PM Motors for Fluid Apparatus with Small Size, High Speed, and High Efficiency

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ABSTRACT

In order to reduce global greenhouse gas emissions to virtually zero by 2050, it is necessary to introduce clean energy and reduce power consumption. Fluid apparatus is required to save energy, such as pumps, compressors, blowers, and coolers, because it accounts for a large percentage of motor applications and consumes a large amount of power. The PM motor Fuji Electric has newly developed is improved in efficiency and cooling performance to achieve compactness, allowing users to downsize their equipment. Furthermore, it achieves better energy savings by using inverter-based variable speed operation and direct drive operation, which uses no belts and gears to avoid mechanical loss.

1. Introduction

Motors are indispensable in the social life and industrial activities. They are used as the power sources of diverse devices and systems, such as elevating machinery, conveyors, fans, pumps, compressors and other infrastructural equipment, as well as machine tools, printing machines, cranes, coolers and other various industrial machines. PM motors (permanent magnet synchronous motors) are small in size, light in weight and highly efficient and have other excellent characteristics. However, they need to be used in combination with an inverter as they cannot be driven alone unlike other common motors, which serve if only connected to a commercial power supply. They will bring about a great deal of advantages to equipment in optimum applications owing to the high-speed motor rotation with an inverter in addition to the reduced energy consumption of the motor itself. This paper covers the PM motor that is applied for fluid apparatus and that contributes to achieve small size, high speed, and high efficiency with the combined use of an inverter.

2. Fluid Apparatus Overview

2.1 Need for global warming countermeasures and energy-saving fluid apparatus

The goal of the “Paris Agreement” is to keep the rise in mean global temperature to below 1.5°C above pre-industrial levels. To achieve this goal, the global greenhouse gas emissions need to be reduced to zero by 2050 with no allowance for absorption by forests, oceans, etc. In Japan, the prime minister in his speech on October 26, 2020 announced the country’s policy to reduce greenhouse gas emissions to net zero by 2050 and pledged the compliance with the Paris Agreement nationally and internationally. From now on, decarbonization and reduced power consumption by conversion to clean energy from the use of electric energy are a matter of urgent necessity.

The global annual consumption of electric energy, which is approximately 20 trillion kWh, is broken down in Fig. 1, which shows that 40% of the whole is consumed by motors. In addition, Fig. 2 shows that fluid apparatus, such as pumps, compressors, blowers, and coolers, represents 80% of the energy consumed by motors. If motor efficiency including that of fluid apparatus is improved by 1%, the global power consumption can be reduced by 64 billion kWh and CO_2 emissions by 27 million t.

The energy-saving requirements for fluid apparatus, which heavily consumes electric energy, are expected to intensify more in the future to come.

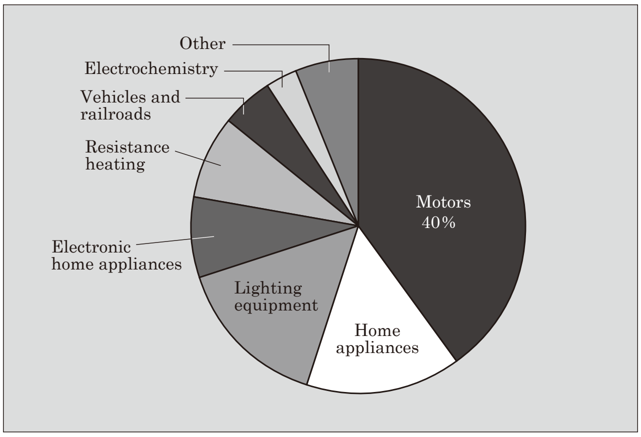

Fig.1 Breakdown of the world’s power consumption[(1)]

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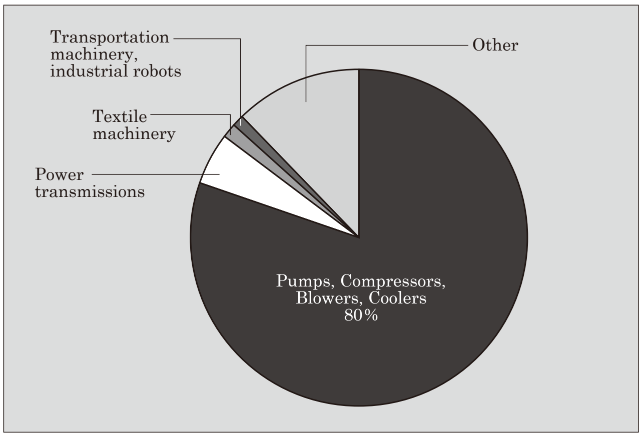

Fig.2 Motor applications

2.2 Application of inverter and PM motor to fluid apparatus

Fluid apparatus is required to reduce in size and weight under the constraints of installation footprint and floor load of the equipment. With typical fluid apparatus, its fluid mechanical unit can be reduced in size and weight if the motor is revved up. However, high-speed rotation produces a mechanical loss when a speed up mechanism, such as belts and gears, is used. In that case, the use of a direct-drive mechanism can remove this mechanical loss and enhance efficiency and energy-saving performance. This also eliminates the maintenance of the mechanical parts for speeding up, such as belt adjustment and inspection. With the employment of a direct-drive mechanism using a PM motor, these effects can be achieved.

In addition, PM motors can save energy because they give intrinsically low-loss operation with no secondary copper loss (rotor copper loss). On the other hand, PM motors need to be driven with a dedicated inverter for the control of frequency, voltage, and current.

However, power consumption can be reduced if the rotational speed is optimally controlled with inverter control. Energy can be saved with optimal control because the flow rate of fluid apparatus that uses the centrifugal force of the bladed wheel is proportional to the rotational speed whereas the needed power is proportional to the cube of the rotational speed. A greater energy-saving effect results especially when the rate of flow is lower.

3. Characteristics of PM Motor for Fluid Apparatus

3.1 Specification of developed motor

Table 1 and Fig. 3 shows the specifications and structural cross-sectional views of the developed PM motor for fluid apparatus, respectively.

The center height, which is from the motor's installation surface to the axial center, is 250 mm with the conventional model and is 160 mm with the developed model, which namely has achieved a size reduction of 36% and also has reached efficiency class IE4, IEC 60034-30-1.

Table 1 Specifications of PM motor for fluid apparatus

Item	Specification
Cooling method	Water-cooled
Rated output	75 kW
Rated rotational speed	7,200 r/min
Center height	160 mm

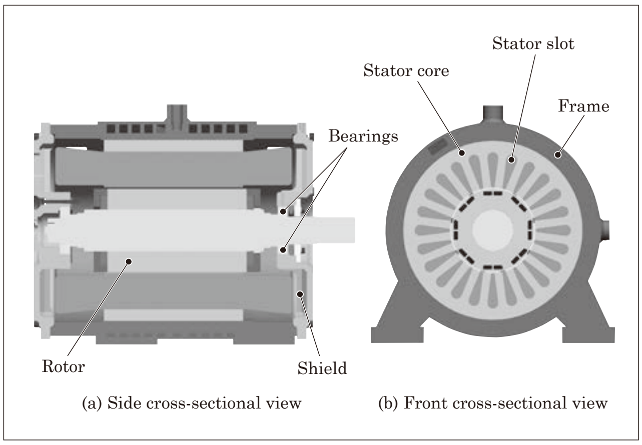

Fig.3 Structural cross-sectional view of PM motor for fluid apparatus

Moreover, depending on customer requests, the motor can be powerfully cooled by taking advantage of part of the refrigerant of the cooler provided for the fluid mechanical unit. As results, the motor can be significantly smaller than the conventional model.

3.2 Loss reduction

To achieve a small sized PM motor for fluid apparatus, the stator core has been designed to be smaller in diameter and higher in magnetic flux density. In addition, the employment of a direct-drive mechanism supports high-speed rotation. To further enhance efficiency, the reduction of iron loss and mechanical loss is required. As a countermeasure for iron loss, we have employed a high-grade thin electrical steel sheet. Furthermore, we have optimized the teeth and yoke widths by considering the trade-off between copper loss and iron loss ratios and at the same time studying the distribution of amount of iron loss at the teeth and yoke as shown in Figs. 4 and 5.

3.3 Cooling capacity improvement

Motor temperature rises when operated. Temperatures, which broadly affect the lifetimes of windings and bearings, need to be curbed below the specifications. Although the losses arising in PM motors are not great, the cooling capacity needs to be improved since the cooling surfaces are reduced when the size re-

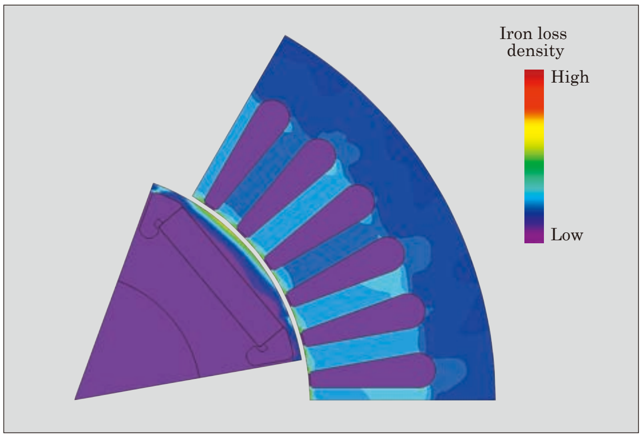

Fig.4 Analysis result of iron loss at the teeth and yoke

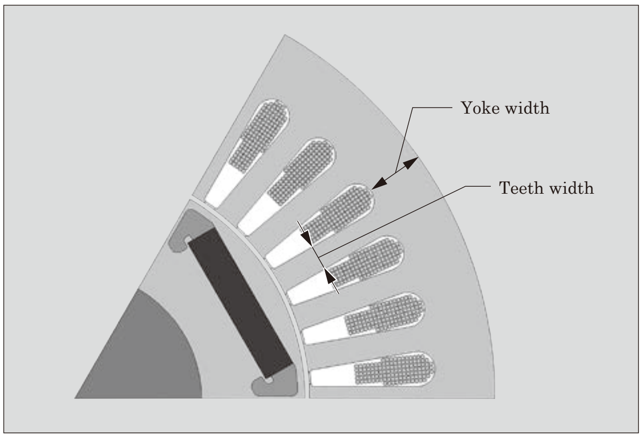

Fig.5 Optimization of teeth and yoke widths

duction of motors advances.

In response, we have used the liquid-cooling method, which has higher cooling capacity than conventional air-cooling methods and contributes to size reduction. For the flow channel, which passes a refrigerant such as cooling water or cooling oil into the motor, there are two methods available—the pipe method and the jacket method (see Table 2). The pipe method reduces the risk of liquid leakage, but the flow channel used is limited to cylindrical shape, which deprives the flow channel of design flexibility. Another shortcoming is that thermal resistance is increased since the pipe and frame are provided as separate parts. In the jacket method, the flow channel is directly placed on

Table 2 Comparison of cooling methods

Item	Jacket method	Pipe method
Advantage	○High design flexibility of flow channel ○Wider heat transfer area → Higher cooling performance	○Reduced liquid leakage risk
Disadvantage	○Liquid leakage risk present	○Low design flexibility of flow channel ○Increased thermal resistance → Lower cooling performance

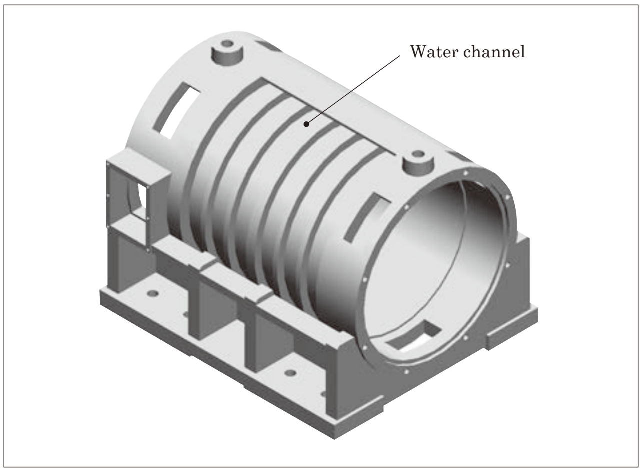

Fig.6 Example of frame in the jacket method

the frame as shown in Fig. 6 and this makes the cross-sectional shape of the flow channel highly flexible to secure a wider surface area for heat transfer. Therefore, this method has a higher cooling performance. In this project, we have adopted the jacket method in order to secure cooling performance. As for liquid leakage, risks have been worked around with prior liquid leakage tests and design measures.

3.4 Control over the heat irradiation performance of the stator

While the stator core of the motor has been greatly reduced in diameter, the stator slots have been made deeper to secure the cross-sectional area required for the conductor. This produced unevenness in heat irradiation performance that varied by conductor position. As shown in Fig. 7, heat irradiation performance is reduced when the conductors are located on the inner radius side. In order to avoid this, we had organized the windings on the outer radius side by elaborating the design and manufacturing process. Furthermore, as shown in Fig. 8, the variations in conductor position in the stator slot is controlled by measuring the inductance of the windings after the completion of winding process.

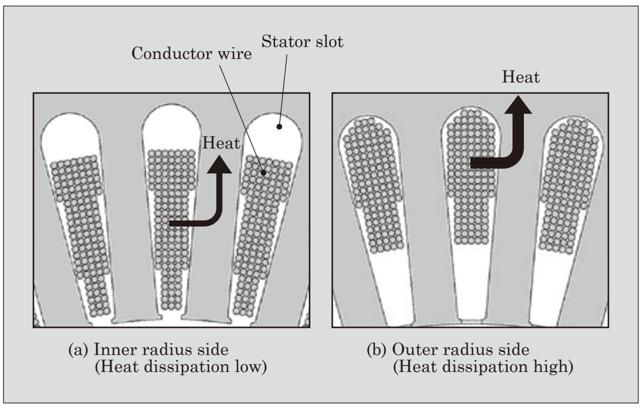

Fig.7 Heat irradiation performance

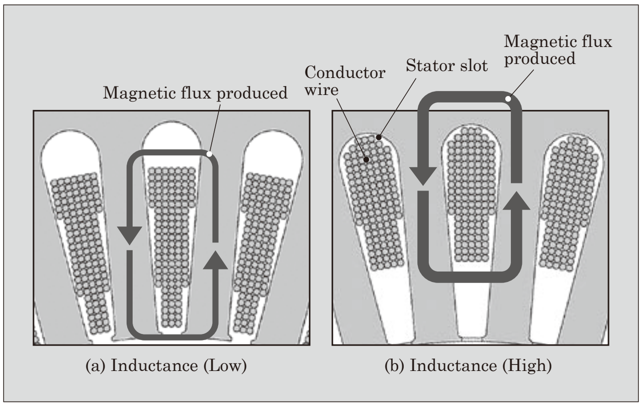

Fig.8 Winding position control

4. Postscript

In this paper, we have presented the PM motors for fluid apparatus with small size, high speed, and high efficiency.

The technological innovation on permanent magnets in Japan is particularly notable in history and is one of the very advanced fields when seen from a global perspective. In addition, inverter drive technology is another distinctive technological field in which the country excels. This PM motor drive system that combines a permanent magnet with an inverter drive is a technological field in which Japan is ahead of other countries, and above all, Fuji Electric possess advanced technical expertise to offer solutions. Facing the social issues of energy saving, the reduction of greenhouse gas emissions and environmental protection, the expectations for more efficient motors and inverters are running higher. To respond to these expectations, we Fuji Electric, as a supplier and a partner striving together with our valued customers to enhance the value of customer products, are fully committed to promote further technological advancement.

References

(1) Roland Brüniger. Motor Systems Annex IEA ExCo Meeting in Paris 14/15 April 2008.

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