High-Efficiency Motors for Air-Conditioner Compressors

*By Hitoshi Kawaguchi and Tomoaki Oikawa**

Although induction motors are used as the source of motive power in a variety of equipment used in the home because of their durability, quietness, and low cost, they are increasingly being replaced by high-efficiency brushless DC motors due to increased environmental concerns. In particular, because the power consumed by air conditioners and refrigerators accounts for some 40 percent of household power consumption, brushless DC motors are being used in both of these appliances.

This article describes the efficiency-enhancing technologies in brushless DC motors for room air-conditioner compressors developed and implemented by Mitsubishi Electric Corporation.

Brushless DC Motors for Room Air-Conditioner Compressors

Beginning in the air-conditioner season of 2001, the corporation completely revised the structure of the 4-pole distributed-winding interior permanent magnet (IPM) motor that had been used until then, successfully improving efficiency through moving to a 6-pole concentrated-winding IPM motor with a jointed separated core structure.

Motor Structures for Compressors

Fig. 1 shows the cross-section of the structure for a room air-conditioner compressor. In the motor for the compressor, the stator is secured (though a thermal-shrinking process) to the inside of the compressor housing, and the rotor and the compressor element are linked by a shaft that transmits the driving force to the rotary compressor section.

Fig. 2 shows lateral cross-sectional diagrams of the new motor for compressors and conventional motors, and Fig. 3 shows the side views. Fig. 3a is a conventional motor, with a structure in which a 3-phase 4-pole 24-slot distributed winding stator is combined with an IPM rotor. Fig. 3b is the new motor, with a structure that combines a 3-phase 6-pole 9-slot concentrated winding stator with an IPM rotor. The stator uses a proprietary jointed-separated core (i.e., a joint-lapped core) invented by the corporation, and the rotor uses an IPM structure with a surface layout in which six double arc-shaped magnets are embedded.

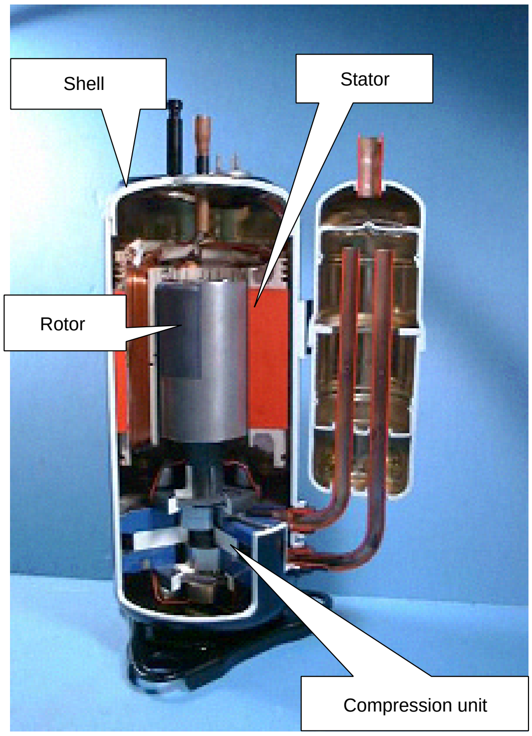

Fig. 1 Cross section of compressor

A Shift to Concentrated Windings Using Jointed-Separated Cores

The new motor dramatically decreases the resistance in the coils through the selection of the concentrated winding approach.

As shown in Fig.2b, concentrated windings, in which the winding is placed directly on each tooth, can reduce the length of the coil windings below that of the distributed winding approach. This reduction in length produces the effect of reducing the copper loss by 22 percent. Furthermore, as shown in Fig. 3a and 3b, the height of the coil end was about halved, also effective in reducing the size of the motor.

In order to fully exploit the benefits of the concentrated windings, a jointed-separated core was used for the first time in a compressor motor. This made it possible to produce perfectly aligned windings, stacked up like drum cans, producing a coil space factor of 95 percent. Fig. 4 shows the

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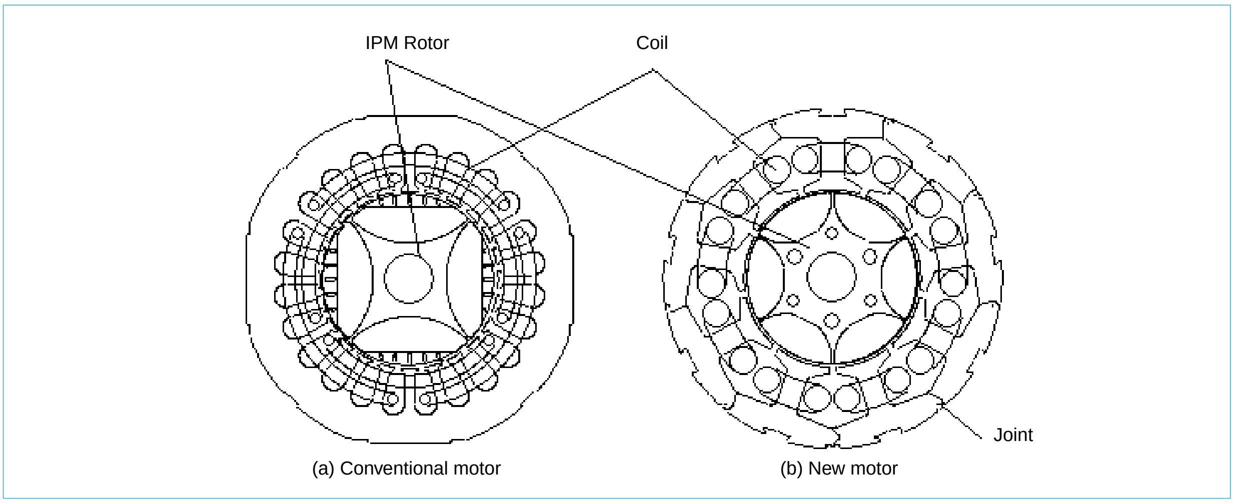

Fig. 2 Cross section of motor

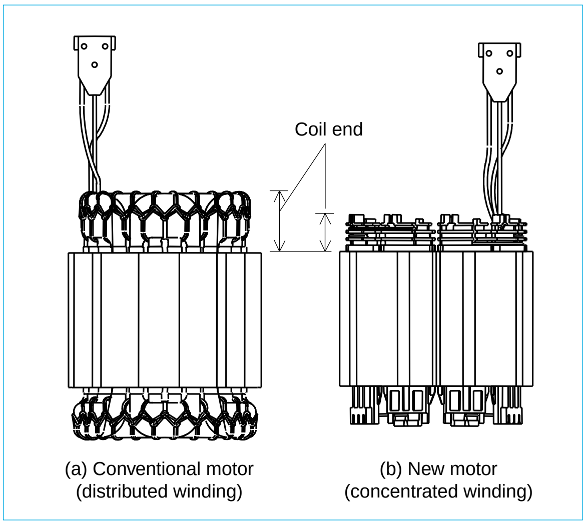

Fig. 3 Side vew of motor

relationship between the coil space factors and the efficiencies achieved by motors at Mitsubishi Electric. The best coil space factor achievable with a conventional one-piece core for the stator was

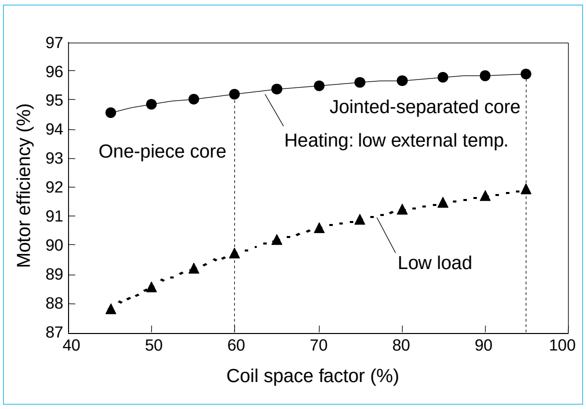

Fig. 4 Relationship between the coil space factor and the motor efficiency

no more than 50 to 60 percent. Conventional motors' copper loss was cut 28 percent by increasing the cross-sectional area of the slots and increasing the coil space factor. When this reduction in copper loss is combined with the reduction in length mentioned above, the copper loss is cut to half that of the conventional motor.

The IPM Structure and the Change to Six Poles

Generally, concentrated windings have tended to suffer from increased iron loss. To reduce iron loss, a change was made from a 4-pole to a 6-pole structure, and the rotor structure was reworked. Moving to six poles from four poles reduced the deviation in the magnetic flux-density distribution in the core, and while the electrical frequency was increased, the iron loss was successfully reduced by 11 percent from the 4-pole concentrated-winding motor under rated conditions (3,180rpm at 1.63N-m). Furthermore, a surface-layout IPM rotor structure was used in which permanent magnets are positioned near to the outer peripheral part of the rotor and electromagnetic steel plate with even lower iron losses was adopted. In addition, the shape of the permanent magnets in the layout on the rotor surface was changed from D-shaped to a double-arc shape in order to increase the thickness of the magnets, thereby increasing the magnetic force. For the orientation of the magnets, a reverse-radial orientation was used to direct the central focus of the orientation towards the outer diameter. Magnetic-field analysis was used to perform optimization so as to maximize the torque constant. Switching to six poles and reworking the rotor structure made it possible to reduce the iron loss by about 20 to 30%, depending on the load conditions.

New Motor Efficiency Performance

Fig.5 compares the efficiency for the output of a 6-pole concentrated-winding jointed-separated core IPM motor, a 4-pole distributed-winding IPM (GD4 rotor) motor, and a 4-pole concentrated-winding one-piece core IPM (GD4 rotor) motor. Motor efficiency was measured at the compressor load points for motor output powers between 200W and 1.2kW. The load points of the compressors are classified broadly into low-power conditions, rated conditions and high-power conditions, and the speed and torques are both adjusted simultaneously for each of these conditions. The results indicate that the efficiency of the 6-pole concentrated-winding jointed-separated core motor was superior throughout the entire range, and

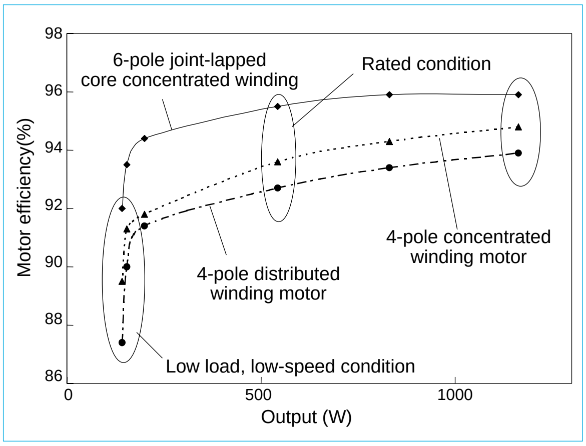

Fig. 5 Comparison of motor efficiencies

there was a particularly dramatic improvement in the efficiency under low-power conditions. The results also indicated efficiency increases of 5% under low-power conditions, 3% under rated conditions, and 2% under high-power conditions. Fig 6 compares the losses in the respective motors when operating under rated conditions. When compared with the 4-pole distributed-winding IPM motor the concentrated-winding IPM motor had a

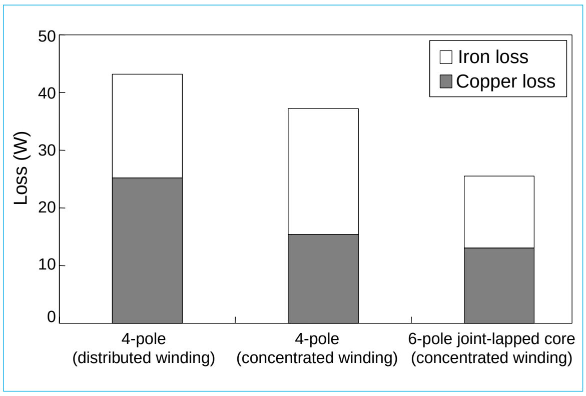

Fig. 6 Comparison of motor losses

40% reduction in copper loss, the iron loss increased by 20 percent, and the improvement in efficiency in the motor was no more than about 1%. In contrast, in the 6-core concentrated-winding jointed-core IPM motor, both the copper loss and the iron loss were reduced, successfully producing dramatic reductions in the copper loss (50%) and the iron loss (20%).

Use of the high-efficiency brushless DC motor is effective in energy conservation and size reductions in equipment for the home. The brushless DC motor, as reported for use in compressors, has produced a dramatic leap in efficiency over conventional motors. However, rapid advances in performance due to joint-lapped cores and new magnetic materials, including electromagnetic steel plate, are being proposed by the corporation, which is planning in this way to continue the development of motors with even higher efficiency levels. ❑

References

[1] Kazuhiko Baba, Hitoshi Kawaguchi et al.: Investigation into Increasing Performance of Brushless DC Motors, Electrical Association Rotary Motor Research Association Materials, RM-00-141

[2] Hiroyuki Akita, Hitoshi Kawaguchi Et al.: Energy Conservation and Increased Efficiency in Compressor Motors for Air Conditioners, Mitsubishi Electric Corp. Technical Reports, 75, No.10,655 to 658 (2001)

[3] Improved Performance in Small Motors, Electrical Association Engineering Reports, No.744