Analytical Prediction and Reduction of the Cogging Torque in Interior Permanent Magnet Motor

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***Abstract*—This paper proposes a technique to reduce the cogging torque in Interior Permanent Magnet Synchronous Motor (IPMSM) without skewing the stator teeth and magnets based on the analytical method. The validity of the proposed method is confirmed by 2-D Finite Element (FE) analysis.**

INTRODUCTION

The components of cogging torque are due to the interaction between permanent magnets and the air-gap permeance harmonics. The Interior Permanent Magnet Synchronous Motor (IPMSM) has some advantages, such as high saliency ration, to reduce the magnet requirements and to improve the field-weakening performance. However, the IPMSM presents significant cogging torque because in the IPMSM structure, the size of effective air-gap is equals to the size of the mechanical air-gap. Therefore, the field computations are quite sensitive to the geometry of the rotor and the stator due to the small air-gap [1].

In this paper, we develop the analytical method to calculate the cogging torque of IPMSM and propose a rotor shape to reduce the cogging torque under the constant magnet size without skewing. The results of the proposed analysis are verified by comparison with the 2-D Finite Element (FE) analysis.

METHODOLOGY OF ANALYTICAL PREDICTION

In this paper, the technique based on the analytical calculation of the air-gap field distribution and the net later force acting on the teeth is proposed to predict the cogging torque. The magnetic field due to magnets is obtained from magnetization and the radial components of flux density in air-gap are obtained from Poissons equation.[1]

Relative permeance is used to calculate the flux density in the slot-opening region and the net cogging torque, at any magnet position, is then calculated by equation (1).

$$T_c = \sum_{k=1}^{Q} l_a \int_{toothside} \left(\frac{B'^2_{\theta b1} - B'^2_{\theta b2}}{2\mu_0} \right) r_r \, d\gamma \qquad (1)$$

where Q is the numbers of slot and r_r is the radious of rotor.

REDUCING OF COGGING TORQUE IN IPMSM

Skewing either the stator teeth or magnet, combining the slot number and the pole number, and designing the air-gap length and slot opening width are all able to reduce the cogging torque. However, these increase the complexity and the constraint of the machine construction in IPMSM. The reduction of cogging torque is therefore achieved by designing the rotor shape under the same magnet size as shown in Fig. 1. In the case of IPMSM, the air-gap flux density caused by the permanent magnet disperses the motor phenomenon, so effective pole ratio is compensated by 2-D FE analysis. Fig. 2 shows the air-gap flux density distribution estimated by 2-D FE analysis for each flux barrier angles and Fig.3 shows the values of coefficients for exact estimation of pole ratio according to flux barrier angles. In the analytical prediction of cogging torque, the change of flux barrier angles is derived to obtain the pole ratio. The tendency of cogging torques taking into account the flux barrier angles is shown in Fig. 4 compared with 2-D FE results. The cogging torque is severely varied by changing of flux barrier angles.

CONCLUSION

In this paper, the technique to predict and to reduce the cogging torque in IPMSM by using analytical method is presented and then the characteristic of air-gap flux density is compensated by coupled 2-D FE analysis. Under the constant magnet size, the cogging torque is severely varied according to flux barrier angles and the results are verified by the 2-D FE analysis.

REFERENCES

[1] Z.Q. Zhu and D. Howe "Analytical Prediction of the Cogging Torque inRadial-field Permanent Magnet Brushless Motors" *IEEE Trans. On Magn.* vol. 28 No. 2 March 1992

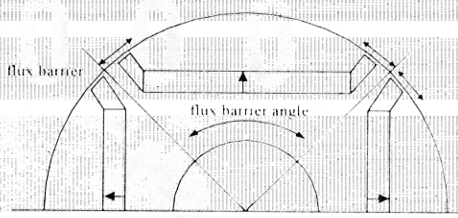


Fig. 1. Geometric layout for reducing cogging torque in IPMSM

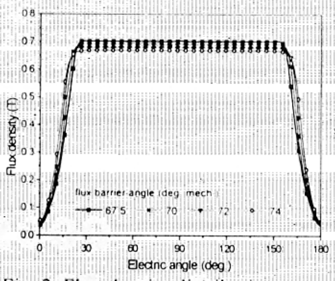


Fig. 2. Flux density distribution

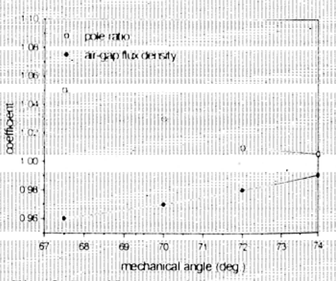
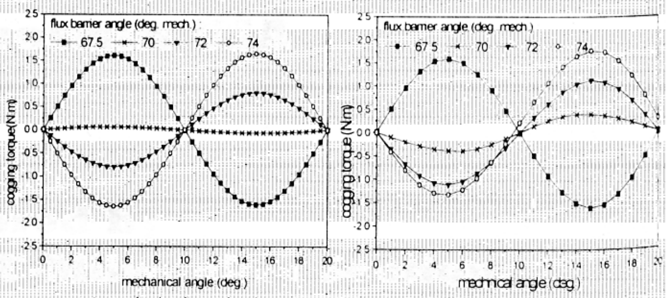


Fig. 3 Coefficient of flux



(a) analytical method (b) 2-D FE analysis

Fig. 4. Cogging torque according to flux barrier angle.

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