

# The Shape Design for Vibration Reduction of IPM Type BLDC Motor

Tae-Seok Jeong, Gyu-Won Cho and Gyu-Tak Kim  
Department of Electrical Engineering, Changwon National University  
#9 Sarim-dong, Changwon, Gyeongnam, 641-773, Korea  
gtkim@changwon.ac.kr

**Abstract**—In this paper, the Radial Magnetic Force(RMF) which cause vibration and noise in IPM type BLDC motor was analyzed. And, the vibration reduction was performed by equilibrium of RMF and cogging torque reduction. Because, the cogging torque and RMF were causes of electromagnetic vibration. So, the notch was installed for the equilibrium of RMF. Also, operating characteristics and efficiency were analyzed and compared.

**Index Terms**—Permanent magnet motors, Brushless motor, Vibration, Harmonic Analysis

## I. INTRODUCTION

An Interior Permanent Magnet Synchronous Motor(IMPSM) has some disadvantages. One is that local flux saturation is generated due to inserting permanent magnet into the rotor. And the other is the large magnetic flux density because of a small effective air-gap. Those reasons make a loud noise and vibration. The radial direction force becomes the external RMF, which generates vibration[1]-[3].

The cogging torque and imbalance of RMF were the primary cause of vibration and noise. In order to solve this problem, the shape design was progressed by using a notch.

In this paper, the notch design was performed at the rotor and stator for the reduction of cogging torque and the equilibrium of RMF. The cogging torque and RMF were causes of electromagnetic vibration in the IPM type BLDC motor. Finite Element Method was used to analyze the cogging torque and RMF.

## II. THE SHAPE DESIGN TO MINIMIZE COGGING TORQUE

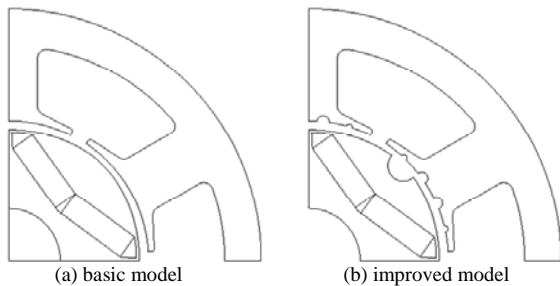


Fig. 1. The shape of model

The shapes of model were shown in Fig. 1.

### A. Design of notch

The position and width of a notch, which can offset the cogging torque, can be calculated with the energy distribution of the air-gap using a Fourier Series[4]. In this paper, a notch

was installed in a rotor and a stator. For more information on the full paper will be described.

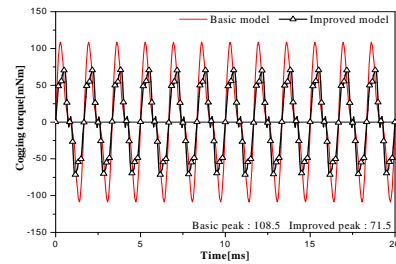


Fig. 2. Comparison of cogging torque

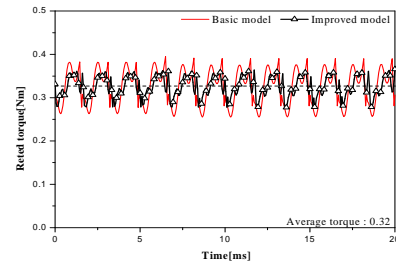


Fig. 3. Comparison of operating torque

The cogging torque of the basic model and the improved model were compared in Fig. 2, and operating torque of the basic model and the improved model were compared in Fig. 3. The improved model showed a 34% decrease in the cogging torque, a 15% decrease in the torque ripple, and a 7% decrease in the operating torque compared to the basic model. Though operating torque was slightly reduced, the overall performance was improved due to the decrease of cogging torque and torque ripple.

## III. RADIAL FORCE ANALYSIS OF IPM TYPE BLDC MOTOR

### A. Mode shape and natural frequency

A modal analysis of the stator was carried out, because the natural frequencies of the stator dominantly contribute to vibration and resonance[5]. Fig. 4 shows the result of a modal analysis.

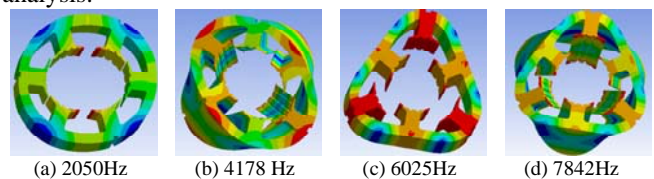


Fig. 4. Mode shapes corresponding to natural frequencies

### B. Radial force analysis

To analyze vibration which was generated by the change of air-gap flux, distribution and condition of RMF were compared to each other.

The electromagnetic vibration and noise are generated by the radial direction force density of the stator surface from the air-gap magnetic field in the open-circuit or on-load. The radial direction force density can be calculated by Maxwell's stress tensor method, as (1).

$$F_{rad}(\theta_s, t) = \frac{1}{2\mu_0} [B_r^2(\theta_s, t) - B_\theta^2(\theta_s, t)]. \quad (1)$$

Where,  $F_{rad}$  is the radial component of force density,  $B_r$  and  $B_\theta$  are radial and tangential components of the air-gap flux density,  $\mu_0$  is permeability of free space,  $\theta_s$  is the angular position and  $t$  is the time.

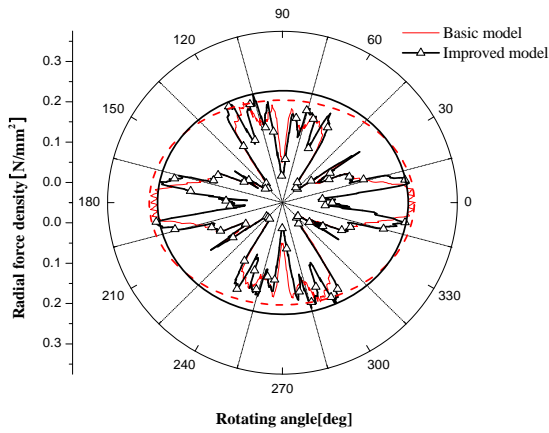


Fig. 5. Comparison of Radial force density

The RMF of the basic model was compared to the improved model in Fig. 5. Fig. 6 shows the harmonic analysis of RMF of natural frequencies. As the results of calculating the axial ratio of the major and the minor axis, the basic model was 0.79 and the improved model was 0.88. Therefore, the improved model is closer to the circle-form than the basic model.

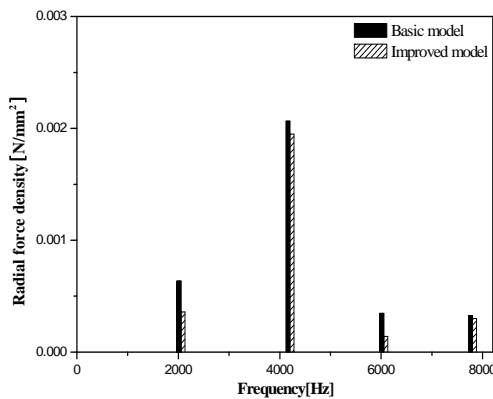


Fig. 6. Harmonic analysis on the natural frequencies of RMF

As the results of the harmonic analysis on the natural frequencies of RMF, it is expected that the vibration would be reduced at the resonance.

### IV. EFFICIENCY COMPARISON

TABLE I  
The rated operating characteristics

Model	Basic model	Improved model
Output power[W]	100	100
Iron loss[W]	8	7.19
Current[A]	3.94	4.25
Copper loss[W]	6.99	8.13
Mechanical loss[W]	7.19	7.19
Efficiency[%]	81.85	81.63

The rated operating characteristics of the basic and the improved model were represented in Table I. Although efficiency of the improved model was decreased 0.22% than the basic model, overall performance of the operating characteristics was improved.

### V. CONCLUSION

In this paper, a notch was installed for the reduction of cogging torque and equilibrium of RMF. And then, operating characteristics of two models were analyzed and compared to each other in the IPM type BLDC motor.

Consequently, the vibration was reduced at the natural frequencies. Because, the RMF of the improved model is closer to the circle-form than the basic model, and cogging torque was reduced. As a result of analysis, operating torque and efficiency slightly decreased. However, the improved model is more useful in operating characteristics and vibration characteristics than the basic model.

### VI. ACKNOWLEDGMENT

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