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ABSTRACT

With the increase of recent environmental concerns, energy saving is one of the most important issues in air conditioning and refrigeration industry. Likewise, in order to improve the annual performance factor of heat-pump air conditioners, capacity modulation by means of motor rotational speed control and multiple fixed speed compressor system are becoming widespread. To meet these demands, we have developed new scroll compressor series for packaged air conditioners with revolutionary high efficiency.
The scroll compressor has advanced asymmetric scroll wrap, optimized axial compliant mechanism and sophisticated oil feeding system. The newly developed ultra-high efficiency magnetic synchronous (MS) motor is adopted instead of conventional induction motor. As a result, the motor's energy loss has been reduced by 40%, thus realizing a noticeable improvement in compressor efficiency.
This paper outlines the series of scroll compressors that has number of useful features in application.

1. INTRODUCTION

The situation faced by refrigerating and air conditioning industry has become increasingly severe, and the greatest issue involved is the global environment. CFC refrigerants, which contain the ozone-depleting substance chlorine, were completely phased out in 1995 in developed countries as a result of the Montreal Protocol signed in 1987. Even HCFC refrigerants were regulated in 1996, and limitations imposed on these substances will lower the level of their use to practically zero by 2020. Consequently, most refrigeration and air conditioning equipment has been transitioning to HFC refrigerants, which contain no chlorine. However, to reduce greenhouse gas emissions in response to the 3rd Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3), the changeover to HFC refrigerants in air conditioning equipment in Japan has been accompanied by efforts to improve the energy efficiency of such equipment.
A compressor is the core of refrigerating and air-conditioning equipment. To further enhance energy conservation, we have developed a new type of scroll compressor equipped with an ultra high efficiency magnetic synchronous (MS) motor based on a novel concept. An MS motor is an ultra high efficiency motor that integrates the functions of an induction motor and a direct current (DC) magnet motor, and can be driven directly by a commercial power source without using an inverter.

2. CONSTRUCTION AND FEATURES OF MS MOTOR

Induction motors have been commonly used in fixed speed compressors that are directly driven by a commercial power source, and high-efficiency DC magnet motors have been used in inverter-driven variable speed compressors. In general, the induction motor is inferior efficiency compared with the DC magnet motor. Therefore we have developed the scroll compressor equipped with a more highly efficient self-start type

magnet synchronous (MS) motor in place of induction motor to enhance the energy efficiency of the fixed speed compressors. Figure 1 shows the concept of the newly developed MS motor, and Figure 2 shows the types and features of motors used in hermetic compressors.

2.1 Induction motor

Directly driven by a commercial power source, an induction motor is one of the most commonly used motors in hermetic compressors. The motor consists of a stator and a rotor that has secondary conductors located in an annular form. The rotor is driven by the rotating magnetic field, generated in the stator. The rotor rotates while slipping with respect to the rotating magnetic field. The efficiency of the induction motor deteriorates compared to the DC magnet motor because the current flows through the secondary conductors.

2.1 DC magnet motor

DC magnet motor is widely used in highly-efficient room air conditioners and package air conditioners. It consists of a stator and a rotor provided with permanent magnets internally, and is driven by an inverter. The rotating magnetic field generated in the stator and the magnetic poles of magnets located in the rotor rotate the motor at a speed that is synchronous with the rotating magnetic field. Although the efficiency of the motor by itself is high, switching losses occur in the inverter circuit.

2.3 MS motor

The MS motor is an ultra high efficiency motor that integrates the features of the induction motor and the magnet motor mentioned above [1]. As shown in figure 1, permanent magnets are located on the inside of the rotor, and secondary conductors in annular form are located on the outside of the magnet. The magnet used was a rare-earth magnet (neodymium magnet) with high flux density. During start, current flows into the secondary conductors inside the rotor, and the motor operates as an induction motor. On the other hand, when the rotational speed of the rotor approaches the synchronous speed, the motor operates as a direct current (DC) magnet motor and performs synchronous operation. During synchronous operation, practically no current flows into the secondary conductors; therefore, there is no degradation in efficiency. Since the motor can be operated directly from a commercial power source, without using an inverter driving circuit from the time of start, there is no energy loss in the driving circuit, and the motor can be operated with high efficiency.

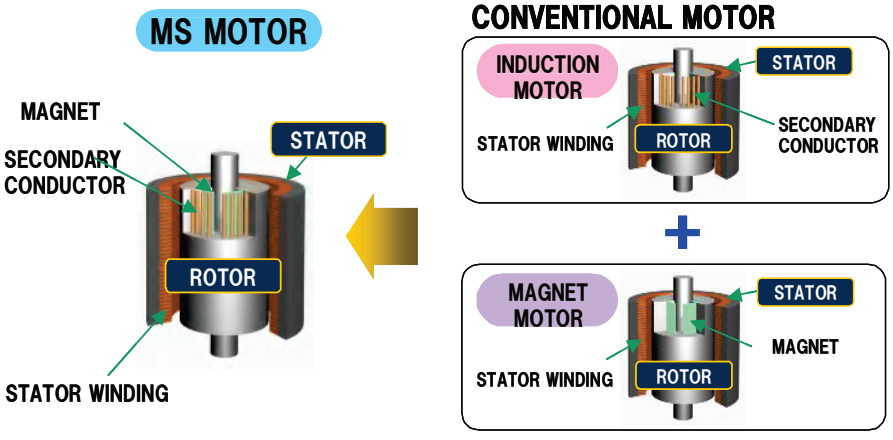

Figure 1 Magnetic Synchronous (MS) Motor

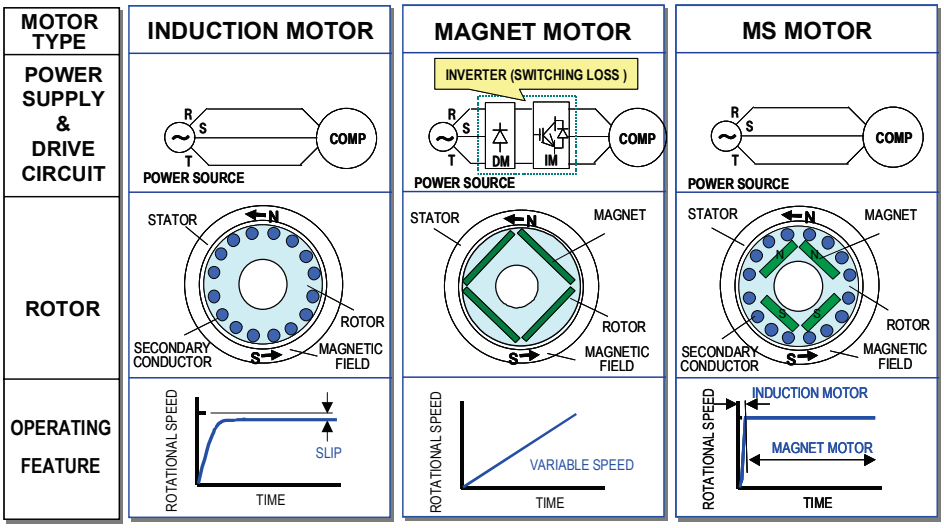

Figure 2 Motor Type and Features for Hermetic Compressors

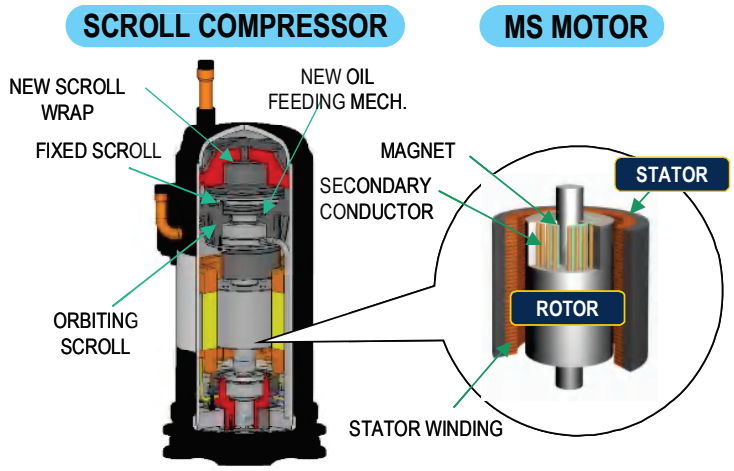

Figure 3 Scroll Compressor with MS Motor

3. MS MOTOR-DRIVEN SCROLL COMPRESSOR

3.1 Configuration of scroll compressor

An ultra high efficiency MS motor-driven scroll compressor has been developed and commercialized. Figure 3 shows a cross-sectional view of the developed scroll compressor, and its specifications are listed in table 1. The compression mechanism of the compressor is located on top, while the MS motor for driving it is located on the bottom, with the motor being cooled by discharged gas. It is important to reduce leakage loss, heating loss, and mechanical loss to improve the efficiency and durability of the scroll compressors [2]-[5]. For this reason, a new asymmetric scroll wrap, in which the wrap profile is formed by an involute based on a circle with varying radius [6], and the intermittent lubricating system to the back pressure chamber were adopted [7],[8].

Table 1 Specification of Compressor

Item	
Compressor Type	Scroll
Scroll Wrap Profile	Asymmetric
Motor	MS Motor
Rated Output	7.5 kW
Displacement Volume	100 cm^3/rev
Refrigerant	R410A

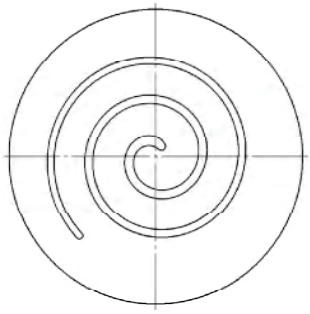

Figure 4 Scroll Wrap Profile

Figure 4 shows the new scroll wrap profile. The scroll wrap pitch and thickness gradually varies with the involute angle, according to the strength requirement. Under the same design conditions, the new scroll wrap dimensions can be reduced more than those with an ordinary involute scroll wrap. In an asymmetric scroll wrap, the compression chamber formed on the internal line of the orbiting scroll wrap moves into its suction and compression strokes in different phase from that of the compression chamber formed on the external line. So the asymmetric wrap has the advantage that the flow passage resistance loss and intake heating loss can be reduced to a minimum.

On the other hand, minimizing sliding losses in the compression mechanism of the compressor is also considered an important factor in achieving high efficiencies. Thanks to the adoption of the intermittent lubricating system, an appropriate amount of lubricating oil to the back pressure chamber is ensured regardless of the operating conditions of the compressor, and a good balance of reliability and high efficiency can be attained.

3.2 Characteristics of MS motor

Since the MS motor can be operated directly by a commercial power source without using an inverter, it is important to clarify the performance of the MS motor at steady state condition and also at start-up condition. We have developed simulation method to analyze motor performance combined with dynamic characteristics of the compressor. Figure 5 shows the typical start-up characteristics of the MS Motor. During start, the motor operates as an induction motor. On the other hand, when the speed of rotation of the rotor approaches the synchronous speed, the motor operates as a DC magnet motor and performs synchronous operation.

Figure 6 shows a comparison of the characteristics of the newly developed MS motor and a conventional induction motor. The efficiency of the MS motor is higher than that of induction motor regardless of the magnitude of load. As shown figure 7, the energy loss in the MS motor was reduced by 40% compared to the induction motor at rated power output.

3.3 Efficiency of scroll compressor

Figure 8 shows a comparison of the efficiency of the scroll compressor with the MS motor and the efficiency of a conventional scroll compressor. In this figure, the efficiency of the conventional compressor at pressure ratio of 3.3 is taken as 100%. The efficiency in the newly developed compressor was able to be enhanced significantly, by more than 6%, compared to the conventional model. Moreover, since the compressor can be directly driven by a commercial power source, higher efficiency could be achieved even when compared to a compressor using a DC magnet motor wherein inverter-driven circuit losses are unavoidable.

Figure 9 shows an example of scroll compressors installed in a multi-package air conditioner. An inverter-driven variable speed compressor and two or more MS-motor driven fixed speed compressors are installed. Capacity modulation by means of rotational speed control of the variable speed compressor and number control of fixed speed compressors are combined according to the cooling load, so that adjustments can be made to achieve optimum cooling performance. As the result, significant COP enhancement was attained in the developed model, compared to the conventional model.

CONCLUSIONS

Compressors are the core components in refrigerating and air-conditioning equipment. We have developed a new type of scroll compressor equipped with an ultra high efficiency magnetic synchronous (MS) motor based on a novel concept, and investigated its performance characteristics. As a result, following conclusions were obtained.

- The MS motor is an ultra high efficiency motor that integrates the functions of an induction motor and a DC magnet motor. It can be operated directly by a commercial power source without using an inverter.
- The MS motor can reduce energy losses by 40%.
- The newly developed compressor, equipped with the MS motor, achieved an increase in efficiency of more than 6%.

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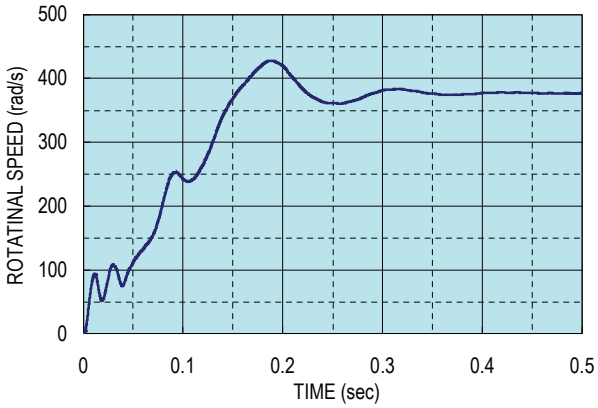

Figure 5 Start-up Characteristics of MS Motor

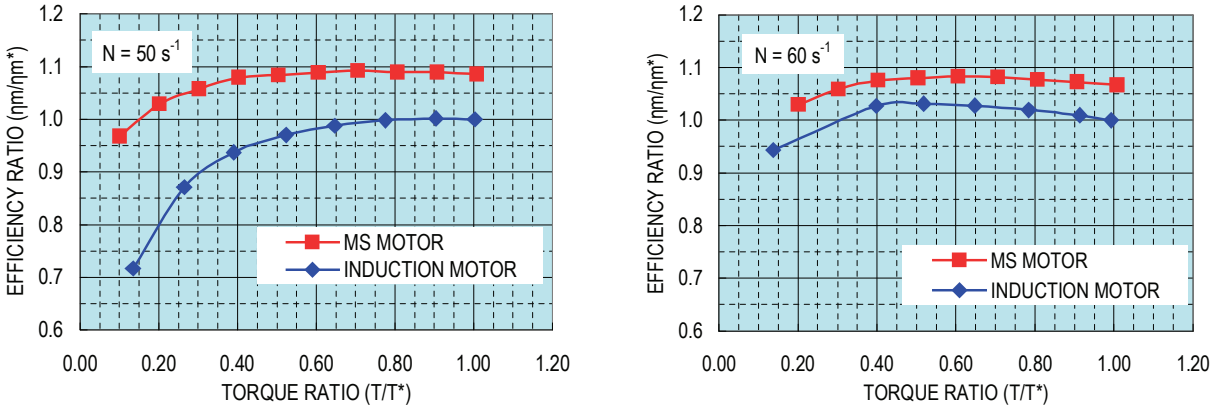

Figure 6 Motor Efficiency (1)

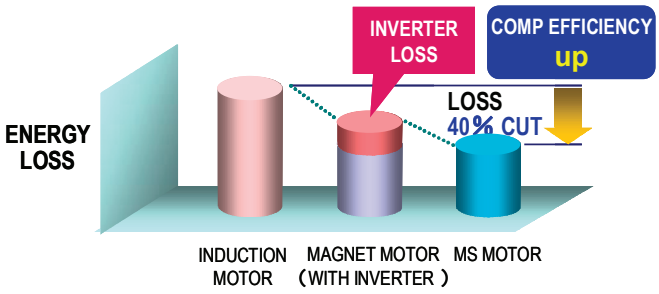

Figure 7 Motor Efficiency (2)

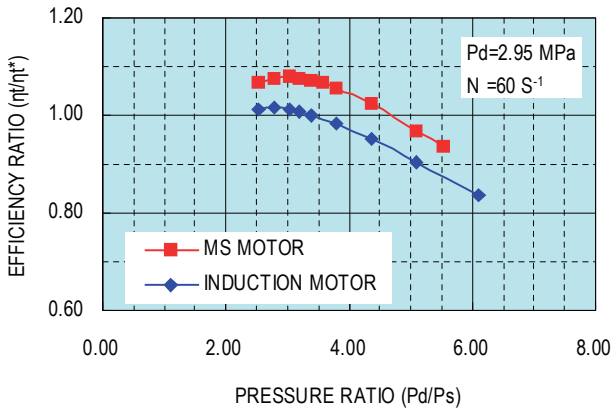

Figure 8 Compressor Efficiency

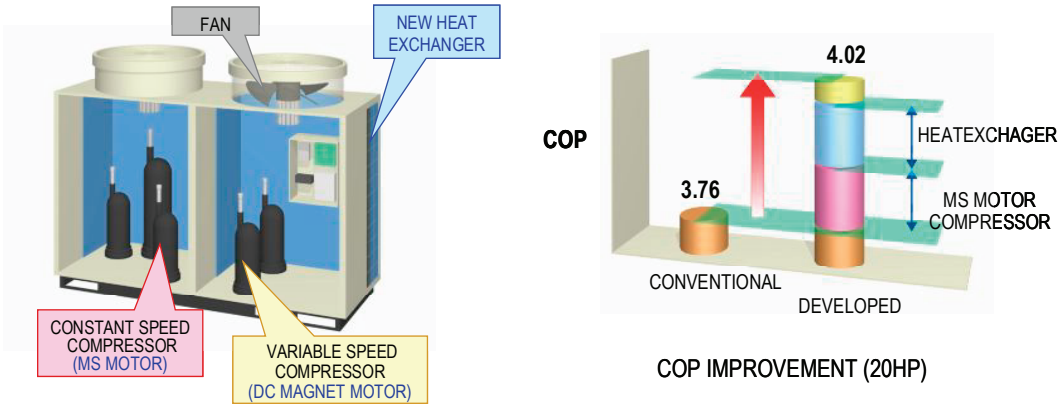

Figure 9 Multi-Packaged Air Conditioner