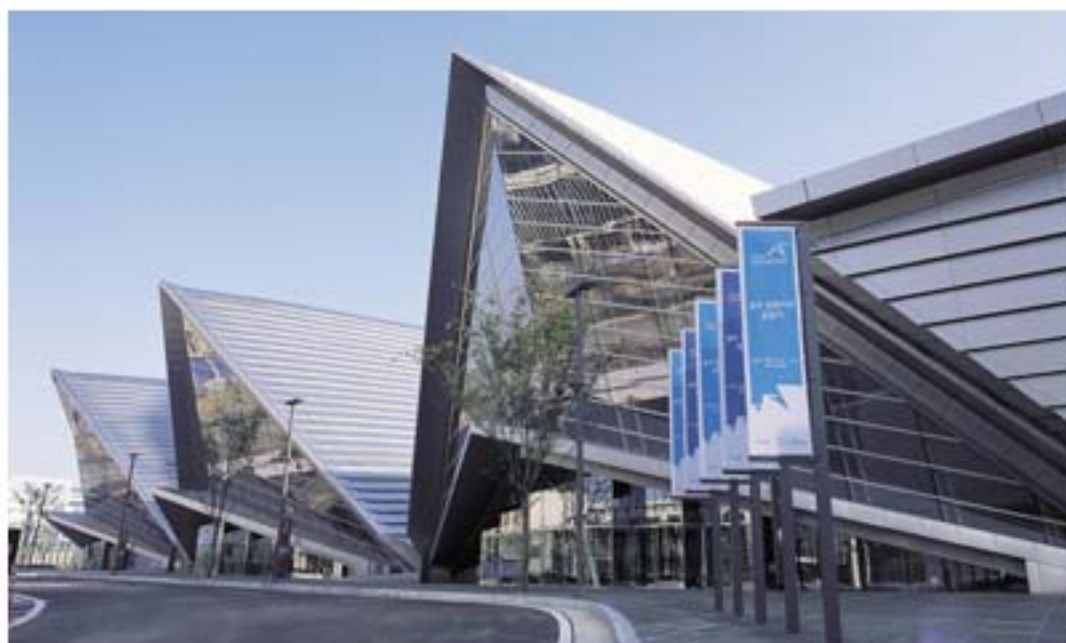




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01. Home



02. Session List



03. Author's Index



04. Search



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▶ **Jung-Pyo Hong**

- The Effect of Silicon Steel Sheet on Core Loss in Induction Motor



▶ **Jung-Pyo Hong**

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



▶ **Jung-Pyo Hong**

- Reduction Design of Eddy Current Loss in IPMSM using Response Surface Methodology



▶ **Jung-Pyo Hong**

- A Study on the Relation Between Rotor Rib and Maximum Power of IPMSM in Flux Weakening Region



▶ **Jung-Pyo Hong**

- Design of an Interior Permanent Magnet Synchronous In-Wheel for Electric Vehicles



▶ **Jung-Pyo Hong**

- Vibration Analysis according to Stator Shape Design in a PMSM



▶ **Jung-Pyo Hong**

- Characteristic Analysis of the Water Pump Motor considering Polar Anisotropic Ferrite Bonded Magnet



▶ **Jung-Pyo Hong**

- A Study on the Reduction of Noise and Vibration of SPM According to Reduction of Permanent Magnet



▶ **Jung-Pyo Hong**

- Evaluation and Improved Design about Acoustic Noise and Vibration in IPMSM



▶ **Jung-Pyo Hong**

- Reduction Eddy Current Loss Design and Analysis of In-Wheel Type Vehicle Traction Motor



Vibration Analysis According to Stator Shape Design in A PMSM

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Abstract — This paper presents a study on motor vibration reduction according to the stator shape design in a permanent magnet synchronous motor (PMSM). Three PMSM models, with different stator tooth width and yoke width, as well as slot opening and tooth tip geometry, are built and analyzed based on the comparison of local force and natural frequency of PMSM with modal analysis. Also, the vibration generated from the deformation of stator is analyzed with considering harmonic component, and the effectiveness of each design parameters on vibration reduction is concluded in final.

I. INTRODUCTION

Permanent magnet synchronous motor (PMSM) is used widely in various field such as hybrid and electric vehicle (HEV) or EV. PMSM has advantages of high power density to the induction motor and reluctance motor.

This paper presents a study on motor vibration reduction according to the stator shape design in a PMSM. The local force acted on the stator tooth of motor is analyzed coupled with the natural frequency of motor. The noise generated from the deformation of stator is analyzed with considering harmonic component, and the effectiveness of each design parameters on vibration reduction is concluded.

By performing harmonic analysis of local force, three different models are analyzed with modal analysis, and confirmed by noise experiment. By using this analysis method, the presented models with changing tooth width, yoke width, slot opening, tooth tip, are analyzed for reducing vibration [1], [2].

II. ELECTRICAL AND MECHANICAL PROPERTIES

A. Comparison of analysis model

Fig. 1 shows that shape of three PMSM model. The base model is given, which has significant vibration problem. Then, model 1 and model 2 are redesigned to reduce rotor radius and amount of permanent magnet. With the less amount of permanent be decreased, the vibration of each model were analyzed and compared. Output of three type model was constrained to be equal. The rotor diameter, tooth width and yoke width of Model 1 and Model 2 decreased than the base model. And tooth tip and slot opening of Model 2 are enlarged than Model 1. Since the serious noise of electric motor is tested at 1500rpm in experiment, we should choose the corresponded current and current phase at 1500rpm in the analysis.

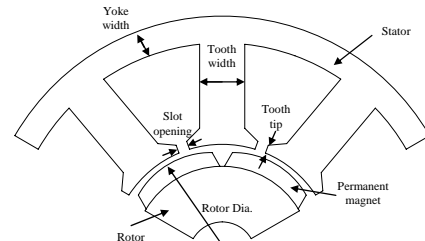


Fig. 1. Shape of PMSM (Base model).

TABLE I
SPECIFICATION OF TEST MODEL

Type	Base Model	Model1	Model2	
Rotor Diameter[%]	100	93	93	
Br[%]	100	103.5	103.5	
PM Volume [%]	100	70	70	
Tooth Width [%]	100	94.2	94.2	
Yoke Width [%]	100	96	96	
Slot Opening [%]	100	100	153	
Tooth Tip Thickness[%]	100	125	275	
Turn number	13	16	15	
1538rpm	Current[A]	Iq = 45	Iq = 45	Iq = 45
	Phase angle[°]	28.5	28.5	28.5

B. Electrical properties

Torque and torque ripple were calculated using FEA(Finite Elements Analysis) in the 1500rpm. Input current and current phase angle of each model are equal. As look in fig. 2, rotor diameter of base model is big relatively. So, base model has many fluxes in the air gap by permanent magnet and torque, torque ripple are big relatively.

Table 2 shows torque and torque ripple for base model and model 1, model 2.

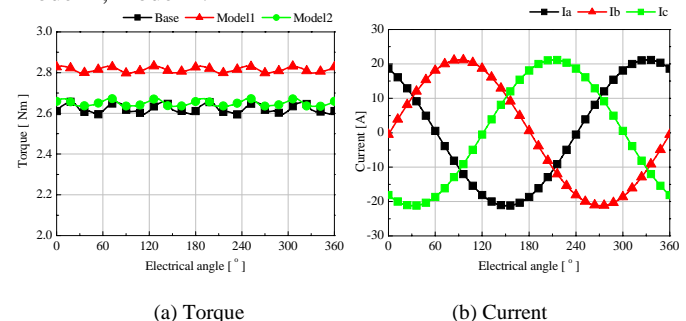


Fig. 2. Torque and Current

TABLE II
TORQUE AND TORQUE RIPPLE

Model	Torque [Nm]	Torque ripple $_{pk-pk}$ [mNm]
Base	2.62	62
Model1	2.81	35
Model2	2.64	39

A harmonic analysis of local force was achieved to look for main frequency that influence to noise and vibration.

Fig. 3 shows that normal force is bigger than tangential force.

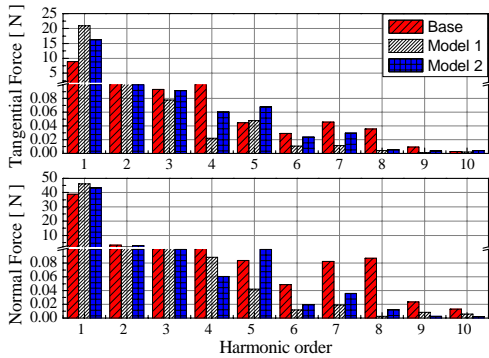


Fig. 3. Harmonic analysis of Local force

Fundamental wave frequency of torque ripple and cogging, local force on 6 poles 9 slots can be calculated in 1500rpm as follows. Table 3 shows fundamental frequency of torque ripple and cogging, local force. A torque ripple is happened by tangential force. Therefore, through analysis of tangential force, noise and vibration of each model is evaluated.

$$f_t = 6 \times (pp) \times \frac{N}{60} \times n \quad (n = 1, 2, 3 \dots) \quad (1)$$

$$f_{n@tooth} = 2 \times (pp) \times \frac{N}{60} \times n \quad (n = 1, 2, 3 \dots) \quad (2)$$

$$f_{cog} = (\text{Least common multiple}) \times \frac{N}{60} \times n \quad (n = 1, 2, 3 \dots) \quad (3)$$

TABLE III
FUNDAMENTAL FREQUENCY

Items	Frequency [Hz]
Torque ripple(n=1)	450
Cogging Torque(n=1)	450
Local force (n=1)	150

C. Mechanical properties

Resonance frequency and deformation of stator outside were calculated using Model analysis and Harmonic analysis. Harmonic analysis of local force is achieved and analysis about effect of resonance frequency be achieved.

First, Modal analysis is achieved to calculate resonance frequency according to vibration mode of each model

Fig. 4 shows 2 mode of resonance frequency on base model.

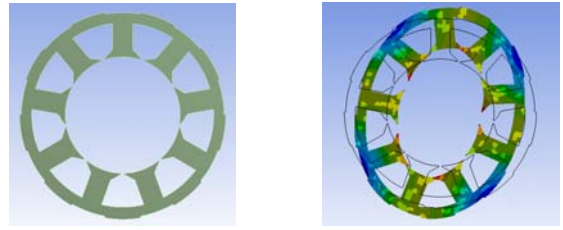


Fig. 4. Modal analysis(Base model)

2 modes of resonance frequency of three models correspond to 8 order harmonics of local force. Therefore, 8 order harmonics is main cause of vibration and noise. Normal force and tangential force were inputted to each stator to calculate deformation of stator. And, a harmonic analysis was achieved.

Harmonic analysis is achieved increasing frequency of local force by 150Hz. Because ratio of pole/slot number is 2 to 3, Phase is different as 120° in each tooth. There is no a binding condition of stator and Surround environment was assumed in the freedom space state.

D. Comparison of the experiment result with FEA result

Fig. 5 is data on the noise experiment with three models. This experiment result displays that noise level of base model is biggest. And, noise level of model 1, model 2 is similar.

Fig. 6 compared experiment data with harmonic analysis. A deformation of base model is very big in whole harmonic orders. Fig 5, 6 shows that tendency of experiment data and FEA data are same.

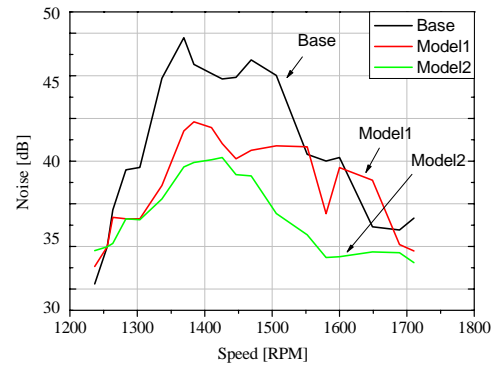
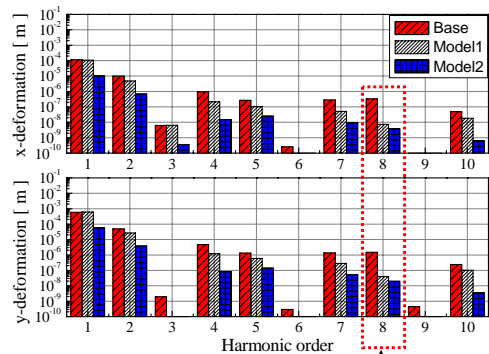
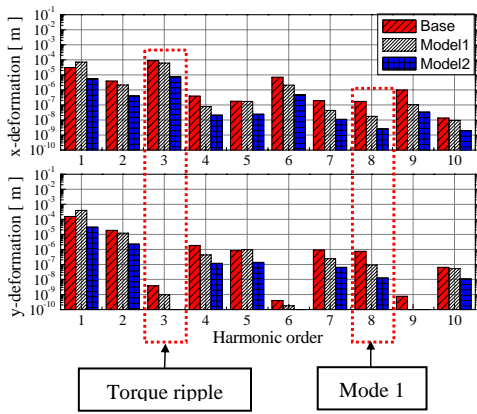


Fig. 5. Noise test data



(a) Normal force



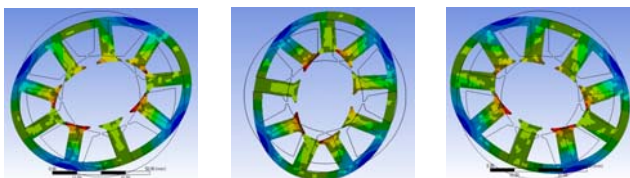
(b) Tangential force
Fig. 6. Deformation analysis

A resonance frequency(1200Hz) with 2 modes correspond to 8 order harmonics frequency. 8 harmonics order is aspect to experiment data. Also, 3 harmonics of Tangential force that is fundamental wave element of torque ripple is analyzed. That is aspect such as torque ripple on analysis that be appeared in the table 2. Through this result, credibility of this simulation is confirmed. Using simulation method, vibration/noise is analyzed according to change of tooth width, yoke width, tooth tip and slot opening.

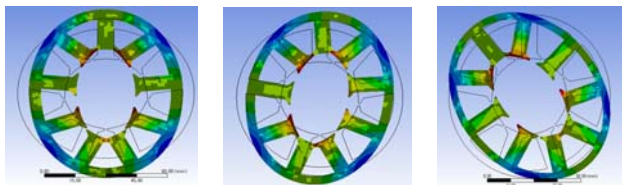
III. CHARACTERISTIC ANALYSIS ABOUT VIBRSTION/NOISE

A. Characteristic comparison by tooth and yoke width

The characteristic of the motor vibration/noise was construed according to change of tooth and yoke width. Thickness of tooth and yoke width was only changed to confirm characteristic of motor according to change of tooth and yoke. Other parameters are equal. The Fig 7 (a), (b), (c) is model which tooth width is changed. The Fig 7 (d), (e), (f) is model which yoke width is changed.



(a)Tooth 7.1mm[1178Hz] (b)Tooth 8.1mm[1158Hz] (c)Tooth9.1mm[1145Hz]

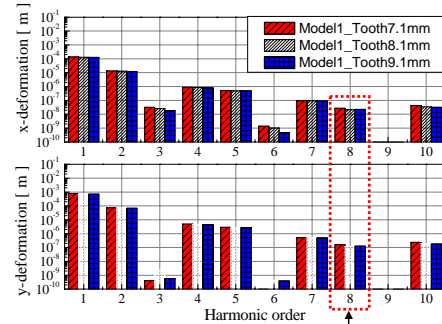


(d)Yoke 5.8 mm[1520Hz] (e)Yoke 4.8mm[1158Hz] (f)Yoke 3.8 mm [830Hz]

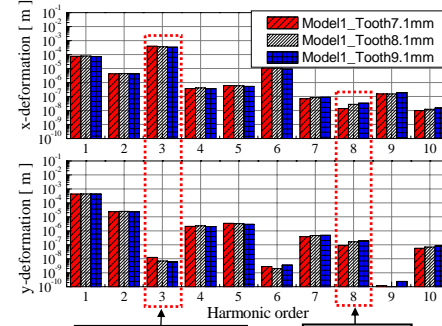
Fig. 7. Modal analysis according to Yoke and Tooth change

As appear to Fig 7, it is no difference of natural frequency by change of tooth width, and natural frequency by change of yoke width is big difference. That is, change of yoke width influences fairly in vibration/noise.

As appear Fig 8 and 9, deformation of stator by yoke width is bigger than deformation of stator by tooth width. That is, it is effective that improve yoke width to reduce vibration/noise.

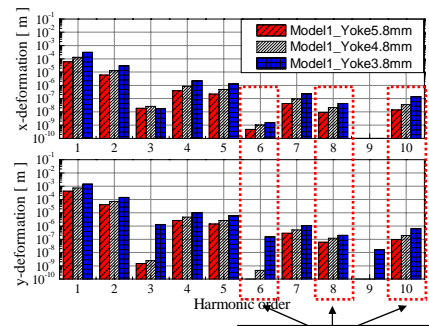


(a) Deformation according to normal force

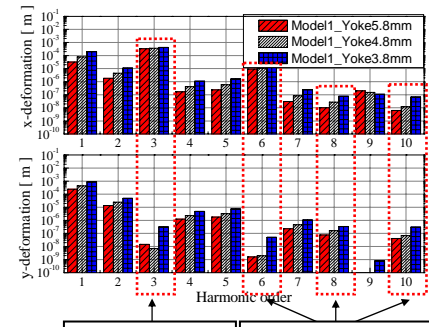


(b) Deformation according to tangential force

Fig. 8. Deformation analysis according to Tooth width



(a) Deformation according to normal force



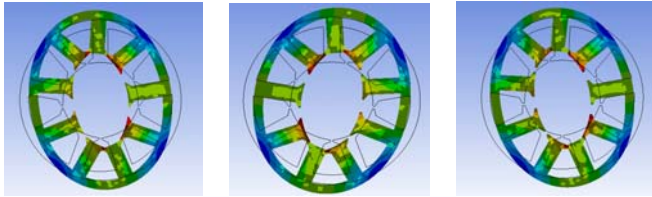
(b) Deformation according to tangential force

Fig. 9. Deformation analysis according to Yoke width

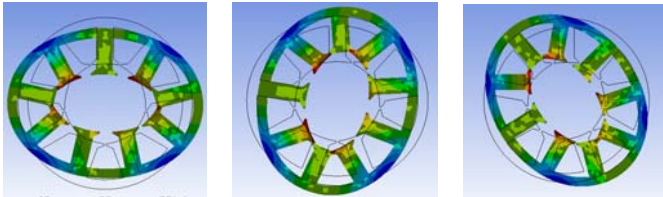
B. Characteristic comparison by Slot opening and Tooth tip

Vibration/noises were analyzed according to change of slot opening and tooth tip. Modal analysis about each model be achieved.

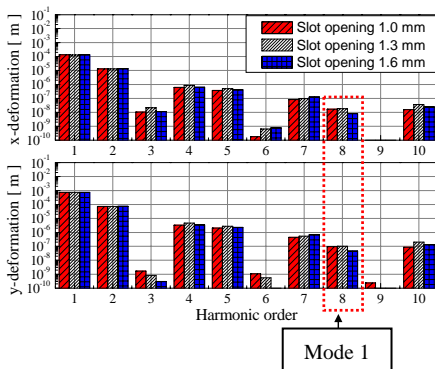
A natural frequency that shows to Fig. 10 is 2 modes. Because it is no difference of mechanical hardness, resonance frequency of 2 modes is equal almost. Using harmonic analysis, deformation of stator be compared and be analyzed. Fig. 11 and 12 show a deformation of stator by change of slot opening and tooth tip. Deformation of stator by change of slot opening and tooth tip happens as is small. That is, deformation of stator opening and tooth tip influences to be less in vibration/noise.



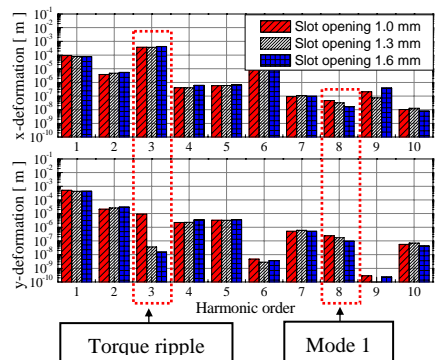
(a) Tooth tip 0.6 [1161Hz] (b) Tooth tip 0.9 [1158Hz] (c) Tooth tip 1.2 [1161Hz]



(d) Slot_O 1.0 [1161Hz] (e) Slot_O 1.3 [1158Hz] (f) Slot_O 1.6 [1161Hz]
Fig. 10. Modal analysis according to Slot opening and Tooth tip

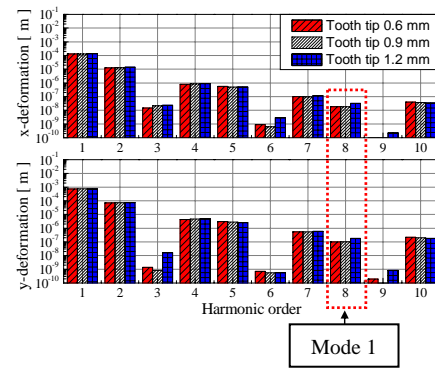


(a) Deformation according to normal force

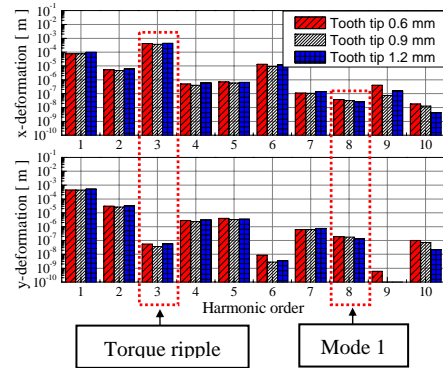


(b) Deformation according to tangential force

Fig. 11. Deformation analysis according to Slot opening



(a) Deformation according to normal force



(b) Deformation according to tangential force

Fig. 12. Deformation analysis according to Tooth tip

IV. CONCLUSION

This paper presented an improve design study on lower deformation of stator structure for reducing the vibration. The deformation of stator due to slot opening, tooth tip, tooth and yoke width is analyzed by considering the local force harmonic with the resonance frequency. Then, the effective design parameters for reducing vibration can be chosen in the motor design.

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