Technologies for High-Efficiency Induction Motors

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1. Introduction

Induction motors are widely used throughout industry, and account for 40–50% of the total electric energy consumed in the world. In Japan, they account for approximately 75% of the electric energy consumed by industry and approximately 55% of the country's total energy consumption.(1) Under such circumstances, the Japanese Top Runner Program in conformance with IEC standards for energy efficiency classes(2) was introduced in April 2015, and IE3 (Premium Efficiency) was made mandatory. To meet this obligation, Mitsubishi Electric Co. released the SF-PR Series of new general-purpose induction motors.(3) Their efficiency is remarkably higher than the IE3 level and offer compatibility(4) as an advantage for users. In addition, the application of IEC standards to single-phase induction motors was started in 2015, and high-efficiency motors for small ventilation fans are undergoing rapid development. This paper outlines the technologies for improving the efficiency of induction motors and realizing compatibility and mass productivity.

2. Compatibility

For a given output, larger motors can improve efficiency rather easily, but it may be difficult to install a larger motor on loading equipment that requires a motor, so upsizing should be avoided. Since induction motors are mass-produced at factories, extremely difficult manufacturing methods cannot be used. In addition, rated conditions vary from country to country. In Japan alone, the rated conditions for 200-V systems include 200 V/50 Hz and 200–220 V/60 Hz. Ideally, the IE3 level and all requirements should be satisfied with one type of motor.

2.1 Maximum torque

Maximum torque refers to the largest torque that a motor can output at the rated voltage and rated frequency. If the torque is low, the motor cannot cope with load changes. Maximum torque is determined mainly based on leakage flux rather than the main flux, which means that, to secure compatibility, the leakage reactance cannot be significantly changed.

2.2 Starting characteristics

When the secondary resistance is reduced, the rated slip factor becomes small, which reduces the secondary copper loss. However, the impedance at the starting time becomes smaller and the starting current becomes larger. When the starting current is larger, the capacity of the breaker and the power supply needs to be increased, so this condition should be avoided. In addition, if the number of turns is increased to reduce the starting current, the starting torque becomes smaller, which may make starting impossible. Thus, it is difficult to improve the efficiency by simply reducing the secondary resistance.

2.3 Power factor

When a load current becomes small due to improved efficiency and it nearly equals the exciting current, the power factor deteriorates. When the power factor is poor, the reactive power increases, which increases the capacity of the power supply. Thus, greatly reducing the load current compared with the exciting current should be avoided.

3. Technologies for improving efficiency

This section describes a technology for improving the efficiency of induction motors while satisfying compatibility, and another technology for improving the efficiency while maintaining mass productivity by short line takt time.

3.1 Shape of rotor slots

To reduce secondary copper loss, the resistance of the secondary conductors needs to be reduced, but this increases the starting current. Rotor flux at the rated load is slip frequency, which is rather low, but it becomes the rated frequency at the starting time. As shown in Fig. 1,

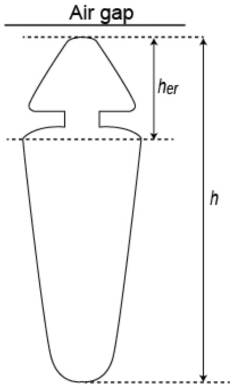

Fig. 1 Rotor slot

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the resistance is high in the range (h_{er}) where a large current flows at the starting time and the overall resistance is low, whereby the secondary resistance can be designed to be low while the starting current is reduced by designing a rotor slot.

3.2 Air gap

Reducing the primary copper loss by reducing the exciting current is effective for improving the efficiency without the problem of a reduction in the power factor mentioned above. The exciting current can be reduced by reducing the air gap between the stator and the rotor. However, a reduced air gap is largely affected by any variation in the accuracy of construction and the rotor tends to deviate from the center of the stator (rotor eccentricity). When the rotor is eccentric, electromagnetic noise is generated and such products are not acceptable from the standpoint of reliability.

It has been found that when a rotor is eccentric, the voltage on the counter coil becomes uneven, and such voltage differences are nearly proportional to the eccentricity and they change in near-sinusoidal waveforms against the direction of eccentricity. Applying this knowledge, Mitsubishi Electric established a production technology (assembly method) for centering the motors.(5) In the production technology, the voltage differences on the counter coil are brought to nearly zero, and the stator and the rotor are press-fitted into a frame and brackets. In addition, counter coil voltage differences in two or more directions are used for centering the motors, so efficiency can be improved in short line takt time, with no deterioration in mass productivity. Figure 2 shows the change in efficiency with the change in size of the air gaps on a motor for small ventilation fans. It can be seen in the figure that as the air gap becomes smaller, the efficiency becomes higher. This centering technology has made it possible to improve the efficiency while reducing the increase in electromagnetic noise.

3.3 Inter-bar current loss

Stator wires are stored in a small slot, so the density distribution of flux in an air gap is not a sine wave in the circumferential direction and includes space harmonics. When these space harmonics interlink with the secondary conductor, stray load loss occurs. When the air gap is made smaller, the space harmonics occurring on the stator further interlink with the rotor secondary conductor, which increases the harmonic secondary copper loss. To reduce this loss, a rotor slot is skewed in the axis direction (rotor skewing). However, because the secondary conductor is manufactured by pouring fused aluminum into a slot, the secondary conductor and the laminated core on the side of the slot are brought into electrically conductive contact and a current flows between the bars (inter-bar current). To reduce this current, the secondary conductor and the rotor core should be electrically insulated. As a method for reliably insulating the secondary conductor and the core in a short line takt time, Mitsubishi Electric has succeeded in introducing twisting and twisting-back processing(6) for small motors. In this process, the rotor core is twisted and twisted back in the circumferential direction. This method has made it possible to provide a gap between the secondary conductor and the core, which significantly reduces the inter-bar current. Figure 3 shows the efficiency measurement results for a motor for small ventilation fans. It can be seen that the efficiency has been greatly improved. In addition, this process minimizes performance variations caused by inter-bar currents.

3. Conclusion

This paper described the technologies for improving the efficiency of induction motors while maintaining compatibility between their starting characteristics and the power factor. We will continue to contribute to a low-carbon society by developing technologies for improving efficiency to reduce electric energy consumption.

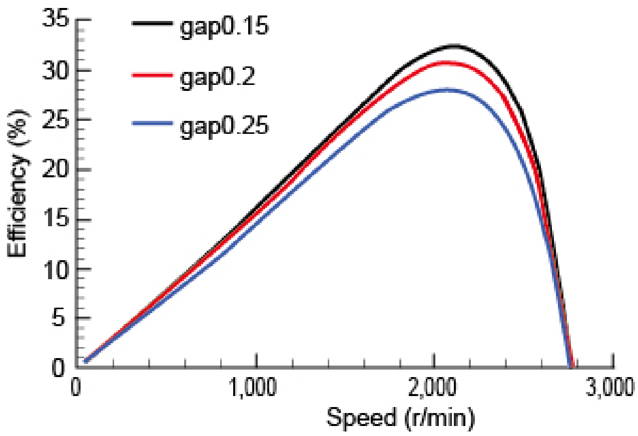

Fig. 2 Speed–efficiency characteristics

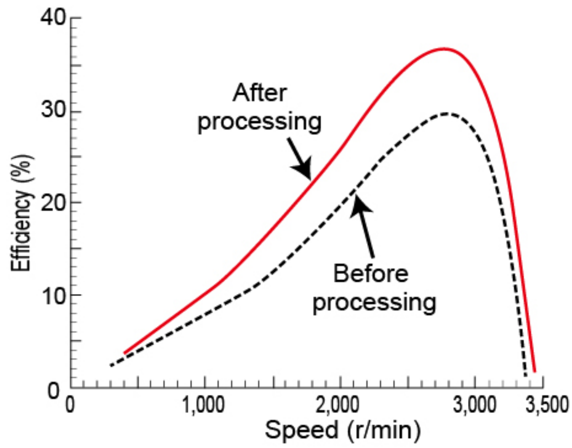

Fig. 3 Speed–efficiency characteristics

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