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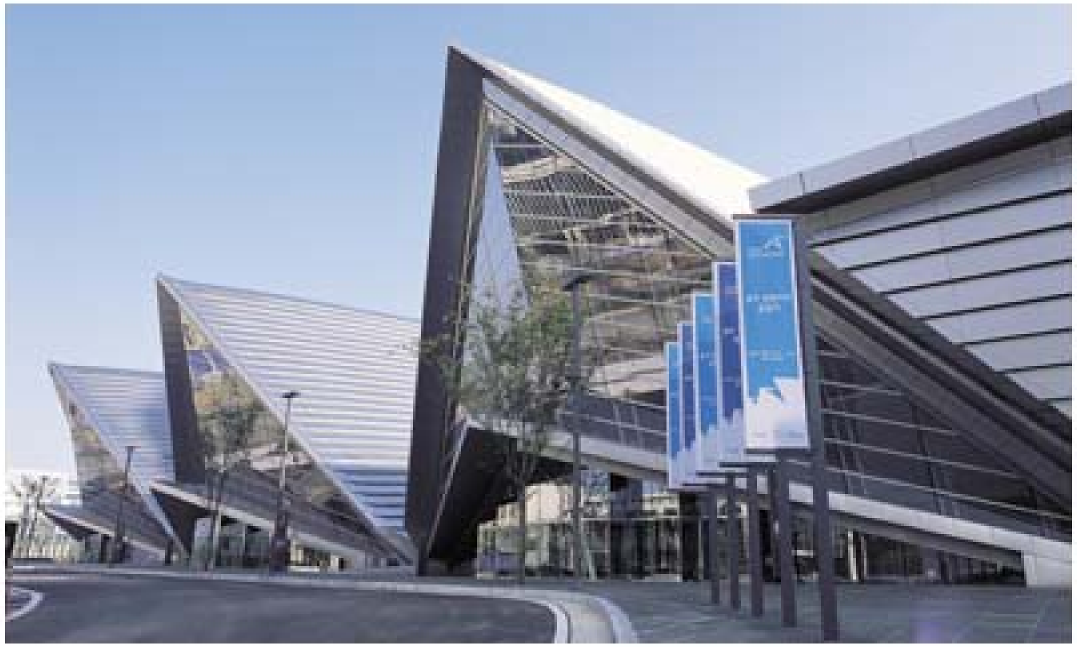

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- Effect of Vibration and Noise on IPMSM Type Integrated Starter and Generator According to Number of Slots

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A study on the reduction of noise and vibration of SPM according to reduction of Permanent Magnet

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Abstract — Electric power steering is designed to use an electric motor to reduce effort by providing steering assist to the driver of a vehicle. EPS have advantages which are economical and eco-friendly compare with hydraulic power steering, because power steering oil is not used and efficiency of vehicle is increased to 3~5 %.[1]

Since EPS is connected to handle of vehicle, noise and vibration have an effect on the driver directly. So study on the reduction of noise of vibration of EPS is proceeding.

This paper deals with reduction of noise and vibration which are generated by electrical forces between stator and rotor according to reduction of permanent magnet. In order to analyze noise of surface permanent magnet (SPM) motor, this paper deals with relation between deformation of stator and noise from motor. The normal and tangential force which affects on the tooth are computed by equivalent magnetizing current (EMC).

I. Introduction

Noise of motor can be classified into three sections. First of all, there higher space and time harmonics eccentricity, phase unbalance, slot opening, magnetic saturation, and magneto-strictive expansion of the core laminations on 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.

The electrical forces are effect on stator yoke, and the noise and vibration is generated by deformation of stator yoke. Therefore, the normal and tangential forces are calculated using equivalent magnetic current, and the effect is analyzed by calculating deformation of stator yoke.

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.

In this paper, in order to reduce noise and vibration, the usage of the permanent magnet is decreased. The characteristic of motor is satisfied and the deformation of stator yoke is reduced. To satisfy characteristic of motor, the permanent magnet is decreased 20% compared with initial model, series turns per phase is increased to satisfy no load back EMF, when the rated speed is 1500 rpm, the rated torque is 2.6 Nm.

In order to verify suggested method, designed motor is manufactured and experimented

Between initial and improved model which is designed by decreasing the usage of permanent magnet. The motor is 6pole 9slot of surface permanent magnet motor.

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).

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

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

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

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

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

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

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

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]

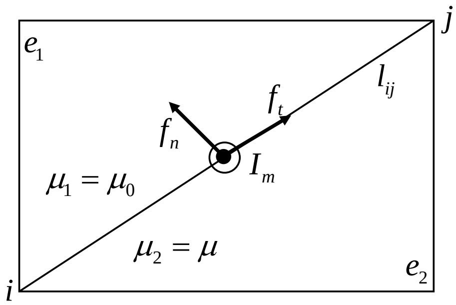


Fig. 1. Magnetizing current between two materials.

B. Spectrum analysis

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)

$$f_c = \sqrt{f_u \cdot f_l} \qquad (5)$$

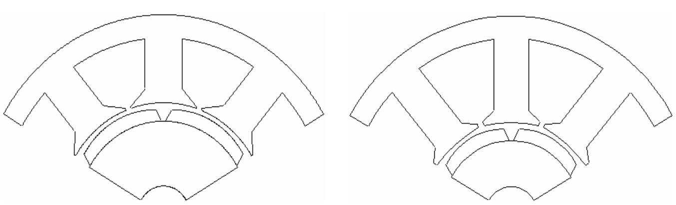
where f_c is center frequency, f_u and f_l are the upper and lower half-power frequencies.

III. Analysis Model

The specifications of analysis model are shown as Table I. The analysis model which consists of 6-pole/9-slots and concentrated windings is driven by BLAC operation and rated speed and torque are 1500rpm and 2.6 Nm, respectively.

TABLE I
Specifications and resonant frequencies of stator

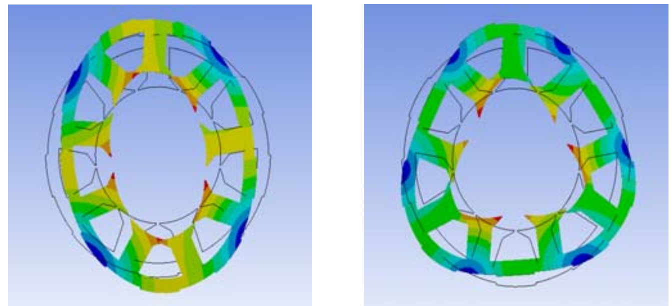
Contents	Values
Number of poles slots	6/9
Stack length (mm)	60
Rated current (A_{rms})	45
Series turn number per phase (turns)	16
Rated speed (rpm)	1500
Rated torque (Nm)	2.6



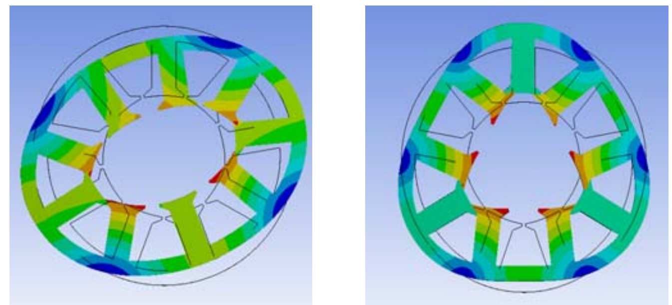
a. Initial model b. Improved model
Fig. 2. Initial and improved model

IV. Analysis Method

Firstly, modal analysis for the stator of analysis model is performed. Fig. 1 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 modal analysis for stator are designated.



(a) *m*=2 (@ 1676 Hz) (b) *m*=3 (@ 4292 Hz)
Fig. 3. Circumferential mode *m*=2, 3 of the stator) of initial model



(a) *m*=2 (@ 1676 Hz) (b) *m*=3 (@ 4292 Hz)
Fig. 4. Circumferential mode *m*=2, 3 of the stator) of improved model

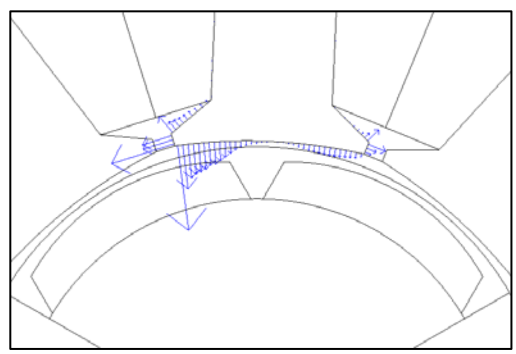


Fig. 5. Local force respect to surface of stator

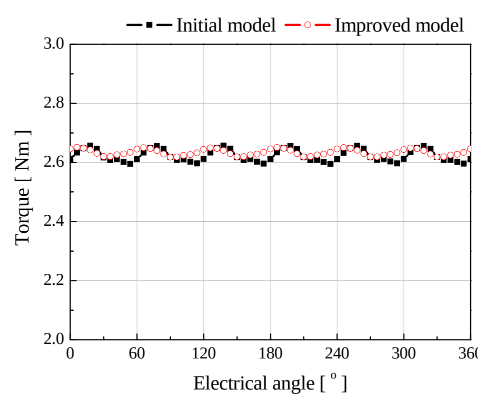


Fig. 6. Torque for proto and improved model

Secondly, the torque characteristic using sinusoidal current is shown in Fig. 6. The characteristic of motor is satisfied under the load condition 1500 rpm and 2.6 Nm.

Thirdly, the exciting forces, which are composed of tangential and normal force, on the stator tooth versus rotor position are calculated by using the equivalent magnetizing current (EMC). And then, the harmonic components of exciting forces are calculated through harmonic analysis. It is shown in Fig. 7. In order to assign the each harmonic component of the calculated the tangential and normal force at the surface of tooth, Fig. 8 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.

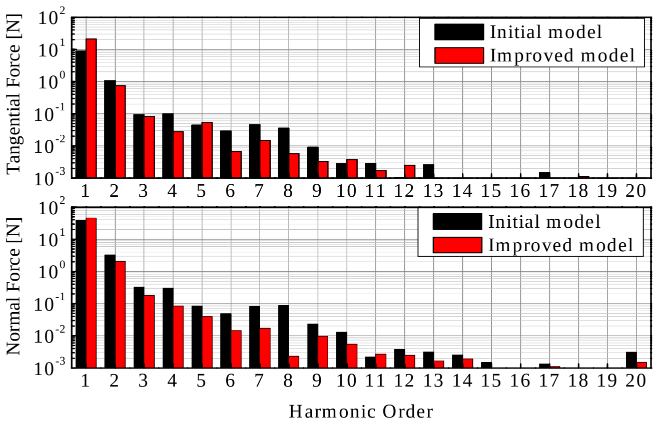


Fig. 7. Torque for proto and improved model

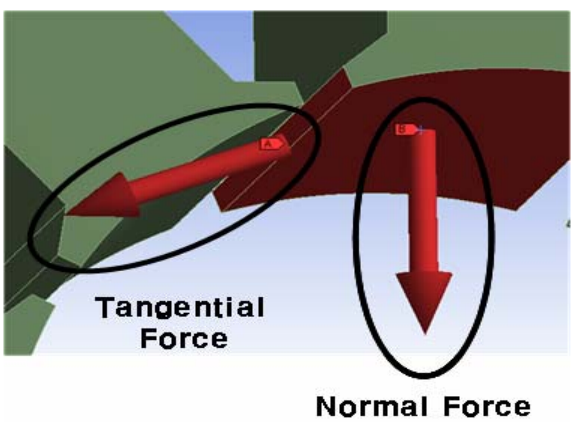


Fig. 8. Definition of local force

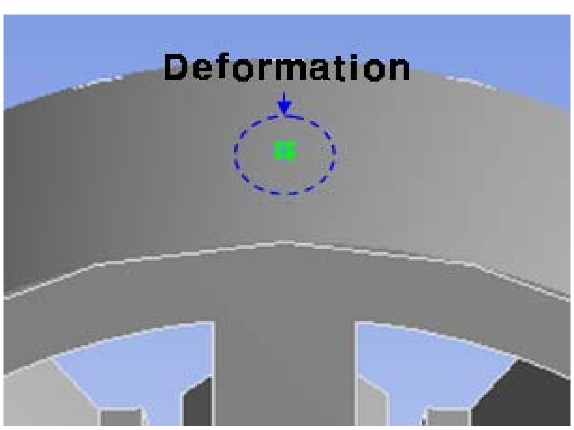
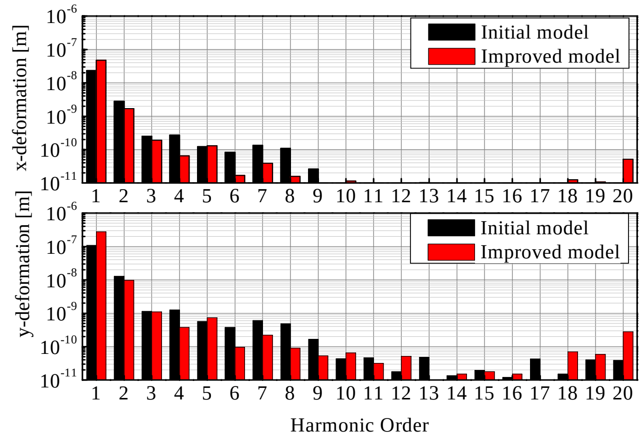
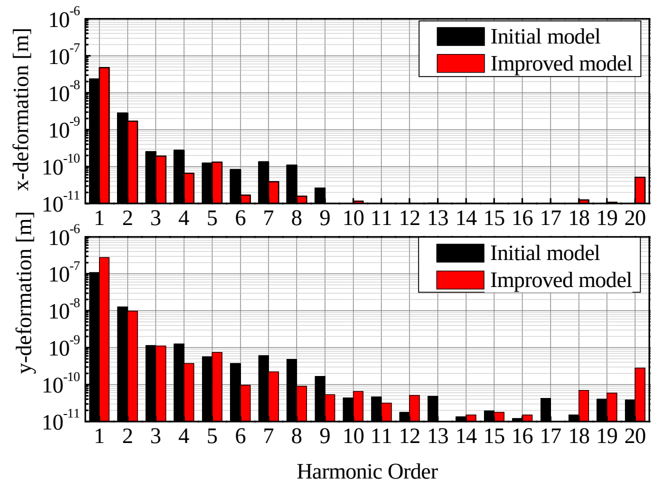


Fig. 9. Position which is to calculate of the deformation of stator yoke



(a) Tangential force



(a) Normal force

Fig. 10. The distribution of the deformation of stator yoke by local force

Fig. 10 shows the distribution of the deformation of stator yoke by normal force and tangential. 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 used permanent of magnet Initial model is smaller than improved model with down 20%.

The reduction of magnetic loading which is generated by permanent magnet could be important to reduce noise and vibration.

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

V. Experimental Result

In order to verify calculation method, the experiment for measurement of noise is conducted. The motor which is with the wheel is experimented at the 1500 rpm and 2.6 Nm and measured 1m away from the configuration of experiment by microphone.

Fig. 11 shows the noise experiment results measurement by 1/3 octave band. The motor which has 6pole 9slot is generated by 18th harmonic noise and compared initial and improved model. The noise of improved model is less than initial model with down 5dB.

VI. RESULT

The designed motors are manufactured and experimented. And then the experimental result of noise and vibration is shown as fig.6. The motor which has 6pole 9slot is generated by 18th harmonic noise vibration and compared initial and improved model. The noise of improved model is less than initial model with down 5dB.

In order to decrease of deformation of stator yoke which is calculated using exciting force, the motor is designed by decreasing usage of permanent magnet. The reduction of magnetic loading which is generated by permanent magnet could be important to reduce noise and vibration.

Accordingly, in order to reduce the acoustic noise, the reduction of usage of permanent magnet is considered.

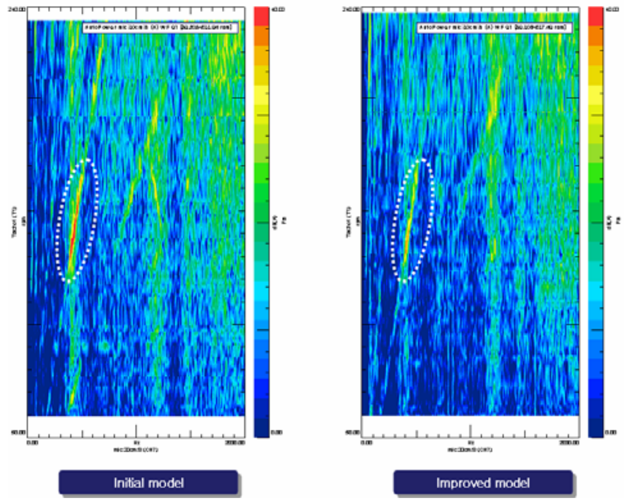


Fig. 11. Experimental result of noise of motor

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