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Session PD2: Electrical machines and Drives V

10:40-12:10 – Room: Poster Session Room I

A Study on the Relation between Deformation of Stator Yoke and Acoustic Noise in Interior Permanent Magnet Motor

Do-Jin Kim[1], Jeong-Jong Lee[1], Ji-Min Kim[1], Jung-Pyo Hong[1], and Myung-Ryul Choi[2]

[1]Department of Automotive Engineering Hanyang University, Seoul, 133-791, Korea
[2]School of EECS, Hanyang University, Ansan, Gyunggi-do 426-791, Korea

This paper deals with relation between deformation of stator yoke and acoustic noise in interior permanent magnet (IPM) motor. Process which is to calculate the deformation of the stator yoke is divided into six steps. Firstly, current is calculated from dynamic simulation considering load conditions. Secondly, local force which consists of normal and tangential force affects on the tooth is computed by equivalent magnetizing current (EMC) between two materials. Thirdly, harmonic analysis for the computed local force is performed. Fourthly, harmonic components of local force put in the tooth surface in stator considering mechanical property through modal analysis. Fifthly, the deformation quantity of stator yoke is calculated and its trend is compared with acoustic noise experimental result. Finally, the relation between the deformation of stator yoke and acoustic noise is analyzed.

***Index Terms*— Acoustic noise, Deformation, Equivalent magnetizing current, Normal force, Tangential force**

I. INTRODUCTION

Noise of motor can be classified into three sections. First of all, there are higher space and time harmonics eccentricity, phase unbalance, slot opening, magnetic saturation, and magnetostrictive expansion of the core laminations in electrical noise. Secondly, there are mechanical noises associated with the mechanical assembly. Thirdly, there are aerodynamic noises associated with flow of ventilating air through or over the motor [1].

The noise and vibration of the motor structure are the direct response of the excitation by these forces. For example, if the frequency of the radial magnetic force is close to one of the natural frequencies of the stator system and the factor order r is the same as the circumferential vibration mode m of the stator system, significant vibration and acoustic noise can be produced [2].

For studying on the relation between deformation of stator yoke and acoustic noise in IPM motor, modal analysis, this paper deals with calculation of exciting force which is composed of tangential and normal force on the tooth, harmonic analysis for the exciting force, the quantity of deformation of stator yoke, and the comparison between calculated the quantity of deformation of stator yoke and acoustic noise.

In order to calculate electrical exciting forces which affect on the acoustic noise, the current is calculated by dynamic simulation considering load condition. The tangential and normal forces which affect on tooth of stator are calculated using finite element method (FEM). Especially, equivalent magnetizing current (EMC) method uses magnetizing current which exists on element boundary and it can directly calculate the electromagnetic force which affects the surface of tooth [3]. The exciting forces are put in the surface of tooth of stator and the quantity of deformation of stator yoke is calculated.

Finally, the tendency of calculation of the quantity of deformation of stator yoke and measured acoustic noise of analysis model is compared.

II. THEORY

A. Equivalent magnetizing current (EMC)

The differentia of tangential component of field intensity between two materials is equal to the magnetizing current on element boundary. On the element boundary, magnetizing current is calculated by eq (1).

$$I_m = \frac{1}{\mu_0}\int \nabla \times \vec{M} \cdot d\vec{s} = \frac{1}{\mu_0}(M_{1t} - M_{2t})l_{ij} \qquad (1)$$

where M_{1t} and M_{2t} are the tangential components of magnetization on element boundary, l_{ij} is the distance on element boundary.

$$\vec{B} = \mu_0 \vec{H} + \vec{M} \qquad (2)$$

The relationship in (2) holds for all materials whether they are linear or not. Substituting (2) into (1) yields.

$$I_m = \frac{1}{\mu_0}(B_{1t} - B_{2t})l_{ij} \qquad (3)$$

where B_{1t} and B_{2t} are the tangential component of flux density in each material.

The electromagnetic force on the element boundary is written as

$$\vec{f_{ij}} = \vec{I_{ij}} \times \vec{B}_{ext} \qquad (4)$$

Flux density value of $\vec{B}_{ext}$ is given as the average value for each element. The electromagnetic force f_{ij} which affect on i, j element on the element boundary is written as [4]

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Corresponding author: Jung-Pyo Hong (e-mail: hongjp@hanyang.ac.kr).
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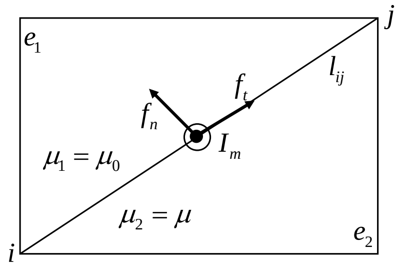


Fig. 1. Magnetizing current between two materials.

B. *Resonant frequency band*

The noise near the resonant frequencies, which affect harmonics of electrical exciting forces, is lager than other natural frequencies. Therefore, modal analysis for stator is performed and then center frequencies for 1/3 octave band based on the resonant frequencies of stator is designated. The center frequencies is defined by eq. (5)

$$f_c = \sqrt{f_u \cdot f_l} \tag{5}$$

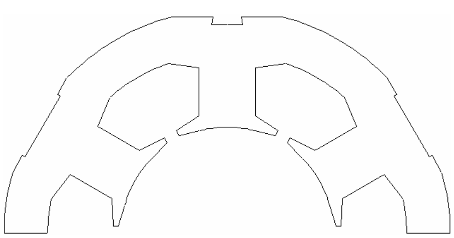
where f_c is center frequency, f_u and f_l are the upper and lower half-power frequencies

III. Analysis Model

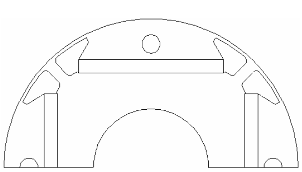
The specifications of analysis model are shown as Table I. The analysis model which consists of 4-pole/6-slots and concentrated windings is driven by BLDC operation and rated speed and torque are 3000rpm and 8.0 Nm, respectively. In addition, pulse width modules (PWM) frequency is 4.0 kHz, respectively. The configuration of analysis model M1 and M2 is shown in Fig. 2

TABLE I. Specifications

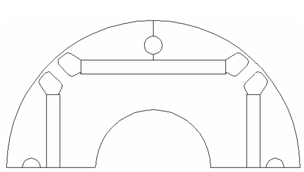
Contents		Values
Number of poles and slots		4/6
Stack length (mm)		80
Rated current (A_{rms})		1.5
Rated speed (rpm)		1800
Rated torque (Nm)		1.0
PWM frequency (kHz)		4.0
Resonant frequency of stator (kHz)	Stator only	1.5
	Assembly of stator and housing	1.8
	Assembly of stator,housing, and Jig	2.6



(a) Stator of M1 and M2

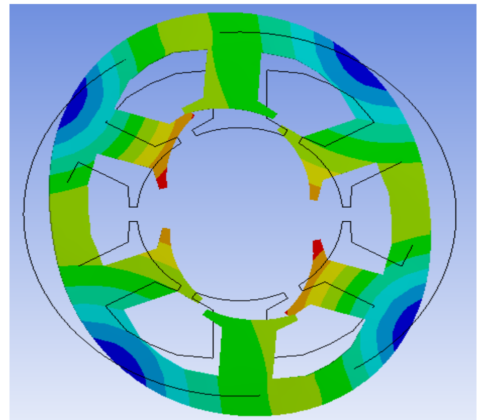


(b) Rotor of M1

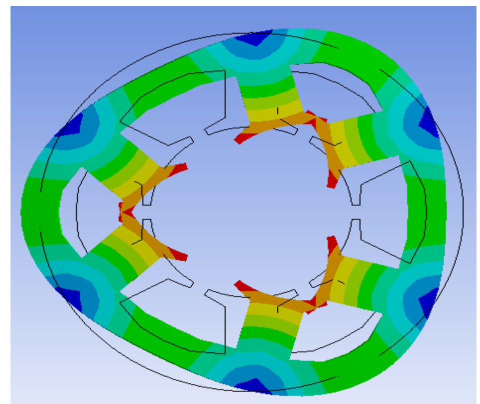


(c) Rotor of M2

Fig. 2. Configuration of analysis model



(a) m=2 (@ 3525 Hz)



(b) m=3 (@ 4300 Hz)

Fig. 3. Circumferential mode m=2, 3 of the stator

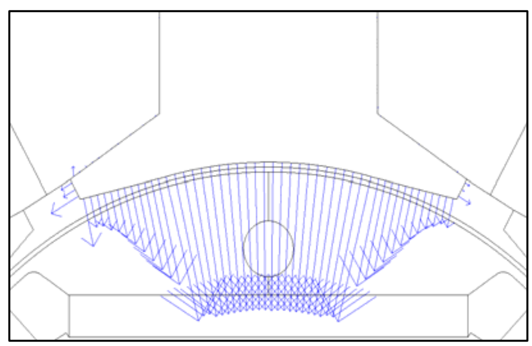


Fig. 4. Distribution of local force using EMC

IV. Calculation of the Deformation of Stator Yoke

Before the calculation the deformation quantity of stator yoke, modal analysis which is to find the resonant frequency for the stator of analysis model is performed. Fig. 3 shows that circumferential mode (m) 2 and 3 of the stator with resonant frequency. And then, center frequencies and band widths for 1/3 octave band based on the result of modal analysis stator are designated.

In order to calculate the exciting sources which occur the deformation of stator yoke, local force on the stator tooth versus rotor position are calculated by using the equivalent magnetizing current (EMC) between two materials.

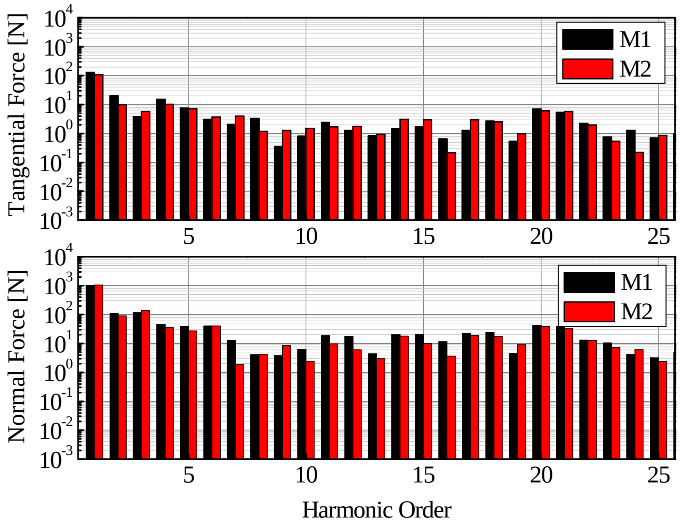


Fig. 5. Harmonic analysis of tangential and normal force at the tooth

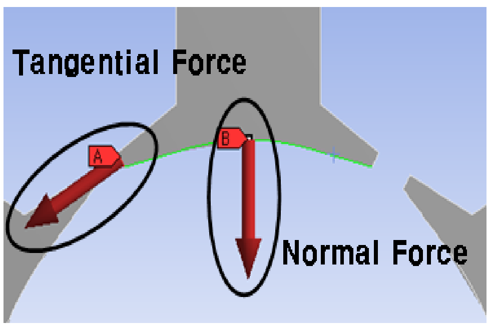


Fig. 6. Definition of local force

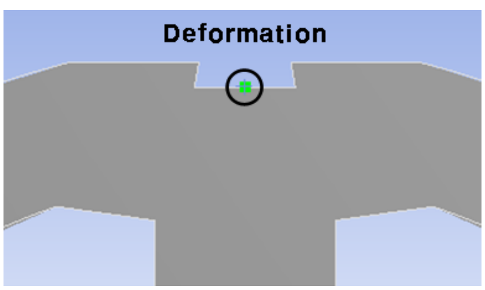


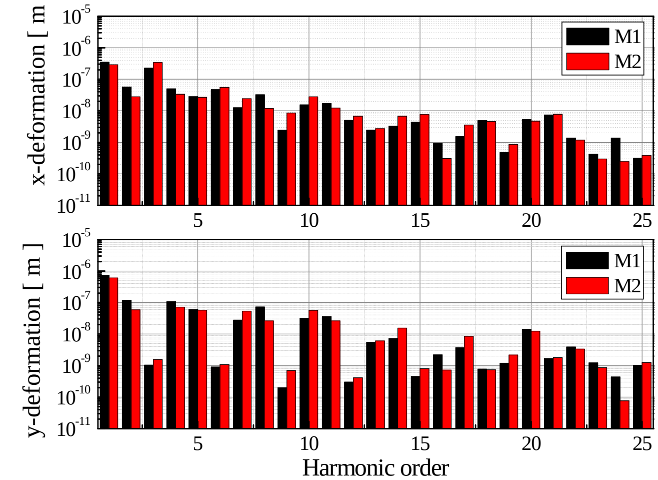
Fig. 7. Position which is to calculate of the deformation of stator yoke

Fig. 5 shows the result of harmonic analysis for tangential and normal force at the tooth. The harmonic components of normal force are entirely so bigger than one of tangential force because normal force is expressed by the square of flux density.

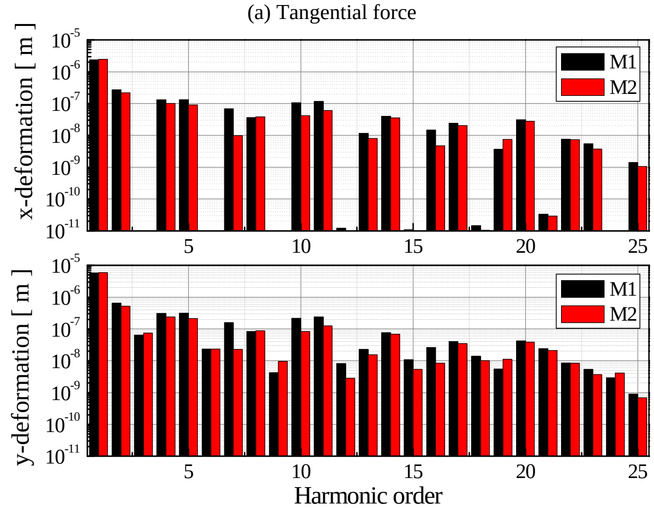
In order to assign the each harmonic component of the calculated the tangential and normal force at the surface of tooth, Fig. 6 shows the definition of local force.

The harmonic component of tangential and normal force versus harmonic order is assigned at the tooth and it is shown in Fig. 3. It should be considering phase difference because each the harmonic component according to the change of rotor position is changed such as sinusoidal.

Finally, the quantity of deformation of stator yoke is calculated by harmonic analysis using the harmonic components of tangential and normal force and the result of deformation of stator yoke as shown in Fig. 8.



(a) Tangential force



(a) Normal force

Fig. 8. The distribution of the deformation of stator yoke by local force

Fig. 8 shows the distribution of the deformation of stator yoke by local force. The quantity of deformation of stator yoke by normal force is bigger than one of tangential force because normal force is expressed by the square of flux density which is generated from magneto-motive force by armature and permanent magnet.

The quantity of deformation of stator yoke versus harmonic order for local force of M2 is smaller than M1. Therefore, we can predict that the degree of vibration of M2 is smaller than M1. In order to verify of analysis method using local force, acoustic noise experiment is performed.

V. Experimental Result

Fig. 9 shows a configuration of noise experiment in the anechoic room where background noise is 41dBA and measured 1m away from the motor by microphone. As a load of the analysis model, generator coupled with the analysis motor produces the active power at the resistance.

Fig. 10 shows the noise experiment results measured by 1/3 octave band at the 3000 rpm and 8 Nm. Total SPLs of M2 compared with M1 are entirely reduced and the values of M1 and M2 are 73.2 and 70.1 dBA, respectively. The noise of two analysis models mainly occurs around the resonant frequency of stator and the noise of M1 around 4.0 kHz is higher than

M2. The reason is that inductance of M1 is lower than M2 due to magnetic saturation according to reduction of pole angle. Therefore, current waveform of M1 more exactly reflects PWM characteristic and the noise at PWM frequency band is more highly measured than M2.

VI. Conclusion

In order to verify the relation between the deformation of stator yoke and acoustic noise IPM motor, the local force using EMC and the deformation quantity of stator yoke using the harmonic components of local force are calculated. In addition, the tendency for the deformation quantity of stator yoke is compared with experimental result. As the result of this study, the acoustic noise of analysis model having low the deformation degree of stator yoke is entirely small.

Accordingly, in order to reduce the acoustic noise in IPM motor, the deformation quantity of stator yoke through the reduction of harmonic components of local force should be decreased.

VII. References

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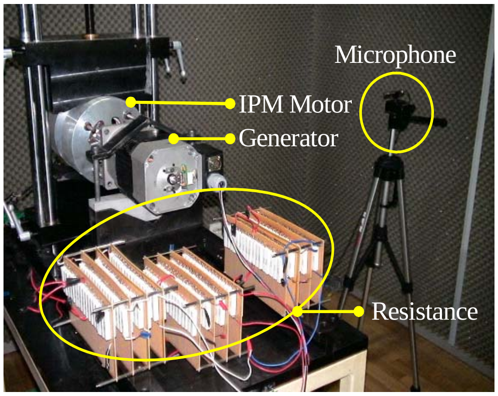

Fig. 9. Configuration of noise experiment

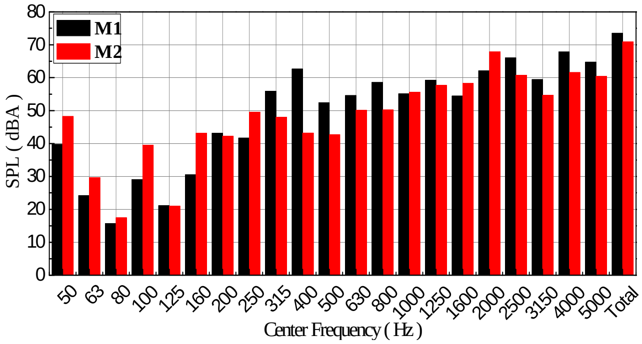

Fig. 10. The result of noise experiment