Study on the Design Process of the Spoke Type Permanent Magnet Synchronous Motor Considering Magnetization Performance

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Abstract

Demagnetization of PMs directly leads to deterioration of the performance characteristics of PMSM. Therefore, it is common for the design process of PMSM to include consideration of demagnetization of PMs. In this paper, we propose the design process of spoke type PMSM considering not only the demagnetization performance of PM but also magnetization performance directly related to mass production. Unlike other motors, spoke type PMSM is difficult to obtain magnetization performance suitable for mass production unless magnetization performance is considered in the design stage. Therefore, the design process proposed in this paper will be a good guide for engineers designing spoke type PMSM in real industry. Finally, in order to verify the validity of the proposed design process, a real motor was fabricated and its performance was evaluated by experiments.

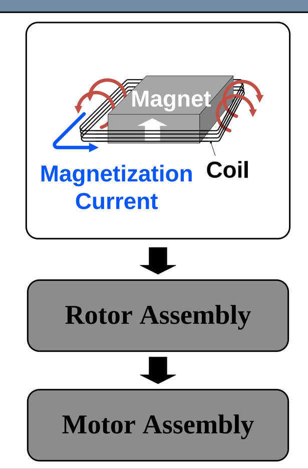
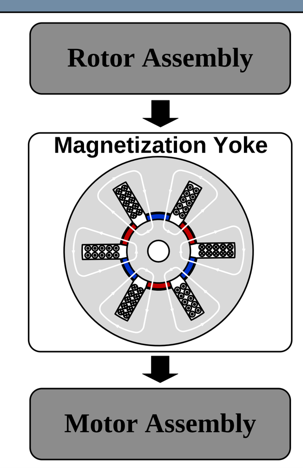
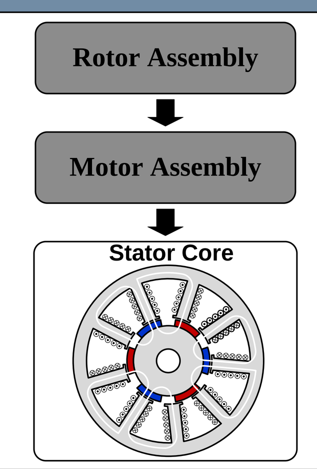
1. Introduction

An important index in determining the performance of a permanent magnet synchronous motor (PMSM) is the maximization of using the permanent magnet (PM) inserted in its rotor. Thus, a process that verifies the demagnetization of PM is generally included in a design process of PMSM. However, the magnetization, which is also one of the important indexes in the design process, has not been much considered. It is due to the fact that most of the mass produced motors are categorized as surface permanent magnet synchronous motors (SPMSMs) and interior permanent magnet synchronous motors (IPMSMs) and the whole magnetization of these motors can be performed using properly designed magnetization yokes without any major trouble.

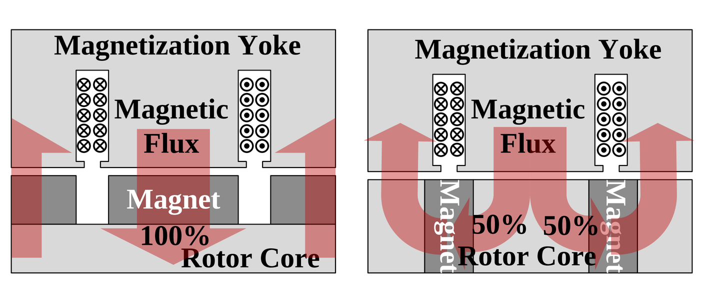
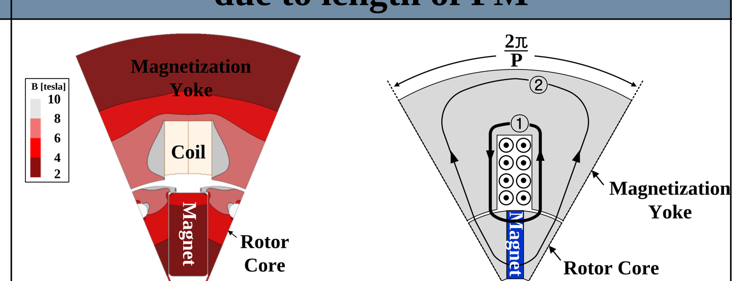
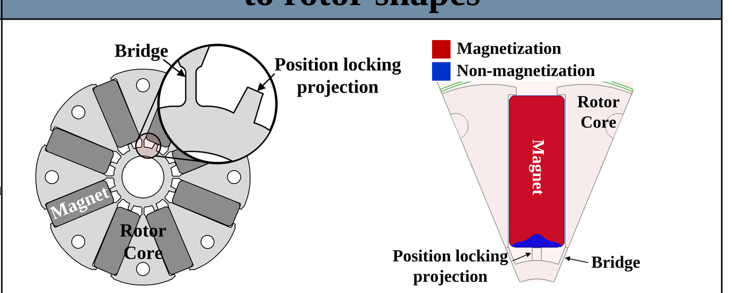
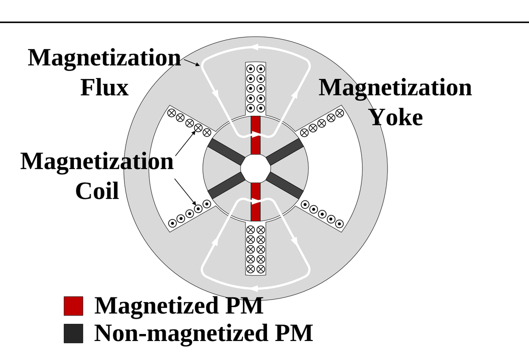
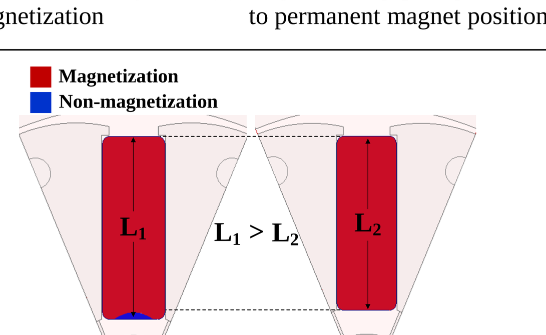
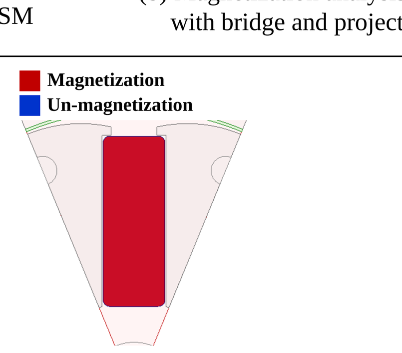
The spoke type PMSM is a shape that maximizes the surface area of PM vertically inserted in a rotor core. Also, studies on SPMSM have been actively performed because of increasing more power density than that of IPMSM. However, it plays disadvantage to the magnetization performance in a rotor structure for improving motor performances. Consequently, the whole magnetization could not possibly be performed depending on models of the spoke type PMSM and it requires a new process that has not been considered in the conventional design process of PMSM. Thus, a new design process of the spoke type PMSM that considers the magnetization performance is proposed in this study.

2. General Magnetization Methods of PMSM

As illustrated in Fig. 1, the magnetization method of PMSM is usually divided into three different types. First, it is a single supply magnetization method that magnetizes PM and assembles it as a single product. Second, it is a yoke magnetization method that first assembles un-magnetized PM on a rotor and magnetizes it in an exclusive yoke. Third, it is an in-situ magnetization method that applies the magnetization through applying magnetization currents to the stator coil after assembling the rotor with un-magnetized PM on the stator.

Explanation	Single Magnetization	Yoke Magnetization	In-situ Magnetization
Conceptual diagram of flowchart			
Magnetization Performance	Very High	High	Low (It is very difficult to be fully magnetized)
Mass production	Very low (The assembly process becomes complicated due to the magnetic force between magnetized magnets and the magnetic force between the magnet and the core.)	High	Very High

3. Decreasing Factors of the Magnetization Performance in the Spoke type PMSM

Item	① Separation of magnetization flux	② Magnetic saturation of the rotor core due to length of PM	③ Leakage magnetization flux according to rotor shapes
Cause of degradation	(a) Conventional SPMSM (b) Spoke type PMSM	(a) Magnetic flux density in magnetization (b) Magnetic air gap length according to permanent magnet position	(a) Rotor core shapes of the spoke type PMSM (b) Magnetization analysis result with bridge and projection
Solution			Magnetization analysis result without bridge and projection

4-1. Indicator of the magnetic saturation caused by the magnetization flux

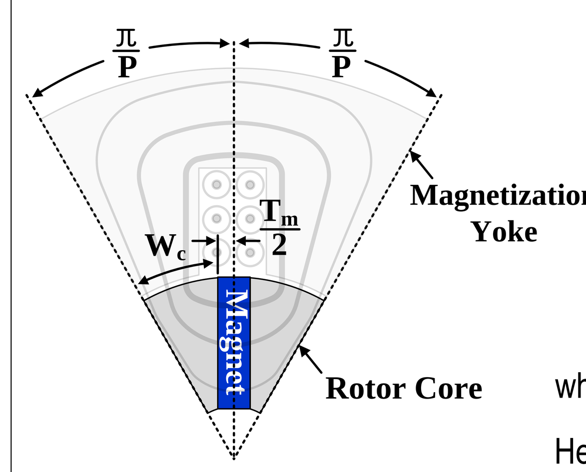


Fig.1 Analysis model for the magnetic saturation

The magnetic saturation of the rotor core caused by the magnetic flux is increased according to increases in the length of the inserted PM. The magnetic saturation of the rotor core can be influenced by the design parameter of the spoke type PMSM. In order to investigate the major factors that affect the magnetic saturation, the analysis model presented in Fig. 1 was used.

$$W_c = R\frac{\pi}{P}\left(1-\frac{T_m}{2}\right) = R\frac{\pi}{2P}(2-T_m) \qquad \text{......................(1)}$$

where P is the number of poles, T_m is the thickness of PM, and R is the radius of the rotor core.

Here, the scale of the magnetic flux density required for the magnetization of PM is assumed as B_m. As shown in Fig. 1, it is assumed that all magnetization fluxes, which pass through PM, are passing through the upper section of the rotor core. In the condition that all sections of PM are to be magnetized, the average value of the magnetic flux density at the upper section of the rotor core is determined as Eq. (2).

$$B_c = \frac{B_m L_m b_s}{W_c b_s} = \frac{2PB_m L_m}{R\pi(2-T_m)} \qquad \text{......................(2)}$$

where L_m is the length of PM, B_c is the average magnetic flux density in the upper section of rotor core during the magnetization process.

$$k = \frac{B_c}{B_m} = \frac{2PL_m}{R\pi(2-T_m)} \qquad \text{......................(3)}$$

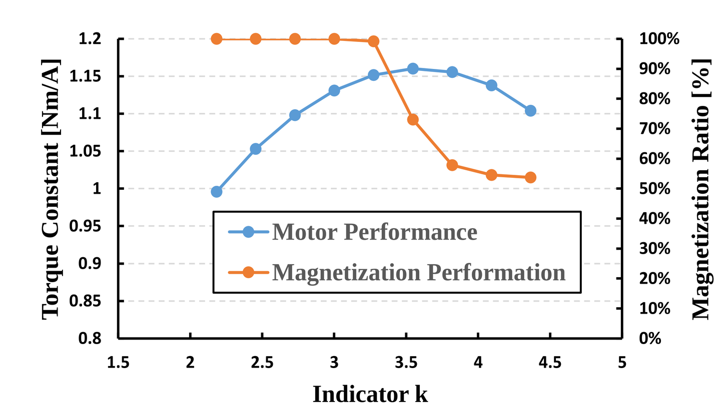


Fig.2 Comparison between the motor and magnetization performances according to the indicator, k

The parameter, k, defined in Eq. (3) is a magnetic saturation indicator in the rotor core that determines the level of magnetic saturation caused by the magnetization flux in the spoke type PMSM.

Design parameters that affect the magnetization performance of the spoke type PMSM also influence the motor performance such as a torque constant. Fig. 2 shows the analysis results of the magnetization and motor performances according to the values of the indicator, k. The relationship between the magnetization performance and the motor performance of the spoke type PMSM represents an inverse proportion. As a result, the spoke type PMSM that is designed by considering the motor performance only without considering the magnetization performance becomes a meaningless design in terms of mass production.

4-2. Design process with the magnetizing performance

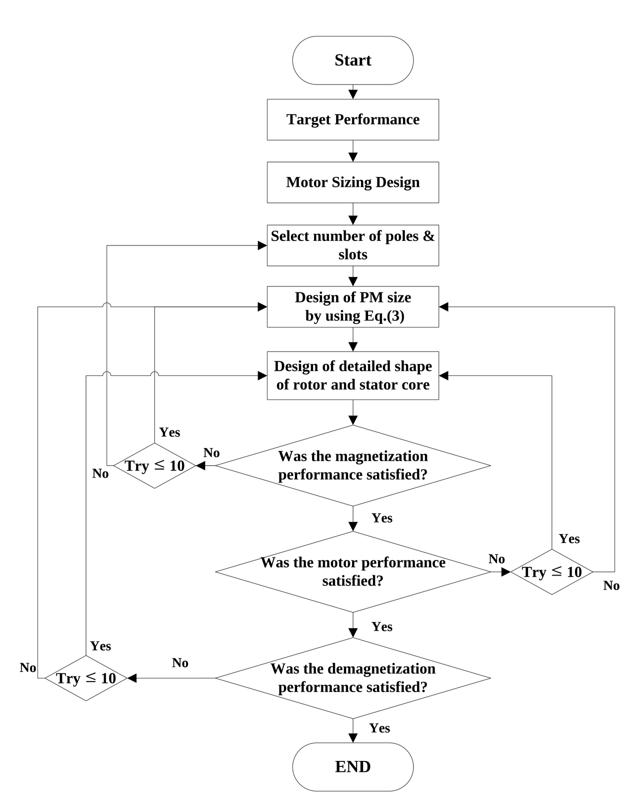


Fig.3 Proposed design process of the spoke type PMSM

The proposed design process makes possible to design spoke type PMSMs that allow the high productivity in mass production and represent excellent motor performances. The design targets of the proposed design process are to highly achieve magnetization performance, motor performance, such as torque constant and efficiency, and demagnetization performance. In addition, it makes possible to add cost as one of the design targets. In the design process, whether or not the selected specification achieves the design target is confirmed using FEA analysis. Here, the magnetization performance is to be verified first using the magnetization analysis after design of detailed shape of core. As the magnetization performance is satisfied, the demagnetization is also verified using the demagnetization analysis. If the target is not achieved in each stage, the design process should be returned to the stage of the PM size. Then, the target performance is to be verified again. If the target evaluation is failed by about 10 times repeatedly, the design process should be returned to the stage of determining the number of poles rather than the stage of the PM size in order to redefine the number of poles. It is due to the fact that the number of poles largely affects the motor and magnetization performances.

5. Verification

1) Fabricated motor and yoke specifications and pictures

Table 1. Specifications of Fabricated motor

Parameter	Unit	*Spec.*
Number of poles	-	8
Number of slot	-	12
Diameter of stator	mm	104
Diameter of rotor	mm	67.2
Air gap length	mm	0.4
Length of PM	mm	18.5
Thickness of PM	mm	8.5
Width of bridge	mm	0.75
Stack length	mm	23

Table 2. Specifications of Magnetization yoke

Parameter	Unit	*Spec.*
Number of slot	-	8
Air gap length	mm	0.7
Diameter of yoke core	mm	150
Turns of magnetization coil	mm	11
Stack length	mm	43

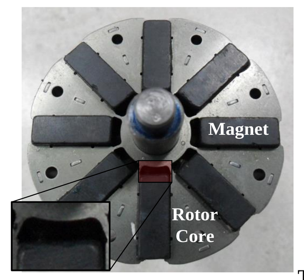
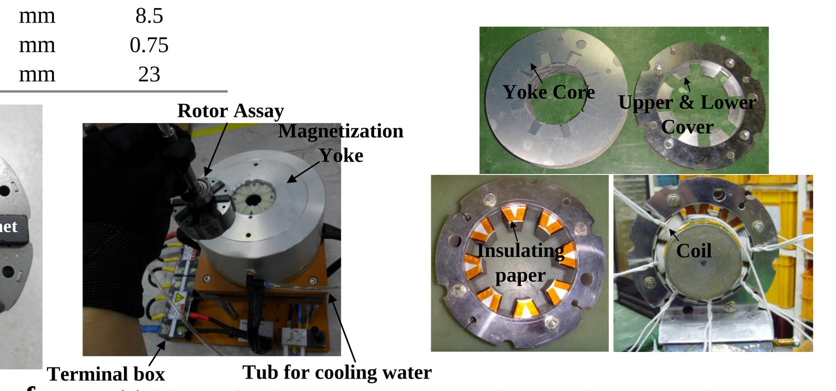


Fig. 4 Rotor core of fabricated spoke PMSM



(a) Magnetization test (b) Details of the yoke

Fig. 5 Fabricated magnetization yoke

2) Experimental Test

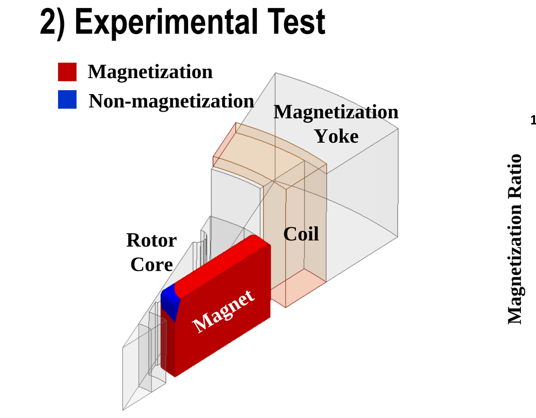


Fig. 6 Analysis result of 3D FEA (99.2%@10kA)

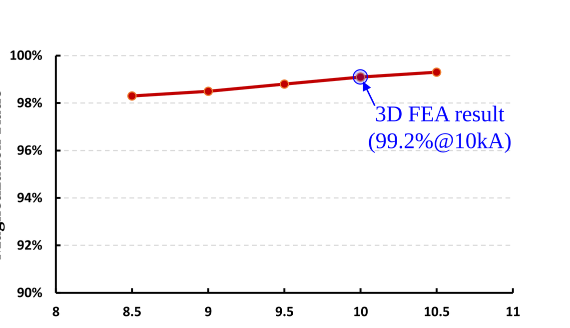


Fig. 7 Magnetization experiment results

9. Conclusion

In this paper, we proposed a new design process considering magnetization performance of spoke type PMSM. For this purpose, we have defined an indicator that can consider the level of magnetic saturation of the rotor core by the magnetization flux, which is the biggest cause of the deterioration of the magnetization performance. Through the design process using the defined indicator, we were able to design a spoke type PMSM with high magnetization performance and excellent motor performance.