Numerical Investigation on Torque Harmonics reduction of Interior Permanent Magnet Synchronous with concentrated winding

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Abstract — The main aim of this paper is studied torque harmonic characteristic for concentrated winding in Interior Permanent Magnet Synchronous Motor. It was selected various model of motor to compare the torque ripple. Using the finite element method, the electromagnetic characteristics of each model are analyzed. And it was analyzed the harmonics of torque ripple using Fourier Fast Transform (FFT). As a result, the design of rotor shape is reduced torque ripple and torque harmonics.

I. INTRODUCTION

IPMSM has been used for application which requires extended speed range capability with assistance of outstanding flux weakening controllability, it can be enhanced by increasing the saliency. In addition, High torque density is resulted in utilizing both magnetic and reluctance torque [1]-[3]. In recent years, IPMSM with concentrated winding have begun to be used instead of ones with distributed winding. The copper loss of concentrated winding motors is lower than distributed winding motors, and the size of concentrated winding motors is small compared with distributed winding motors. The torque ripple caused the vibration and the noise. As a result, it is important to find out method for reducing torque ripple [4]. Basic methods proposed for reducing the cogging torque are the adjustment of the magnet are width relative to the pole pairs, the skewing of the stator and the optimization of the rotor magnet shape and the flux barrier shape [5]-[6].

In this paper also describes a method of reducing the torque ripple in an IPMSM with concentrated winding. These motor are three-phase and 16 poles 24 slots with concentrated winding. To analyze the torque ripple for various shapes of the rotor, the 2D finite element method is introduced. The torque ripple and average torque in each rotor shape are calculated by FEM, and these values are compared and discussed. As a result, it is found that there exists the better shape of the rotor that can obviously reduce the torque ripple and torque harmonics [7].

II. BASIC OF TORQUE RIPPLE HARMONCIS IN IPMSM

The air-gap flux of Interior Permanent Magnet Synchronous Motor (IPMSM) is non sinusoidal due to the magnet shape and saturation of the leakage flux paths in the stator slots. The interaction between the flux linkage harmonics and sinusoidal currents introduces the ripple in the electromagnetic torque. Also, the cogging torque caused reluctance change. And 3-phase Motor has torque ripple frequency as follow equation (1).

$$T = 1.5\hat{I}\hat{B}mDLPK_{w1}[1 + \frac{K_3K_{w3}K_{I3}}{K_{w1}} + \frac{K_5K_{w5}K_{I5}}{K_{w1}} + \cdots + (K_{I7} - K_{I5} + \frac{K_3K_{w3}K_{I9}}{K_{w1}} - \frac{K_3K_{w3}K_{I3}}{K_{w1}} + \frac{K_5K_{w5}}{K_{w1}} + \frac{K_7K_{w7}}{K_{w1}} + \frac{K_9K_{w9}K_{I3}}{K_{w1}} + \cdots)\cos 6\omega t + (K_{I13} - K_{I11} - \frac{K_3K_{w3}K_{I9}}{K_{w1}} - \frac{K_5K_{w5}K_{I7}}{K_{w1}} - \frac{K_7K_{w7}K_{I5}}{K_{w1}} + \cdots)\cos 12\omega t + \cdots] \quad (1)$$

Where, I is peak phase current, B is air gap flux density, L is length of machine, m is turns in series per pole per phase, D is stator diameter, P is Pole, K_{wn} is nth harmonic winding factor, K_n is nth harmonic in flux density distribution.

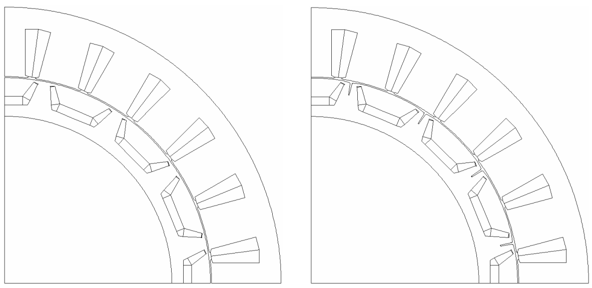
Torque ripple harmonics will be 6, 12, 18 ⋯ cycles per pole of rotor rotation. As a result, In this paper, The minimization of torque ripple harmonics, motor shape design.

III. DESIGN OF INTERIOR PERMANENT MAGNET MOTOR

Table I shows the specification of the IPMSM used in this study. This IPMSM has the concentrated winding and 16Pole 24Slots (q=0.5). To analyze the motor performance, the two-dimensional FEM is used.

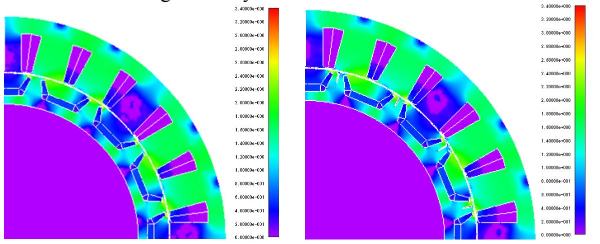
TABLE I
DESIGN SPECIFICATION OF Interior Permanent Magnet Motor

	Designed Parameter	Design Specification
General	No. of Pole/Phase	24 / 3
	Air-gap	1 [mm]
	Stack length	120 [mm]
Stator	No. of Slots	24
	Outer Diameter	430 [mm]
	Core material	Silicon Steel
Rotor	No. of Pole	16
	PM Property	Nd-Fe-B (Br=1.2T)
	PM Configuration	1 Layer



(a) Initial Model (b) Proposed Model

Fig. 1. Analysis Motor Structure



(a) Initial Model (b) Proposed Model

Fig. 2. Magnetic flux density

A. *Torque Ripple*

Fig. 3. shows the torque ripple result. Fig. 3. indicate generated torque of the analysis model by a sinusoidal current at the base speed . At the base speed, the torque is obtained when current 826Arms when electric degree is 135°. Each result is obtained by 2D-FEA. As a result, Initial model has 17.0 % torque ripple. And rotor shape proposed design in torque ripple has 5.4%.

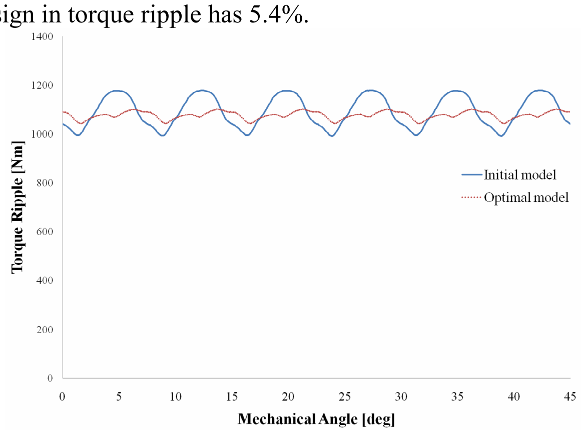


Fig. 3. Comparison of Torque Ripple (Initial model Vs. Proposed model)

TABLE II
Comparison of Torque Ripple Result

Model	Scale	Analysis Result
Initial model	Max	1178.0 [Nm]
	Min	992.0 [Nm]
	Average	1093.0 [Nm]
	Torque Ripple	17.0 %
Proposed model	Max	1101.0 [Nm]
	Min	1043.0 [Nm]
	Average	1077.0 [Nm]
	Torque Ripple	5.4 %

B. *Torque Ripple Harmonics*

Fig. 4. shows Torque ripple harmonic at base speed, it is normalization. The torque ripple harmonic analysis results of using Fourier Fast Transform(FFT). In the torque ripple harmonic analysis result, 6th 12th 18th ⋯ are dominant harmonic. Specially, torque ripple harmonic 6th of proposed model is lower than initial model.

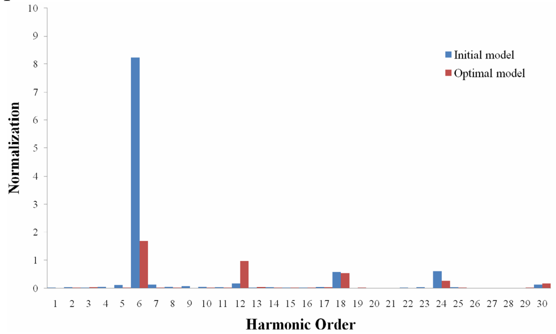


Fig. 4. Normalized spectrum of Torque Ripple Harmonics (Initial model [Blue] Vs. Proposed model [Red])

IV. Conclusion

This paper has presented a promising design approach of reducing torque ripple harmonics in IPM machines with concentrated windings. The proposed motor shape design is decreased from 17.0% to 5.4%. As a result, this paper has proposed a method to reduce minimization torque ripple and harmonic.

V. References

[1] C. Mademlis, V. G. Agelidis, "A High-Performance Vector Controlled Interior PM Synchronous Motor Drive with Extended Speed Range Capability," *Proc. of IECON'01*, vol. 2, pp.1475-1482, 2001..

[2] Wen L. Soong, Mesimi Ertugrul, "Field-Weakening Performance of Interior Permanent-Magnet Motor," *IEEE Trans. on Industrial Application*, vol.38, No.5, September 2005.

[3] Lovelace.E.C., Keim.T., Lang.J.H., Wentzloff.D.D., Jahns.T.M., Wai. J., McCleer.P.J., "Design and experimental verification of a direct-drive interior PM synchronous machine using a saturable lumped-parameter model," *Proc. of 37th IAS Annual Meeting*, vol. 4, pp. 2486-2492, Oct. 2002.

[4] Pia Marjatta Lindh, Hanne Kaarina Jussila, Markku Niemela, Asko parviainen, Juha Pyrhonen, "Comparison of Concentrated Winding Permanent Magnet Motors With Embeeded and Surface-Mounted Rotor Magnets," *IEEE Trans. Magnetic,* vol. 45, pp. 2085-2089, May. 2009*,* .

[5] Z. Q. Zhn, and D. Howe, "Influence of Design Parameters on Cogging Torque in Permanent Magnet Machines," *IEEE Trans .Magnetic .*, vol. 15, pp. 407-412, 2000.

[6] Saito. N, Nijima. R, Shimomura. S, "The design method to minimize torque ripple in interior permanent magnet synchronous motor with concentrated winding," *Power Electronics Conference (IPEC).* , pp1293-1298, 2010.

[7] Bolton, H.R , Ashen, R.A , "Influence of motor design and feed-current waveform on torque ripple in brushless DC drives," *Electric Power Application* , vol. 131, pp82-90, 1984.