The Optimization of Flux-Barrier Shape for Minimization Cogging torque and Radial Magnetic Force in IPMSM

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Abstract — In this paper, flux-barrier was installed in a motor to reduce cogging torque, then the characteristics of cogging torque and Radial Magnetic Force(RMF) were analyzed. Reduction of cogging torque by flux-barrier causes the decrease the torque ripple and the resonance by RMF.

I. INTRODUCTION

An Interior Permanent Magnet Synchronous Motor (IPMSM) has an advantage of high output power per unit volume because magnetic torque and reluctance torque caused by inductance differences of d-axis and q-axis are combined[1]. However, there is a disadvantage that the cogging torque is higher than SPMSM because a permanent magnet inserted in the IPMSM produces high flux density and saturation which was resulted from concentrated flux. As a result, vibration and noise are produced largely while operating a motor. To solve these problems, the flux-barrier which makes a sinusoidal flux density of an air gap in the basic model was installed to minimize the cogging torque. In addition, both the effects of cogging torque and RMF on vibration were investigated through the modal analysis.

II. FLUX BARRIER DESIGN AND VIBRATION

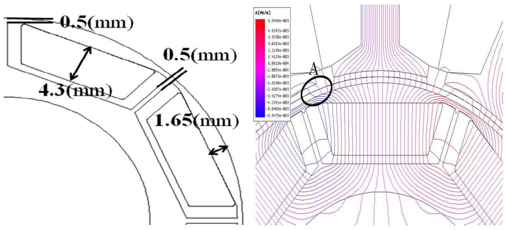
A. Design model and specification

TABLE I. SPECIFICATION OF BASIC MODEL

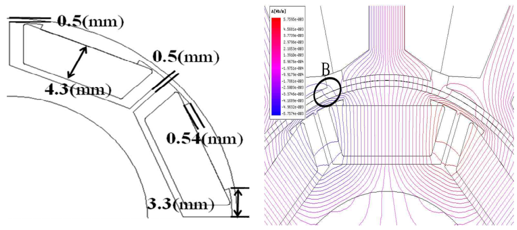
Item	Specification
Rated speed (min^{-1})	3000
Rated torque (Nm)	2
Pole/Slot	8/12
Air-gap length (mm)	1
Winding type	Concentrated winding
Br (T)	1.3
Stack length (mm)	45
Stator diameter (mm)	75

The symmetrical flux-barrier was installed at the ends of the permanent magnetic pole and the partial demagnetization; both are the significant disadvantages of the basic model, to decrease the cogging torque. Optimization was only carried out the motor rotor, and the usage amount of permanent magnets was same as the basic model. To minimize the cogging torque, the shape of flux-barrier was selected to determine the path of the flux and to concentrate leakage flux in one direction.

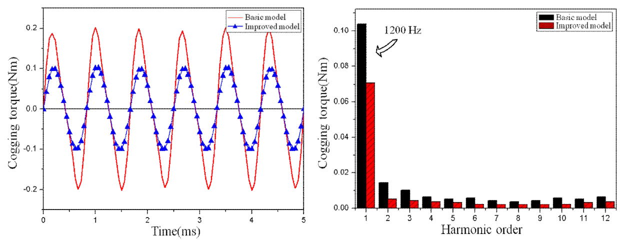
Table I shows specification of the basic model. Fig. 1 shows the rotor shape, magnetic flux line of the basic model and the improved model. The leakage flux which causes cogging torque was concentrated like A of a Fig. 1(a). To minimize the leakage flux, flux-barrier was installed in the part of A.



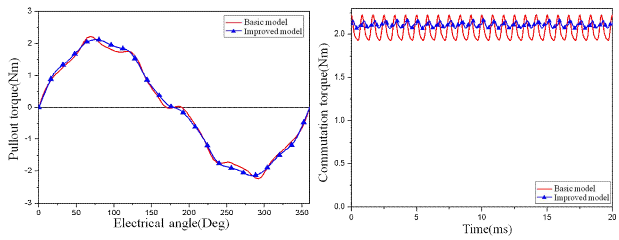
(a) basic model



(b) improved model
Fig. 1. Comparison of rotor shape and flux line



(a) cogging torque and harmonic analysis



(b) pullout torque and commutation analysis
Fig. 2. Comparison of performance

The cogging torque was selected as an objective function. As for the condition, each of dimensions was set up as shown in a Fig 1 after consideration of a mechanical intensity of rib as well as the production possibility.

A Fig. 2 shows cogging torque, pull out torque, commutation torque of basic model and improved model.

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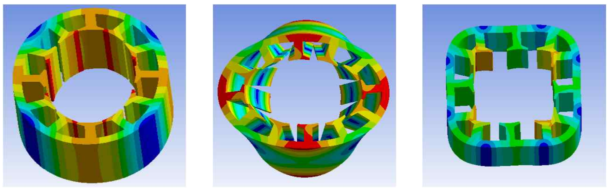
The cogging torque was decreased in about 50(%) while the torque ripple was extremely improved to 14.5(%) from 4.5(%). Moreover, the torque was increased to 2.4(%) by decrease of the leakage flux and the sinusoidal distribution of flux. Those results reflex that the characteristics of performance has remarkably improved.

TABLE II. COMPARISON OF PERFORMANCE CHARACTERISTICS

Item	Basic model	Improved model
Cogging torque (Nm)	0.2	0.1
Average torque (Nm)	2.05	2.10
Commutation torque ripple (%)	14.5	4.4

B. *Vibration and Radial magnetic force*

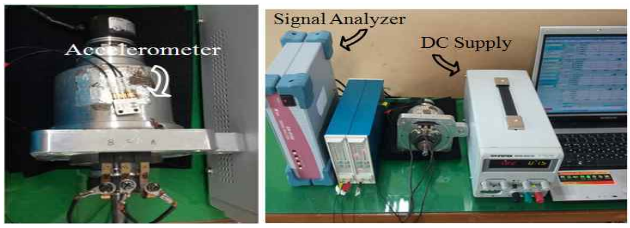
Modal analysis was performed on the stator because the natural frequencies of a stator dominantly effects to the vibration and the resonance[2]. Silicon steel plate (S60-50PN1650) was selected as a material of stator and the mass density, the Young's modulus and Poisson ratio was input 7850(kg/m³), 200(Gpa) and 0.24 respectively.



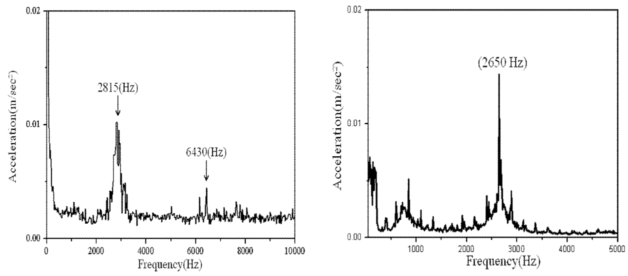
(a) 1415(Hz) (b) 2865(Hz) (c) 6522(Hz)

Fig. 3. Mode shapes corresponding to natural frequencies

The result of the modal analysis is described in the Fig. 3. A Fig. 4 shows the natural frequency motor used in the experiment, experimental devices and the vibration spectrum. The acceleration sensor was used the PV-97C. SA-01A-4 model was adopted as a signal analyzer, and a vibration signal was amplified by UV-06A amplifier. The experiment of 1-phase excitation was carried out while the motor was stopped. Additionally, the voltage source was applied by pulse wave in the one phase of the three phases. Then the vibration signal was measured in radial direction which was impacted by electromagnetic pulling force. In the experiment of 3-phase excitation, the vibration was measured when each phase was on the rated current. As a result, the vibration was generated at the lower frequency than the mode of (b) at a Fig.3. The reason is that the part of the frontier was different from the model of the analysis because the mounting of the motor is installed on the frontier. Thus, satisfied results were obtained as the analysis value was relatively consistent with the experimental value. The vibration will be extremely reduced in case of the improved model because the cogging torque was 30% reduced than the basic model which has the fundamental frequency, 1,200(Hz), of cogging torque like a Fig. 2(a). If the fundamental component of cogging torque is higher, the vibration will be more produced since the fundamental frequency of modal analysis is 1415(Hz). A Fig. 5 shows the calculation and harmonic analysis of RMF to predict the electromagnetic radial force. The radial force was slightly increased due to the increase in radial component of air gap flux. On the contrary, the harmonics of 1,200(Hz), which is relevant to the cogging torque frequency, was highly decreased. Thus, it is predicted that vibration will be extremely decreased by the huge reduction of the RMF in the natural frequency band.



(a) acceleration sensor attachment and experimental unit



(b) 1-phase excitation (c) 3-phase excitation

Fig. 4. Experimental unit and result

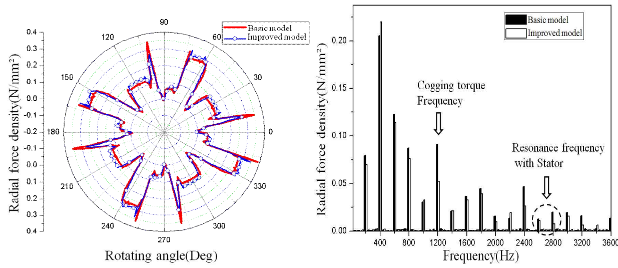


Fig. 5. RMF and harmonic analysis

III. CONCLUSION

In this paper, flux-barrier was installed in the motor to reduce cogging torque, then it was analyzed that the characteristics of the cogging torque and RMF. In conclusion, the reduction of cogging torque by flux-barrier results in the decrease of both the torque ripple and the fundamental frequency of resonance mode which is relevant to RMF of 1,200(Hz).

IV. REFERENCES

[1] Gyu-Hong Kang, el."Improved Paramater Modeling of Interior Permanent Magnet Synchronous Motor Based on Finite Element Analysis", IEEE Trans. on Magnetics, vol.36.No.4,pp.1867~1870, July.2000.

[2] P. Vijayraghavan and R. Krishnan, "Noise in electrical machines: A review," IEEE Trans. Industry Appli., Vol 35, No. 5, pp. 1007-1013, 1999.