Inverter-Integrated Motor

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ABSTRACT

Recently, energy saving by improving motor efficiency and adopting variable speed control systems have come to be accelerated. Fuji Electric has developed an inverter-integrated motor, which incorporates inverter functions into a motor. In addition to adopting a high efficient motor, variable speed operation with inverter control achieves significant energy saving effect. Moreover, it achieves downsizing by the incorporation. The energy-saving effect amounts to a reduction of 45% (1,923 kWh per year) from standard motors with IE1 class efficiency and 43% (1,742 kWh per year) compared to IE3 "Premium Efficiency Motors."

1. Introduction

As efforts for the prevention of global warming are being widely promoted, efficiency improvement of motors and energy saving of systems are being accelerated. In the field of air conditioners, the number of inverter-integrated products is increasing in order to save energy with variable-speed operation. Fuji Electric offers a wide array of motors and inverters, which can be combined to meet the needs of various systems.

In view of the increasing demand for smaller size, space saving and shorter installation work time, in addition to energy conservation, we have recently developed an inverter-integrated motor that incorporates inverter functions into a motor.

2. Demand for Energy Saving

2.1 Present condition of power consumption of motors

The total number of motors owned in Japan combining those for household and industrial use is said to be approximately 100 million. The annual amount of power consumed by these motors accounts for approximately 55% of the total power consumption in Japan. The annual amount of power consumed by industrial motors in the industrial sector alone accounts for approximately 75% of the sector's power use (see Fig. 1). The amount of power consumed by motors amounts to more than half, which has led to the demand for energy-saving motors.

2.2 Energy saving by variable-speed operation

Generally, the air volumes of fans and flow rate of pumps are adjusted by using dampers or valves. These adjustment methods, however, do not offer much reduction in the motor shaft power even if the air volumes or flow rates are reduced. To deal with the issue, applying rotating speed control with inverter can achieve significant energy saving because the power is proportional to the cube of the rotating speed. Figure 2

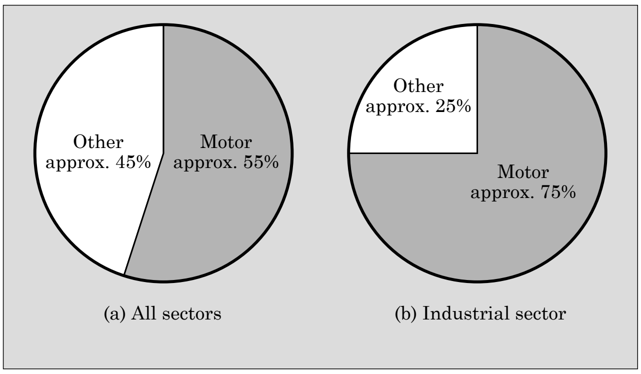

Fig.1　Percentage of motors occupied in annual power consumption in Japan

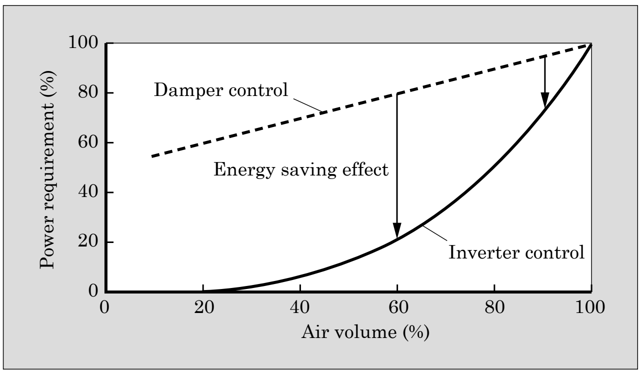

Fig.2　Relationship between air volumes and power requirements

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shows the relationship between air volumes and power requirements. In inverter control, a greater energy saving effect can be obtained especially when air volumes are small. In air conditioning applications such as fans, energy can be saved by controlling the rotating speed according to the air volume required.

3. Specification and Structure of Developed Motor

3.1 Specification of developed motor

Table 1 shows the specification of the developed motor. With the rotating speed range specified between 50 and 1,000 r/min, the efficiency of the motor itself has achieved a high value of the efficiency class IE4 or more, which is referred to as the Super Premium Efficiency as defined by IEC 60034-30-1. The performance and functions of the inverter are equivalent to those of Fuji Electric's "FRENIC-Mini (C2S)." The developed motor is not only highly efficient in itself but also capable of saving a substantial amount of energy by combining variable-speed drive that uses inverter control.

3.2 Structure of developed motor

Figure 3 shows the external appearance of the developed motor. The motor frame incorporates inverter functions. Assuming applications to drive air conditioning equipment fans, it makes use of the cooling air of the fan to cool the inverter-integrated motor. To improve the cooling capability, an aluminum frame is adopted. In the frame that houses the inverter, the structure can prevent excessive resistance of the airflow while maintaining sufficient cooling areas especially in locations where a large amount of heat is expected to be generated from electronic components inside the frame. Considering the high efficiency of the motor itself at the efficiency class IE4, output and torque magnitudes and needless of the constant-output power operation range, we have designed the product as a permanent-magnet type synchronous motor using ferrite magnets. The structure also features a reduced distance from the inverter output to motor input, which offers a decrease in insulation degradation due to micro-surge voltage resulting from the wiring constant.

Table 1 Specifications of inverter-integrated motor (developed motor)

Item	Specification
Rated output power	1 kW
Rated speed	1,000 r/min
Input voltage	3 phase, 200 V series
Efficiency	84.1% or more (single motor) (Class IE4 as defined by IEC 60034-30-1)
Temperature range	−20 °C to +60 °C
Inverter performance	Equivalent to FRENIC-Mini (C2S)
Vibration resistance	1 G, 10-150-10 Hz × 20 cycles 1 octave/min, in 3 directions X-Y-Z

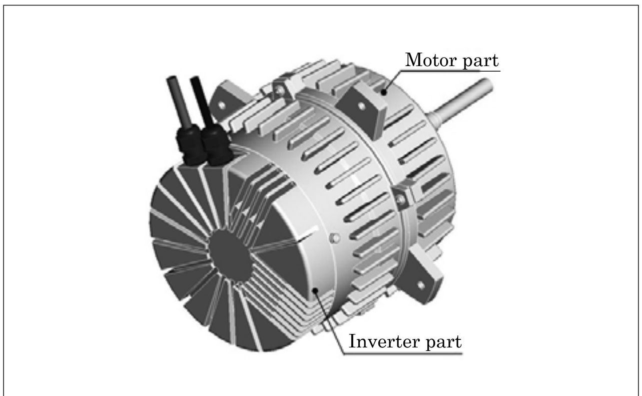

Fig.3 Inverter-integrated motor (developed motor)

4. Test Results

4.1 Efficiency measurement

Because it is difficult to conduct a torque-efficiency characteristic test with the fan mounted, the shaft of the inverter-integrated motor was connected via a coupling to the motor used as the load of a machine for taking measurement in the cold state. Figure 4 shows load characteristics on the constant rotating speed condition at 1,000 r/min. At the rated torque of 9.55 N·m, a measured efficiency of 86.3%, which is higher than the efficiency requirement of the motor itself of 84.1%, has been observed.

4.2 Temperature-rise test with actual load

Figure 5 shows the actual load test device. Some simplified wind tunnel equipment was built, and the device was mounted in it for testing. The airflows, static pressures and temperatures of various parts of the inverter-integrated motor were measured by using a flowmeter, pressure gauge and thermocouple respectively.

Figure 6 shows the measured temperature of various parts with the rated load applied and the analyzed values obtained by thermal fluid analysis. The horizon-

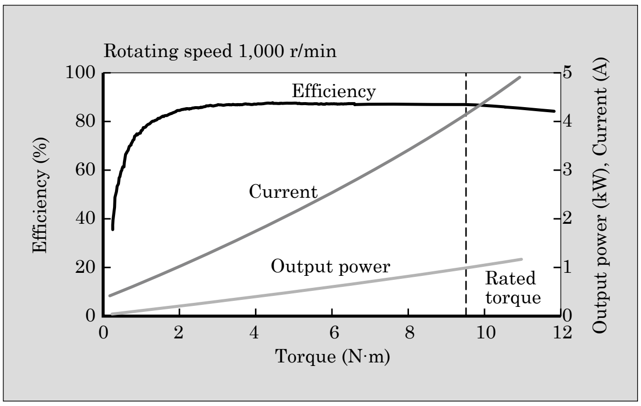

Fig.4 Load characteristics (single motor)

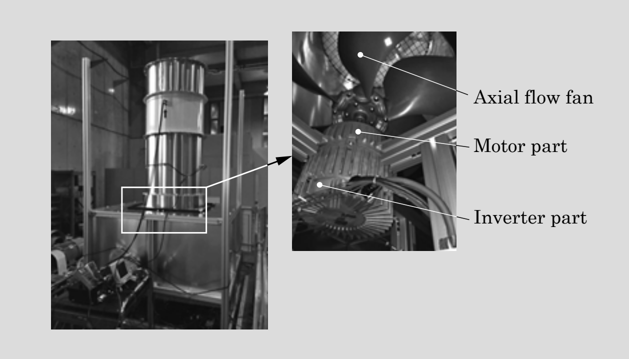

Fig.5 Actual load test device

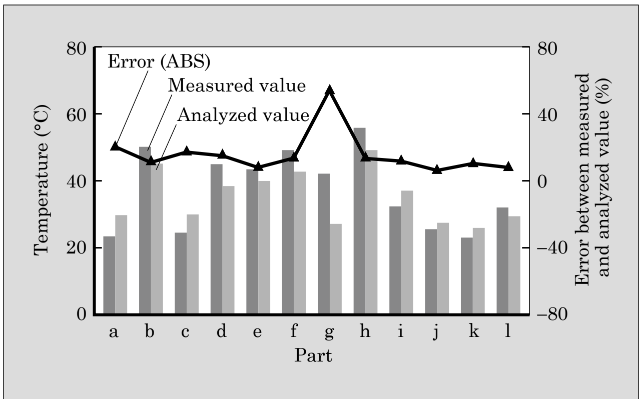

Fig.6 Measured and analyzed values of temperatures of various parts under rated load

tal axis (a to l) of the figure represents the respective parts including the inverter board. The figure indicates that:

(a) The analyzed values of the temperatures of the respective parts roughly agree with the measured values, and the temperature rise error is 17% on average.

(b) The measured temperatures of parts do not exceed the allowable values.

Parts with a large difference between the measured and analyzed value such as part g, are considered to be under the influence of heat generation from other parts located in the vicinity. In addition, study items for improving the analysis accuracy have been identified such as a reduction in the cooling capacity caused by separation of the cooling air flowing in the frame of the inverter-integrated motor.

4.3 Vibration test

Outdoor units for air conditioning such as gas heat pumps incorporate a compressor and engine inside the equipment. Vibration of these devices causes a vibration to be applied to the motor integrated in the same equipment. Accordingly, we conducted a vibration test under Table 1 and verified after the test that there was no damage to various parts of the inverter-integrated motor.

For measuring the natural frequency (resonance frequency) of the respective parts of the inverter, we conducted an impact test on the inverter board alone and also modal analysis of the board itself by using an analysis tool called ANSYS Workbench[*1], and the results were compared with the actual measurements. Figure 7 shows the measured and analyzed values of the natural frequency of the inverter board. The horizontal axis (A to I) represents the respective parts including the inverter board. The error between the measured and analyzed values is not exceeding 5%, showing good accuracy. It has been revealed, however, that some parts have a natural frequency between 10 and 150 Hz, which is the vibration resistance frequency range of the development specification. This frequency range is the frequency band of vibration from the engine and compressor in the air conditioning equipment. We noticed that those parts required specific consideration at a vibration test so that a defect isn't caused on the use.

Figure 8 shows how the vibration test was carried out. In the test, the jig for securing the inverter-integrated motor has been proven to show a natural frequency value of 200 Hz or higher in the natural value analysis, and the jig has been confirmed to have no influence.

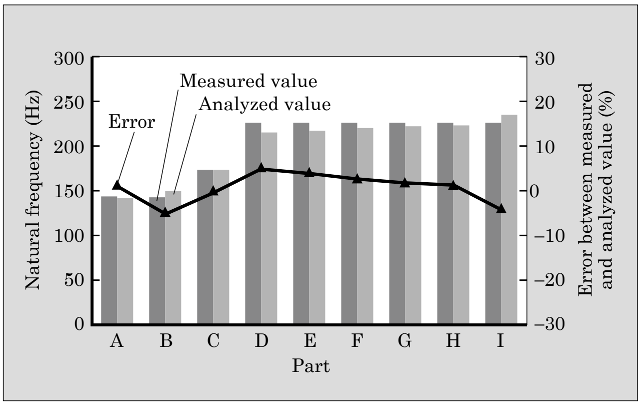

Fig.7 Measured and analyzed values of natural frequency of inverter board

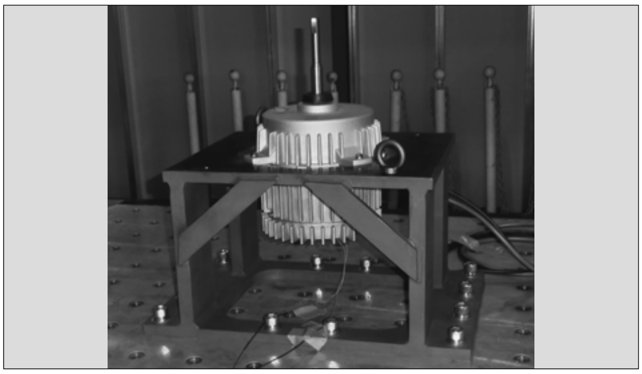

Fig.8 Vibration test

*1: ANSYS Workbench: trademark or registered trademark of ANSYS Inc. and its subsidiaries

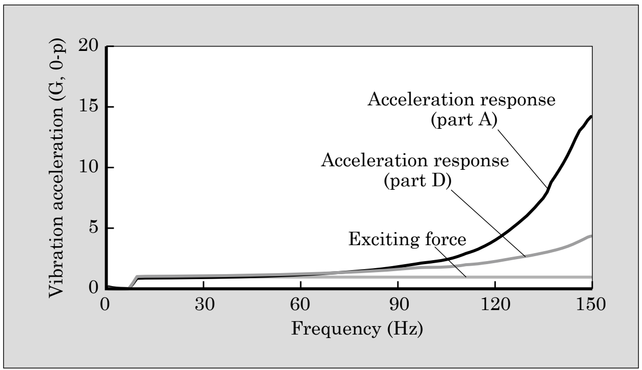

Fig.9 Example of vibration acceleration frequency characteristics of parts A and D (in the Y-axis direction)

Figure 9 shows an example of vibration acceleration frequency characteristics of parts A and D (in the Y-axis direction). No resonance was observed at 150 Hz or lower and the development specification was satisfied. The inverter-integrated motor was disassembled after the vibration test, and the motor, including its parts, has been confirmed to have no failure.

5. Energy-Saving Effect and Downsizing

5.1 Energy-saving effect

This section presents verification of the inverter-integrated motor in terms of energy-saving effect by comparing it with a standard motor (efficiency class IE1) and the top-runner motor "Premium Efficiency Motor" (IE3) that conforms to the efficiency regulation starting in April 2015. Figure 10 shows an example of the energy-saving effect. It shows a comparison of the annual power consumption and energy charge of the respective types.

The power consumption and energy charge have been calculated based on the following conditions.

(1) Types

○ Standard motor: MLC1107B, 1.5 kW, 6-pole
○ Premium efficiency motor: MLU1107B, 1.5 kW, 6-pole
○ Inverter-integrated motor: 1.5 kW, 1,000 r/min

(2) Conditions

○ Run for 10 hours/day, operated 250 days/year at 80% air volume
○ Energy charge unit price 16 yen/kWh [unit price used for calculating energy-saving effect of top-runner motors by the Japan Electrical Manufacturers' Association (JEMA)]
○ Standard motor and premium efficiency motor: damper control Inverter-integrated motor: inverter control (calculated using the relationship between air volumes and power requirements shown in Fig. 2)

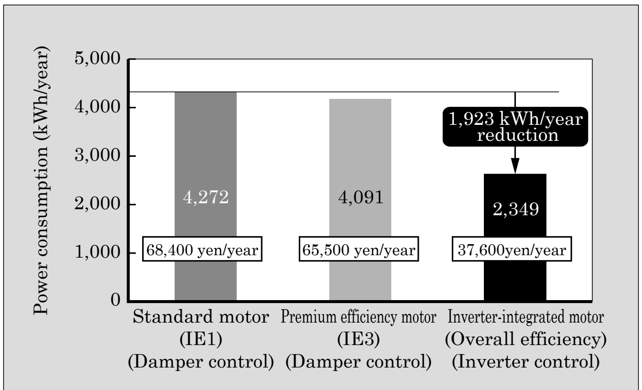

Fig.10 Example of energy-saving effect

Based on Fig. 10, the energy-saving effect of the inverter-integrated motor is a 45% decrease (1,923 kWh/year) from that of the standard motor and a 43% decrease (1,742 kWh/year) from that of the premium efficiency motor. Regarding energy charges, the reducing effect obtained is 30,772 yen/year from the standard motor and 27,872 yen/year from the premium efficiency motor.

5.2 Downsizing

Figure 11 shows the dimensions of the standard motor, general-purpose inverter and inverter-integrated motor, and Table 2 shows a comparison in terms of volume and mass. The inverter-integrated motor and standard motor have equivalent torques. As compared with the standard motor, the inverter-integrated motor has achieved a volume reduction of 7% and a mass reduction of 24%. In the comparison with a variable-

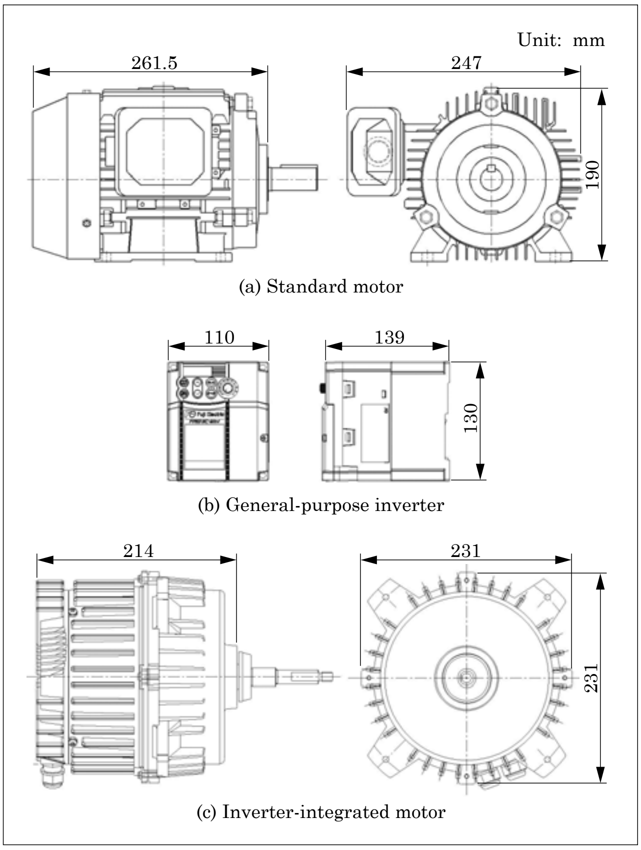

Fig.11 Dimensions of each model

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Table 2 Volume and mass comparison

Type	Volume and mass
Standard motor MLC1097B 1.5 kW, 4 poles	Volume: 12.27×10^6 mm^3 Mass: 16.5 kg
General-purpose inverter FRN1.5C2S-2J	Volume: 1.99×10^6 mm^3 Mass: 1.7 kg
Inverter-integrated motor	Volume: 11.42×10^6 mm^3 (Comparison with single standard motor: −7% Comparison with standard motor and general-purpose inverter: −20%) Mass: 12.5 kg (Comparison with single standard motor: −24% Comparison with standard motor and general-purpose inverter: −31%)

speed drive system that combines the standard motor and general-purpose inverter, the volume has been reduced by 20% and mass by 31%.

In addition to the evaluation of the efficiency characteristics, temperature and vibration resistance of the inverter-integrated motor described above, we have conducted drive evaluation of the inverter board itself and comparison with a general-purpose inverter to successfully verify its equivalent performance in terms of the drive performance and harmonic current level.

6. Postscript

This paper has described an inverter-integrated motor that incorporates inverter functions in a motor. In the future, we intend to work on the development to improve the efficiency, energy-saving and downsizing and lightening using the inverter/drive and rotating machine technology to help prevent global warming.