Optimum Shape Design of Spoke Type Motor and Magnetizer using Finite Element Method and Response Surface Method

Young Hyun Kim[1], Jung Ho Lee[1], Sang Yeon Hwang[2], and Jin Kyonug Lee[1]

[1]Electrical Engineering Department, Hanbat National University, Daejeon, 305-719 Korea, kimyh@hanbat.ac.kr
[2]TSA Co.,Ltd, Gyeonggi-do, 449-935 Korea, yoonacjs@hanmail.net

This paper proposes criteria for an optimal shape design and a magnetizer system design to be used for a high-output spoke type motor. The paper also discusses methods of reducing high cogging torque and torque ripple, in order to prevent noise and vibration. The optimal design of the stator and rotor can be enhanced using Response Surface Method (RSM) and Finite Element Method (FEM). In addition, a magnetizer system has been optimally designed for the magnetization of permanent magnets to be used in the motor. Finally, this paper verifies that the proposed motor can efficiently replace interior permanent magnet synchronous motor (IPMSM) in many industries.

***Index Terms*—Spoke type Motor, Magnetizer, Cogging torque and torque ripple.**

I. Introduction

Performance efficiency in interior permanent magnet synchronous motors(IPMSM) can be improved by replacing rare earth permanent magnets. But, the rare earth magnets contain materials such as neodymium, the cost of which has increased over the last few years [1]-[2]. To solve this issue, cheaper ferrite magnets can be used as a substitute. This substitution results not only in a lower production cost, but also in a motor which has an output that is equal to or higher than that of IPMSM.

The ferrite magnet is disposed in a spoke type motor in a radial direction. Because this motor has both reluctance torque and a concentrated magnetic flux, the torque density increases [3]-[5]. However, the cogging torque of the spoke type motor is larger than that of IPMSM as it generates large differences in magnetic reluctance on the air gap. This cogging torque causes noise and vibration which has an adverse harmonic effect on components within the motor [6]-[7]. Also, there is a problem with the assembly of the permanent magnet, as it is magnetized due to the large repulsive force within the suction force in the permanent magnet. In order to solve this issue, we can apply an optimum designed motor and magnetizer system for the spoke type motor, using ferrite magnets. This can not only improve performance, but also reduces manufacturing costs.

In this paper, validity is verified using a finite element method (FEM) together with a response surface method (RSM) in order to optimize the shape of the stator and rotor, as well as the magnetization system. Using these methods enables an efficient system for mass-production of the motor.

II. Optimum Design and Characteristic Analysis

A. Design of the spoke type motor

In this paper, in order to reduce the cogging torque, a spoke type motor design method is proposed such as fig.1.

Based on this initial model, the stator and rotor are designed to reduce cogging torque.

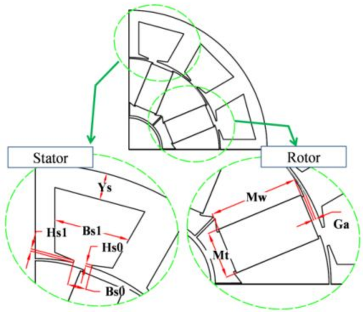

Fig.1 spoke type motor of the proposed model

In addition, a notch and arc have been applied in order to reduce cogging torque, and to obtain a sinusoidal air-gap flux density.

B. Optimum Design method

Fig. 2 and fig. 3 shown the analysis result of cogging torque and torque ripple using RSM. Variables such as Hs0, Hs1 and Bs1 have a significant effect on cogging torque changes. Since, in terms of torque characteristics, each of the design variables are independent, this combination enables us to produce a suitably efficient design model with an excellent level of cogging torque.

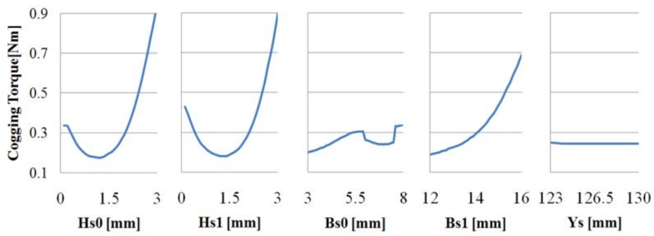

Fig.2 Cogging torque for each of the design variables

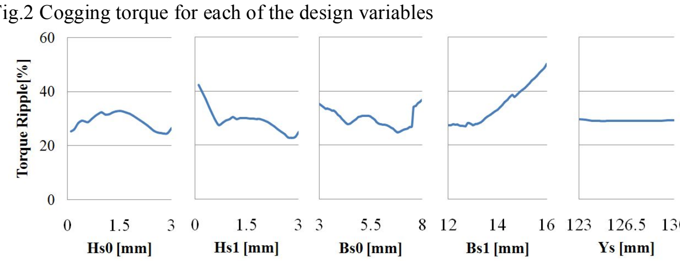

Fig.3 Torque ripple for each of the design variables

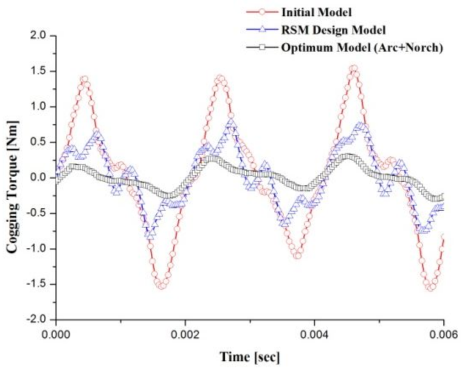

Fig.4 Cogging torque waveforms of each model

From the analysis results, cogging torque is reduced as a result of applying the notch to the stator tooth. The notch enables the reduction of cogging torque by generating a torque in the opposite direction. Fig. 4 shows the comparison of model cogging torque applying only the arc, and both the arc and notch. The cogging torque is reduced from 0.77[Nm] to 0.08[Nm]. Reduced cogging torque from only the notch shows less change and reduction of output in comparison to both the arc and notch. Therefore, for the Spoke-type electric motor design, we must consider the application of both the arc and notch.

C. Design of Magnetizer

Compared to other methods, magnetization using capacitor discharge requires a lower power consumption and can be obtained from a simple electrical circuit. In designing a magnetizer, the charging voltage and the capacitance are the main factors in generating the magnetization flux. Therefore these aspects are the most essential part of the design process.

In order to increase the magnetomotive force(MMF), when designing the magnetization Yoke, the number of winding turns should be reduced and the cross-sectional area increased. In this situation, a higher level of current is generated due to the decrease in both resistance and inductance. This larger current generates a larger MMF. However, if the number of winding turns is too small, then over a lapse of time, this can causes rapid variations within the current. These points must be carefully considered in the design process.

As shown in fig. 5, the magnet must be magnetized in the direction, $\mathbf{H_x}$. A ferrite magnet (12E) requires an intrinsic coercive force ($\mathbf{I_{hc}}$) of 360~420[kA/m] for magnetization. Therefore, for sufficient magnetization, a coercive force of at least 420[kA/m] in the direction of $\mathbf{H_x}$ is required.

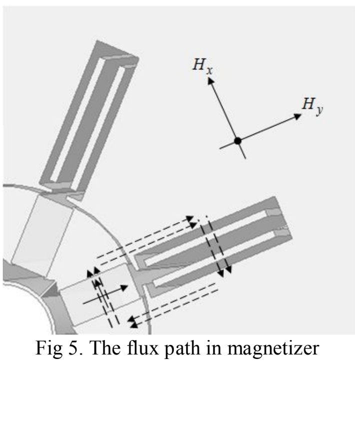

Fig 5. The flux path in magnetizer

The flux line of the ferrite magnet flows in the $\mathbf{H_x}$ direction, as shown in fig. 6(a). Fig. 6(b) shows the strength of the magnetic field required to magnetize a ferrite magnet according to each magnetization direction. The red portion of fig. 6(b) denotes a magnetic field with a strength of 420[kA/m] or above. This signifies that, in this direction the ferrite magnet (12E) will be fully magnetized.

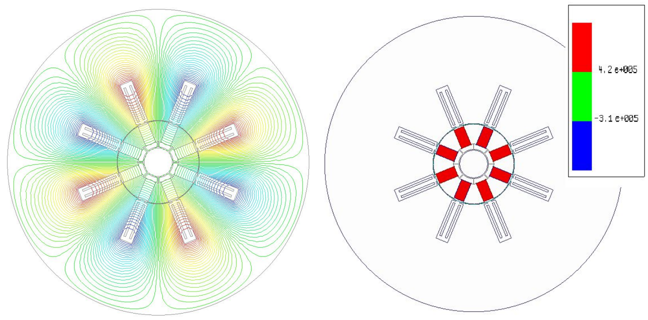

Fig 6. Fully magnetized ferrite magnet in magnetizer (Flux lines(a) and the strength of the magnetic field (b))

III. Conclusions

This paper proposes a design method for a system which can replace IPMSM which uses rare earth magnets. To verify the optimal design, torque characteristics are analyzed using FEM and RSM. Excellent results have been achieved in the reduction of cogging torque and torque ripple. Moreover, the design of the magnetizer enables a cost-effective mass-production system for the motor.

References

[1] A. Chiba, Y. Takano, M. Takeno, T. Imakawa, N. Hoshi, M. Takemoto, and S. Ogasawara, "Torque density and efficiency improvements of a switched reluctance motor without rare-earth material for hybrid vehicles," IEEE Trans. Ind. Appl., vol. 47, May/Jun. 2011.

[2] D. G. Dorrell, A. M. Knight, and M. Popescu, "Performance improvement in high-performance brushless rare-earth magnet motors for hybrid vehicles by use of high flux-density steel," IEEE Trans. Magn., vol. 47, no. 10, Oct. 2011.

[3] B. K. Lee, G. H. Kang, J. Hur, and D. W. You: "Design of Spoke type BLDC Motors with High Power Density for Traction Applications", Proceedings of IEEE-IAS Annual Meeting, vol. 2, pp.1068-1074 (2004).

[4] K. Y. Hwang, S. B. Rhee, J. S. Lee, and B. I. Kwon: "Shape Optimization of Rotor Pole in Spoke type Permanent Magnet Motor for Reducing Partial Demagnetization Effect and Cogging Torque", Proceedings of Int. Conf. on Electrical Machines and Systems, pp. 955-960 (2007).

[5] K. K. Han, D. Y. Lee, G. H. Kang, K. B. Jang, H. K. Shin, and G. T. Kim: "The Design of Rotor and Notch to Improve the Operation Characteristics in Spoke type BLDC Motor", Proceedings of Int. Conf. on Electrical Machines and Systems, pp. 3121-3125 (2008).

[6] T. Ishikawa, M. Yamada, and N. Kurita, "Design of magnet arrangement in interior permanent magnet synchronous motor by response surface methodology,"*IEEE Trans. Magn*., Vol. 47, No. 5, pp. 1290-1293, May 2011.

[7] E. S. Hamdi, DESIGN OF SMALL ELECTRICAL MACHINES, John Wiley & Sons Ltd, 1994.