(N•m)**	8.83	11.8	14.7	9.81
	Voltage	**(V)**	44	123	346	434
	Current	**(A)**	3.09	4.15	5.27	4.11
	Power	**(W)**	213	849	3005	3000
	Motor Eff.	**(%)**	78.1	87.2	92.3	92.5
	Total Eff.	**(%)**	67.3	82.9	90.4	90.6
100%-Torque	**Torque**	**(N•m)**	11.8	15.7	19.6	13.1
	Voltage	**(V)**	47	130	367	429
	Current	**(A)**	4.11	5.57	7.14	5.39
	Power	**(W)**	298	1159	4048	3978
	Motor Eff.	**(%)**	74.6	85.2	91.4	93.1
	Total Eff.	**(%)**	65.3	81.2	89.6	91.2

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	46.1	32.0	19.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks;

Model No.		Capacity	
MM-EF5524		5.5kW	

Rating	Phases	Poles	r/min	Torque
CONT	3	6	1800	29.2N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP540J-5.5K	400 to 440V 50/60Hz	11.0A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
1.252Ω	189.3mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	39	124	363	426
	Current	(A)	2.10	2.06	2.11	3.63
	Power	(W)	21	62	177	219
	Drive unit Eff.	(%)	37.8	78.7	94.6	81.7
50%-Torque	Torque	(N•m)	8.76	11.7	14.6	9.73
	Voltage	(V)	41	118	338	431
	Current	(A)	3.01	4.02	5.12	5.09
	Power	(W)	202	829	2991	3059
	Motor Eff.	(%)	81.6	88.5	91.9	89.9
	Total Eff.	(%)	68.0	84.0	90.0	87.9
75%-Torque	Torque	(N•m)	13.1	17.5	21.9	14.6
	Voltage	(V)	43	122	347	430
	Current	(A)	4.44	5.96	7.56	6.55
	Power	(W)	308	1242	4456	4485
	Motor Eff.	(%)	80.4	88.6	92.6	92.0
	Total Eff.	(%)	69.3	84.8	90.7	90.4
100%-Torque	Torque	(N•m)	17.5	23.3	29.2	19.5
	Voltage	(V)	45	127	366	429
	Current	(A)	5.90	7.94	10.1	8.21
	Power	(W)	424	1673	5895	5930
	Motor Eff.	(%)	77.9	87.7	93.3	92.7
	Total Eff.	(%)	68.4	84.2	91.3	91.1

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	47.6	25.0	18.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks;

Model No.		Capacity		
MM-EF7524		7.5kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	39.8N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP540J-7.5K	400 to 440V 50/60Hz	14.5A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.759Ω	186.5mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	39	120	353	428
	Current	(A)	2.71	2.65	2.70	4.38
	Power	(W)	28	82	244	321
	Drive unit Eff.	(%)	42.2	68.4	85.1	88.7
50%-Torque	Torque	(N•m)	11.9	15.9	19.9	13.3
	Voltage	(V)	39	115	331	433
	Current	(A)	4.21	5.63	7.11	6.65
	Power	(W)	272	1127	4082	4193
	Motor Eff.	(%)	82.6	88.7	91.9	89.5
	Total Eff.	(%)	71.2	85.2	90.6	88.5
75%-Torque	Torque	(N•m)	17.9	23.9	29.8	19.9
	Voltage	(V)	41	119	339	425
	Current	(A)	6.19	8.33	10.5	8.99
	Power	(W)	411	1684	6060	6127
	Motor Eff.	(%)	82.1	89.1	92.8	91.8
	Total Eff.	(%)	72.5	86.0	91.5	90.8
100%-Torque	Torque	(N•m)	23.9	31.8	39.8	26.5
	Voltage	(V)	43	123	357	426
	Current	(A)	8.21	11.1	13.9	11.2
	Power	(W)	562	2272	7982	8079
	Motor Eff.	(%)	80.1	88.0	94.0	92.9
	Total Eff.	(%)	71.5	85.1	92.0	91.8

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	50.5	30.5	23.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks;

Model No.		**Capacity**		
MM-EF11K24		11kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	58.4N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP540J-11K	400 to 440V 50/60Hz	21.5A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
0.606Ω	178.3mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	38	119	352	423
	Current	**(A)**	4.32	4.08	4.14	3.70
	Power	**(W)**	34	77	248	352
	Drive unit Eff.	**(%)**	40.2	63.2	84.2	87.2
50%-Torque	**Torque**	**(N•m)**	17.5	23.4	29.2	19.5
	Voltage	**(V)**	38	112	323	426
	Current	**(A)**	6.35	8.37	10.6	8.65
	Power	**(W)**	393	1596	5911	6024
	Motor Eff.	**(%)**	84.1	91.9	93.1	91.3
	Total Eff.	**(%)**	72.6	86.3	91.5	89.9
75%-Torque	**Torque**	**(N•m)**	26.3	35.0	43.8	29.2
	Voltage	**(V)**	41	117	339	424
	Current	**(A)**	9.36	12.4	15.7	12.3
	Power	**(W)**	605	2433	8838	8878
	Motor Eff.	**(%)**	81.9	90.4	93.4	92.9
	Total Eff.	**(%)**	72.4	85.4	91.8	91.6
100%-Torque	**Torque**	**(N•m)**	35.0	46.7	58.4	38.9
	Voltage	**(V)**	44	125	371	424
	Current	**(A)**	12.4	16.4	20.8	16.0
	Power	**(W)**	850	3298	11757	11774
	Motor Eff.	**(%)**	77.7	89.0	93.6	93.4
	Total Eff.	**(%)**	69.5	84.2	91.7	92.0

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	65.8	38.0	28.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks;

Model No.		Capacity		
MM-EF15K24		15kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	79.6N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP540J-15K	380 to 480V 50/60Hz	27.5A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.425Ω	186.2mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	40	123	362	421
	Current	(A)	5.32	5.09	5.19	6.46
	Power	(W)	38	92	307	428
	Drive unit Eff.	(%)	40.4	64.0	84.9	87.7
50%-Torque	Torque	(N•m)	23.9	31.8	39.8	26.5
	Voltage	(V)	40	115	332	424
	Current	(A)	8.34	11.1	14.0	12.3
	Power	(W)	518	2184	7992	8094
	Motor Eff.	(%)	86.8	91.6	93.9	92.7
	Total Eff.	(%)	76.4	87.8	91.8	91.1
75%-Torque	Torque	(N•m)	35.8	47.8	59.7	39.8
	Voltage	(V)	42	121	352	419
	Current	(A)	12.3	16.5	20.6	17.0
	Power	(W)	813	3324	11989	11981
	Motor Eff.	(%)	83.0	90.3	93.9	93.9
	Total Eff.	(%)	74.3	86.7	91.8	92.2
100%-Torque	Torque	(N•m)	47.8	63.7	79.6	53.1
	Voltage	(V)	45	129	378	420
	Current	(A)	16.3	21.8	27.3	22.1
	Power	(W)	1120	4524	15970	15927
	Motor Eff.	(%)	80.4	88.4	94.0	94.2
	Total Eff.	(%)	71.8	84.8	92.0	92.5

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	75.7	44.5	29.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks;

Model No.		Capacity	
MM-EF18K24		18.5kW	

Rating	Phases	Poles	r/min	Torque
CONT	3	6	1800	98.1N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP740-18.5K	400 to 440V 50/60Hz	35A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.258Ω	179.8mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	35	109	321	431
	Current	(A)	0.583	0.618	0.845	5.43
	Power	(W)	29	94	373	796
	Drive unit Eff.	(%)	45.2	93.2	90.5	90.7
50%-Torque	Torque	(N•m)	29.1	38.9	48.7	32.3
	Voltage	(V)	38	113	330	433
	Current	(A)	10.4	13.8	17.5	13.9
	Power	(W)	628	2636	9824	10128
	Motor Eff.	(%)	87.3	92.7	93.4	90.2
	Total Eff.	(%)	75.9	88.6	91.3	88.2
75%-Torque	Torque	(N•m)	43.8	58.5	73.2	48.7
	Voltage	(V)	40	119	352	430
	Current	(A)	15.4	20.4	25.9	20.0
	Power	(W)	963	4013	14658	14876
	Motor Eff.	(%)	85.7	91.6	94.1	92.6
	Total Eff.	(%)	75.9	87.8	91.9	90.5
100%-Torque	Torque	(N•m)	58.9	78.5	98.1	65.4
	Voltage	(V)	42	127	379	426
	Current	(A)	20.5	27.4	34.6	26.7
	Power	(W)	1352	5505	19745	19726
	Motor Eff.	(%)	82.1	89.6	93.7	93.7
	Total Eff.	(%)	74.1	86.7	92.4	92.5

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	57.7	63.5	21.0

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks; Carrier frequency 2kHz

Model No. MM-EF22K24		**Capacity** 22kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	117N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP740-22K	400 to 440V 50/60Hz	42A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
0.258Ω	179.8mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	34	109	320	437
	Current	**(A)**	0.68	1.07	1.59	4.78
	Power	**(W)**	23	95	403	783
	Drive unit Eff.	**(%)**	41.5	72.2	90.6	93.9
50%-Torque	**Torque**	**(N•m)**	35.0	46.7	58.4	38.9
	Voltage	**(V)**	38	115	337	431
	Current	**(A)**	12.1	16.3	20.8	16.2
	Power	**(W)**	746	3177	11705	11941
	Motor Eff.	**(%)**	88.4	92.4	94.1	92.1
	Total Eff.	**(%)**	77.9	88.5	92.2	90.5
75%-Torque	**Torque**	**(N•m)**	52.5	70.0	87.5	58.4
	Voltage	**(V)**	41	123	366	420
	Current	**(A)**	18.1	24.3	30.9	24.2
	Power	**(W)**	1162	4845	17501	17618
	Motor Eff.	**(%)**	85.2	90.8	94.2	93.7
	Total Eff.	**(%)**	76.1	87.4	92.4	92.2
100%-Torque	**Torque**	**(N•m)**	70.0	93.4	116.7	77.8
	Voltage	**(V)**	44	133	398	418
	Current	**(A)**	24.0	32.5	41.8	32.6
	Power	**(W)**	1639	6580	23466	23386
	Motor Eff.	**(%)**	80.5	89.2	93.7	94.1
	Total Eff.	**(%)**	72.7	85.9	91.8	92.4

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	83.8	51.0	27.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks; Carrier frequency 2kHz

Model No.		Capacity		
MM-EF30K24		30kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	6	1800	159N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP740-30K	400 to 440V 50/60Hz	57A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.172Ω	179.4mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	Voltage	(V)	35	109	323	427
	Current	(A)	0.82	0.88	1.10	7.9
	Power	(W)	33	102	425	921
	Drive unit Eff.	(%)	36.9	65.8	88.2	90.6
50%-Torque	Torque	(N•m)	47.7	63.7	79.6	53.1
	Voltage	(V)	38	114	334	423
	Current	(A)	16.9	22.6	28.4	22.6
	Power	(W)	1026	4353	15868	16243
	Motor Eff.	(%)	87.6	92.0	94.6	92.4
	Total Eff.	(%)	77.5	88.5	92.9	91.3
75%-Torque	Torque	(N•m)	71.6	95.5	119.4	79.6
	Voltage	(V)	40	122	363	421
	Current	(A)	25.1	33.5	42.2	32.8
	Power	(W)	1595	6603	23758	23959
	Motor Eff.	(%)	84.6	90.9	94.7	93.9
	Total Eff.	(%)	75.9	87.8	93.0	92.8
100%-Torque	Torque	(N•m)	95.5	127.3	159.1	106.1
	Voltage	(V)	43	131	398	419
	Current	(A)	33.2	44.7	56.9	44.2
	Power	(W)	2198	8955	31916	31829
	Motor Eff.	(%)	81.9	89.3	94.0	94.3
	Total Eff.	(%)	74.3	86.3	92.3	93.1

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	88.7	59.5	38.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks; Carrier frequency 2kHz

Model No. MM-EF37K24		**Capacity** 37kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	8	1800	196N•m

Drive Unit

Model No.	**Volt Hz**	**Current**
FR-FP740-37K	400 to 440V 50/60Hz	68A

Parameters At 20°C

Winding Resistance Between Terminals	**E.M.F Const. Between Terminals**
0.095Ω	183.6mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	35	109	324	429
	Current	**(A)**	1.07	1.23	2.03	14.3
	Power	**(W)**	38	148	690	1601
	Drive unit Eff.	**(%)**	31.8	70.6	90.7	90.2
50%-Torque	**Torque**	**(N•m)**	58.9	78.5	98.1	65.4
	Voltage	**(V)**	37	113	330	422
	Current	**(A)**	20.5	27.3	34.5	30.4
	Power	**(W)**	1253	5252	19468	20161
	Motor Eff.	**(%)**	88.6	93.9	95.0	91.7
	Total Eff.	**(%)**	74.0	89.2	92.8	89.9
75%-Torque	**Torque**	**(N•m)**	88.3	117.8	147.2	98.1
	Voltage	**(V)**	39	117	349	425
	Current	**(A)**	30.6	40.4	51.0	41.2
	Power	**(W)**	1906	7897	29121	29605
	Motor Eff.	**(%)**	87.3	93.7	95.3	93.7
	Total Eff.	**(%)**	74.2	89.4	93.1	91.8
100%-Torque	**Torque**	**(N•m)**	117.8	157.0	196.3	130.9
	Voltage	**(V)**	41	124	373	423
	Current	**(A)**	40.5	53.7	68.0	53.5
	Power	**(W)**	2582	10680	38909	39100
	Motor Eff.	**(%)**	86.0	92.4	95.1	94.7
	Total Eff.	**(%)**	73.7	88.3	92.9	92.7

Temperature Rise Test

100%-Torque	**Rev. (r/min)**	**Temperature Rise °C(K) by Thermometer Method**		
		Stator		**Bearing**
		Winding by Resist Method	**Frame**	**Load Side**
	1800	59.9	40.5	24.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks; Carrier frequency 6kHz

Model No.		Capacity		
MM-EF45K24		45kW		
Rating	**Phases**	**Poles**	**r/min**	**Torque**
CONT	3	8	1800	239N•m

Drive Unit

Model No.	Volt Hz	Current
FR-FP740-45K	400 to 440V 50/60Hz	81A

Parameters At 20°C

Winding Resistance Between Terminals	E.M.F Const. Between Terminals
0.081Ω	186.9mV/(r/min)

Load Characteristics (Actual Load Method)

Rev. (r/min)			180	600	1800	2700
No-Load	**Voltage**	**(V)**	35	112	331	434
	Current	**(A)**	1.34	1.48	2.21	16.8
	Power	**(W)**	58	158	711	1678
	Drive unit Eff.	**(%)**	45.1	69.4	88.0	89.9
50%-Torque	**Torque**	**(N•m)**	71.6	95.5	119.4	79.6
	Voltage	**(V)**	38	115	339	426
	Current	**(A)**	24.4	32.7	41.0	36.2
	Power	**(W)**	1501	6380	23628	24332
	Motor Eff.	**(%)**	89.9	94.1	95.3	92.5
	Total Eff.	**(%)**	76.3	89.6	92.9	90.5
75%-Torque	**Torque**	**(N•m)**	107.4	143.2	179.0	119.4
	Voltage	**(V)**	40	121	360	424
	Current	**(A)**	36.4	48.3	60.7	50.2
	Power	**(W)**	2291	9600	35289	35881
	Motor Eff.	**(%)**	88.4	93.7	95.6	94.1
	Total Eff.	**(%)**	75.9	89.4	93.2	92.1
100%-Torque	**Torque**	**(N•m)**	143.2	191.0	238.7	159.2
	Voltage	**(V)**	42	128	387	419
	Current	**(A)**	48.2	64.2	80.9	65.7
	Power	**(W)**	3108	12951	47073	47458
	Motor Eff.	**(%)**	86.9	92.7	95.6	94.9
	Total Eff.	**(%)**	74.8	88.4	93.1	92.7

Temperature Rise Test

100%-Torque	Rev. (r/min)	Temperature Rise °C(K) by Thermometer Method		
		Stator		Bearing
		Winding by Resist Method	Frame	Load Side
	1800	64.2	40.0	28.5

Insulation Resistance (by 500V Megger) & Dielectric Test

Insulation Resistance	100MΩ (by 500V Megger)
Dielectric Test	AC 60Hz 2000 V…1 min. Good

Remarks; Carrier frequency 6kHz

REVISIONS

* The technical note number is given on the bottom left of the back cover.

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