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Study of the Stacking Method for Reducing Magnetic Flux Density and Torque Ripple in Interior Permanent Magnet Synchronous Motor

Chung-Hui Lee
Mater course, Department of Electrical Engineering, Hanbat National University, Daejeon, 34158 Korea

Hong-Rae Noh
Mater course, Department of Electrical Engineering, Hanbat National University, Daejeon, 34158 Korea

Ki-Chan Kim*
Professor, Department of Electrical Engineering, Hanbat National University, Daejeon, 34158 Korea
kckim@hanbat.ac.kr

Abstract

In traction motors, efficiency characteristics are important, but vibration characteristics are also important. The vibration of the motor is caused by the magnetic flux generated by the current flowing through the stator winding and the magnetic flux on the rotor side. This is called armature reaction. The armature reaction not only generates torque, but also causes a pulsation called torque ripple.

This paper aims to reduce the torque ripple of the Interior Permanent Magnet Synchronous Motor (IPMSM) used in the electric vehicle driving motor. Rotor asymmetric barrier and skew are applied to the asymmetric element applied to the model as a torque ripple reduction method. For comparison, the N-pole and S-pole asymmetric barrier models of the rotor are centered on the model without skew applied. Finite element method(FEM) based simulation tools are used to determine the degree of reduction.

Keywords: IPMSM, Torque ripple reduction, Asymmetric barrier, Skew, Double layer V-type.

1. Introduction

IPMSM or Induction Motor(IM) is used as a motor for driving commercial electric vehicles. In designing a motor, various characteristics such as efficiency, Back ElectroMotive Force(BEMF), and mechanical output are considered. Among them, vibration and noise are also included in the design parameters. This is related to the air gap flux density due to the torque ripple and the distribution of the permanent magnet.

The torque is generated by the reaction between the magnetic flux on the rotor side and the magnetic flux by the current flowing in the stator winding. This is called armature reaction. As magnetic flux flows through the rotor and stator core, pulsation occurs in the magnetic flux due to saturation and rotor and stator phenomena. These pulsations appear in relation to the pulsations of torque, and are referred to as torque ripple.

The characteristic part of IPMSM is that a permanent magnet is inserted into the rotor. In the design of the rotor shape, it is necessary to consider how much magnetic flux to concentrate and how large the permanent magnet will be.[1-3] If the magnetic flux generated from the permanent magnet of the rotor is excessively concentrated, there is a possibility that the vibratory component may also increase accordingly.[4,5] As these characteristics change, they appear as vibration and noise of the motor, which is another expression called noise, vibration and harshness (NVH). In order to reduce such NVH, there are various methods such as a method of applying a step skew to the rotor, a method of applying a to the transform shape of a magnet, and a method of giving an asymmetric barrier in the stacking direction. [6-8]

This paper deals with a method of reducing torque ripple for a Double-layer V-type IPMSM used in an electric vehicle driving motor. As a reduction method, the method of applying asymmetry barrier in the stacking direction of the rotor, the two-step skew method, and the skew method by making the rotor shape symmetrical are applied. The main model was selected as a model in which the N and S poles of the rotor are asymmetric, and the characteristics change according to the torque characteristics, harmonic characteristics, and air gap flux density waveforms are analyzed based on the FEM simulation. In the case of pore magnetic flux density, it is analyzed to symmetrically configure the asymmetric part between the existing N and S poles through distribution.

2. Electromagnetic analysis of torque ripple

2.1. Main model specification and characteristic analysis

Figure 1 shows the shape of the permanent magnet inserted into the rotor of the target model. The barrier angles of the N pole and the S pole are different from each other. This difference results in an imbalance of the air gap flux. The specification of the model has an output of 150 kW, a torque of 360 Nm, and base and maximum speeds of 4,980 rpm and 8,540 rpm. The pole number slot combination is an 8-pole 72-slot structure.

Figure 2 shows the air gap flux generated in the rotor of the target model.

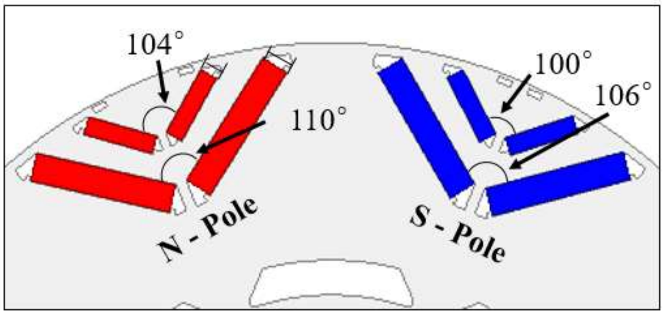


Figure 1. Asymmetric barrier angle between N and S poles

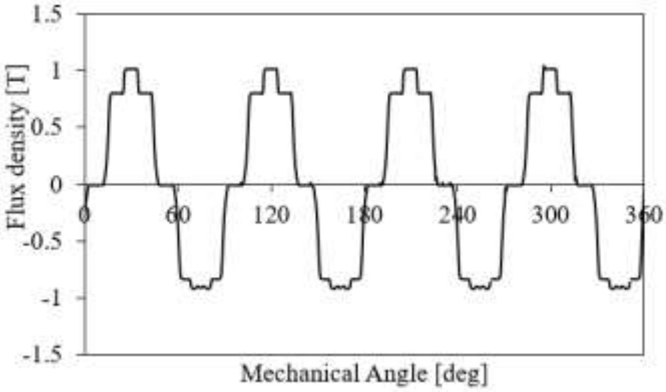
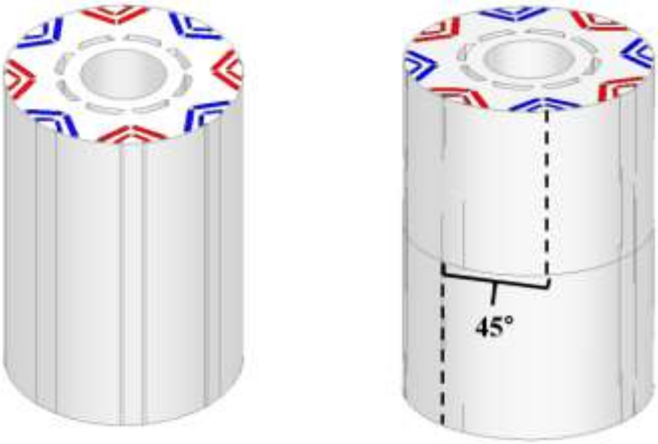


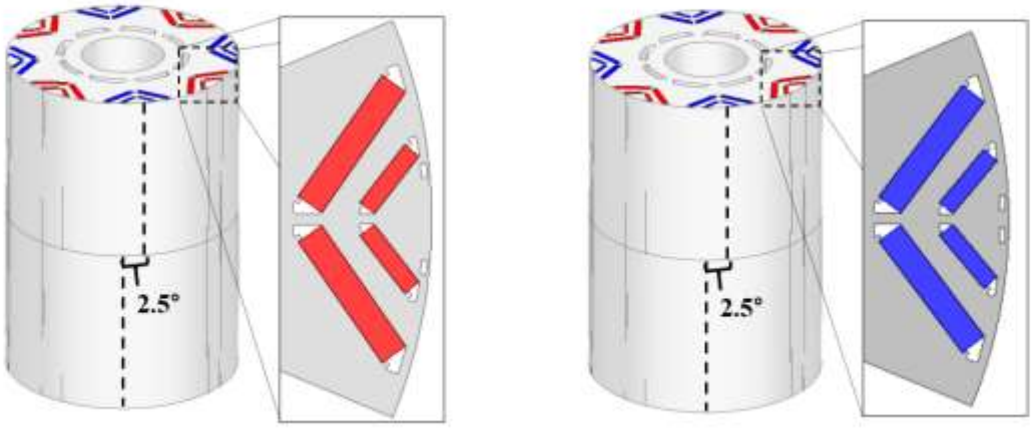
Figure 2. Air gap flux before skew application

2.2. Torque ripple reduction model FEM analysis

In the structural part of the main model, there are asymmetric elements such as barrier angle asymmetry between the magnet poles of the rotor. Among these asymmetry elements, the barrier asymmetry between the magnet poles appears as an asymmetry in the air gap flux density, which causes torque ripple. Model 2 is divided into a load side and a semi-load side, and it is a method in which the rotor core is rotated 45 degrees by separating it into two stages. At this time, the permanent magnets between the load side and the anti-load side are composed of the same pole. Model 3 and Model 4 have N-pole and S-pole symmetrical barrier angles. By additionally applying skew, the skew angle with the lowest torque ripple is selected. The skew angle at which the torque ripple of the two models is the lowest is 2.5 degrees.



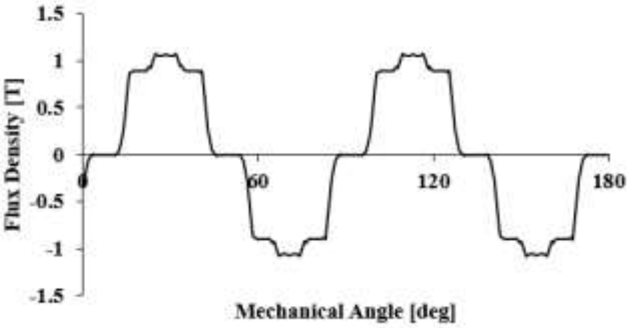
(a) (b)



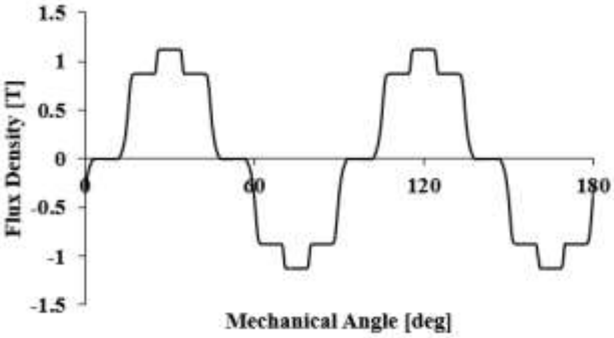
(c) (d)

Figure 3. Torque ripple reduction model shape. (a) Applied model, (b) Load side and anti-load side 45 degree rotation model, (c) Model with skew after N-pole symmetry, (d) Model with skew after S-pole symmetry

Figure 4 shows the pore magnetic flux density for each model. As for the pore flux density of the remaining models except for the target model, the N pole and S pole structures have a symmetrical structure, so the pore flux density is the same. In the case of Model 2, the barrier angle between the N pole and the S pole is different, but when looking at the load side and the anti-load side as a whole, it can be confirmed that the N pole and the S pole of the void flux density are formed identically because they have a symmetrical structure..



(a)



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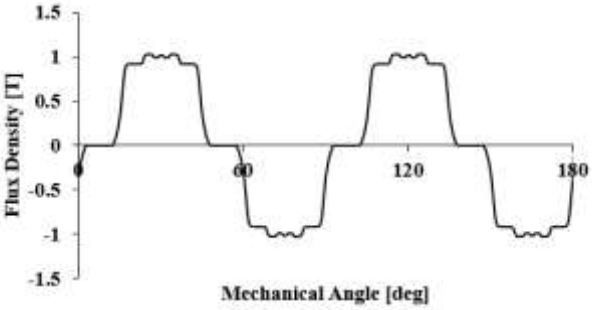


(c)

Figure 4. Torque ripple reduction model air gap magnetic flux density
(a) 45 degree rotation model on the load side and the anti-load side, (b) Model with skew after N-pole symmetry, (c) Model with skew after symmetry with S-pole

For analysis, torque ripple is derived from the base speed and the maximum speed. All analysis models use the same winding method, and the analysis proceeds by deriving a control point that satisfies the characteristics at the base speed and the maximum speed. Table 1 shows the torque ripple for each model.

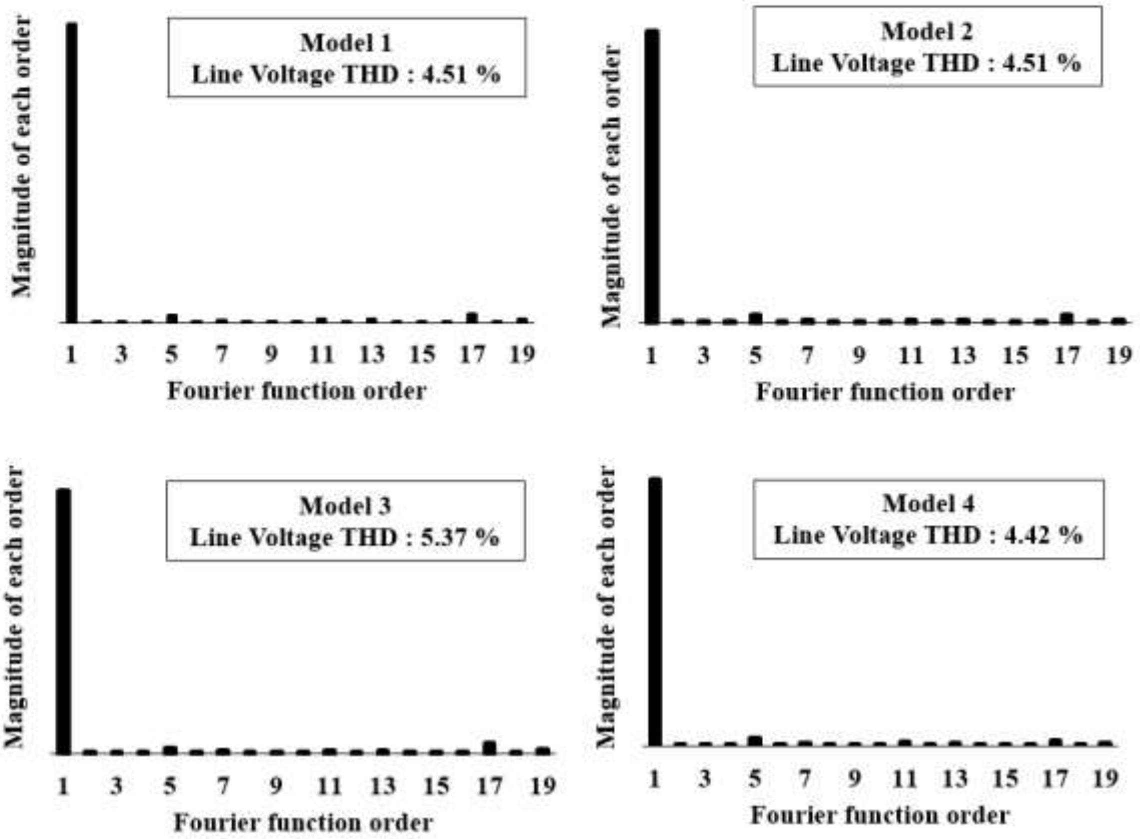
Table 1. Characteristics of torque ripple

Specification	**Model 1**	**Model 2**	**Model3**	**Model 4**	**Unit**
Base Speed	5.43	4.84	7.52	5.37	%
Max. Speed	12.99	13.13	8.80	18.89	

Model 1 is the target model, and for torque ripple characteristics, the characteristics of Model 2 are the best at base speed, and Model 3 is the best at maximum speed.

In order to analyze the difference in torque ripple, the occurrence of torque ripple is analyzed. The torque ripple of IPMSM is caused by the armature reaction between the magnetic flux generated when current is applied to the stator winding and the magnetic flux generated from the permanent magnet of the rotor. That is, the harmonic components of the voltage can consequently affect the armature reaction flux and also the torque ripple.

For harmonic analysis, Total Harmonic Distortion (THD) for line voltage at base speed and maximum speed of each model is analyzed. Figure 5 shows the THD of line voltage at base speed and maximum speed by model. As a result, it can be confirmed that the torque ripple increases as the harmonic component of the line voltage increases.



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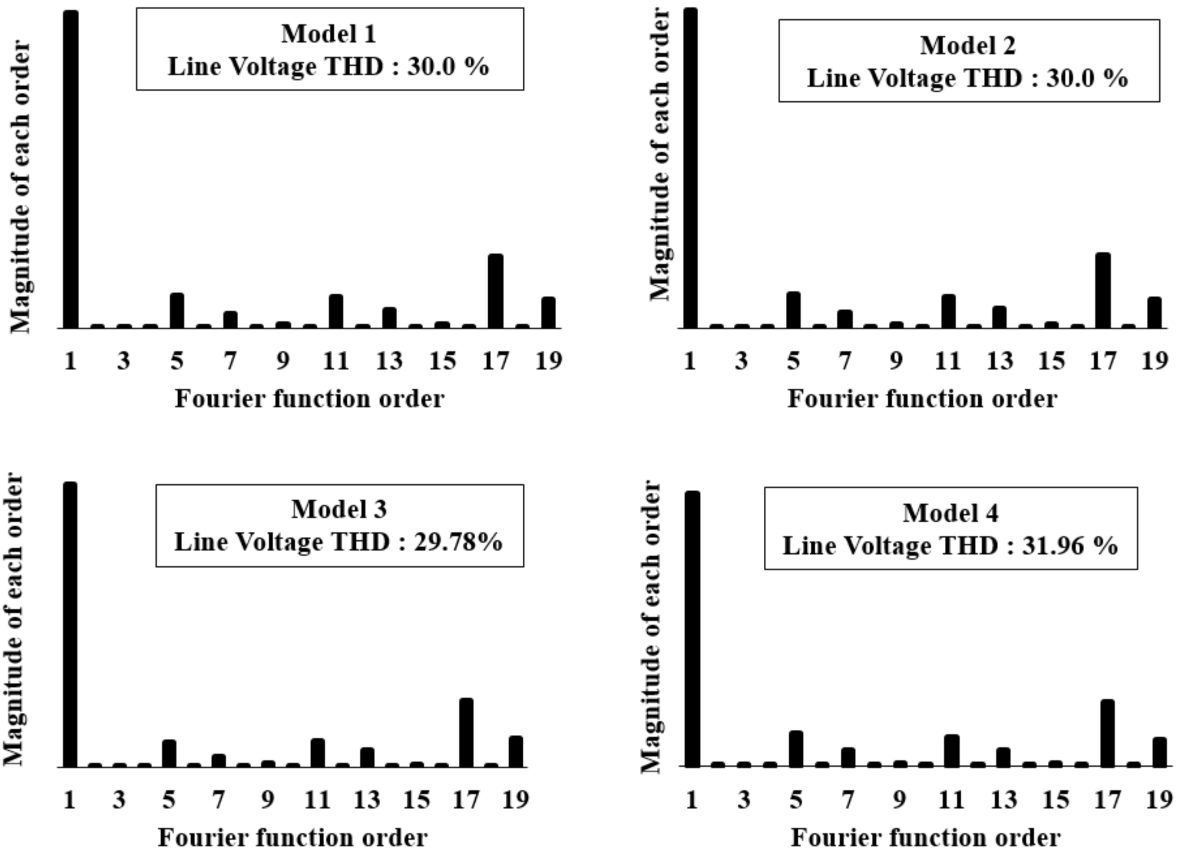

(b)

Figure 5. Total harmonic distortion of line-to-line voltage by model
(a) Line voltage THD at base speed (b) Line voltage THD at maximum speed.

(b)

3. Conclusion

This paper analyzes the torque ripple reduction method according to the stacking method of the rotor. The model to be analyzed has different N-pole and S-pole angles of the permanent magnet. As a result of analyzing the air gap flux density for the target model before analyzing the torque ripple, it is confirmed that the air gap flux density between the N and S poles is different. In order to give symmetry to these asymmetric elements, we present three models in two ways. Model 2 is a model in which the cores of the load side and the half load side of the rotor are rotated with a difference of 45 degrees from each other. Model 3 and Model 4 respectively design the barrier angle to be symmetrical to the N and S poles, and a general skew method is applied here. At this time, the distribution of the air gap magnetic flux density is derived and the symmetry is checked, and the analysis of torque ripple is performed at the base speed and the maximum speed of the motor.

As a result of the analysis, the characteristics of Model 2 are the best at the base speed, and the torque ripple characteristics of Model 3 are the best at the maximum speed. This torque ripple is generated by the reaction of the armature, but the factor that creates the reaction magnetic flux is made by the permanent magnet on the rotor side and the winding on the side of the stator. Therefore, when voltage is applied to the stator windings, the harmonic component affects the torque ripple. As a result of deriving the harmonic component of the line voltage, it is derived that the torque ripple also increases as the THD increases.

In the analysis, it is derived that the stator winding pattern is the same, and the harmonic component changes depending on the arrangement of the rotor permanent magnets as well as the winding pattern or the shape of the stator side. Although the arrangement of permanent magnets did not show any effectiveness in this model, research is needed to apply it to models with other types of permanent magnet shapes.

4. Acknowledgments

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