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Analysis of Cogging Torque Reduction of IPMSM applying Skew Method

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Abstract

Background/Objectives: In a rotating machine such as Interior Permanent Magnet Synchronous Motor (IPMSM), which is widely used in industrial fields. The reluctance torque is generated by the difference when magnetic energy varies according to the relative position of the pole and slot in a slot shaped motor. The reluctance torque acts as a torque ripple in electrical equipment and causes noise and vibration. It generated by the influence of the slot in the permanent magnet device is called cogging torque, and a skew was applied as a method to reduce the cogging torque to analyze the characteristics of the motor. In this paper, we analyze the back electromotive force and torque characteristics of IPMSM motors applying 3-stage skew among various cogging torque reduction methods, and reduce torque ripple in the instantaneous and continuous sections of the motor through Finite Element Method (FEM). **Findings**: Therefore, in this paper, we discuss how to apply skew among many analysis methods for reducing cogging torque. It shows the procedure for reducing cogging torque by applying skew from the comparative model. Finally, it analyzes the characteristics of the existing model and the model to which the skew is applied, and indicates how much it has increased. **Improvements/Applications:** By applying a three-stage skew to the model applied in this paper, the effect of noise and vibration can be reduced through cogging torque reduction.

Index Terms

Cogging Torque, IPMSM, Skew, THD, Torque Ripple

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I. INTRODUCTION

Many studies have been conducted on the high efficiency and high output of IPMSM motors that are used in various ways. Motor efficiency is greatly influenced by design, but among them, coking torque and torque ripple cannot be ignored. As the ripple is reduced, the efficiency of the motor can be increased, and the life of the motor is also increased, so the ripple reduction is important. The cogging torque and torque ripple in the IPMSM (Interior Permanent Magnet Synchronous Motor) generates vibration and noise in the motor and, in severe cases, has a problem of lowering the efficiency. Methods of reducing cogging torque include increasing the length of the air gap, increasing the number of slots or poles, or applying skew to the stator or rotor, changing the shape of the magnet, using a magnet with low magnetic flux density, and the shape of the stator teeth. There are many methods such as change, but the method of increasing the length of the pores lowers the magnetic flux density of the pores, which has a bad effect on the output. have. Therefore, the most common method is to offset the cogging torque using the skew of the permanent magnet rotor. However, if the rotor to which the skew is applied is also applied in three or more stages, an additional skew jig is required, and there is a problem in that the manufacture ability is deteriorated and the cost is increased.

In this paper, the optimal model was selected by analyzing the back EMF and harmonics of the model with two-stage skew and three-stage skew at no load. After that, the effect of skew application was verified by comparing the cogging torque and torque ripple of the existing model and the optimal model. For all analysis, electromagnetic field analysis simulation was used, and back electromotive force, harmonics, torque and torque ripple were analyzed through Finite Element Method (FEM).

II. THE ANALYSIS MODEL

A. Base model 1kW IPMSM

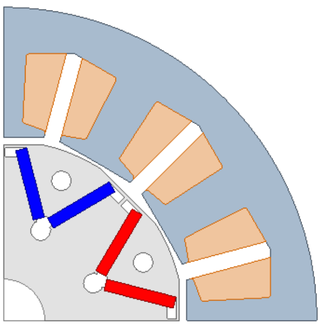


Fig. 1. 1kW IPMSM (Base Model)

Fig. 1. is a model to reduce cogging torque and apply skew in this paper. It is an 8-pole 12-slot IPMSM of 1kW class, and its output is up to 1kW. The stator diameter is 66.7Φ, and the outer diameter is 114Φ. The pore length is 1.2mm and the pores are not uniform. The inner diameter of the rotor is 15Φ and the outer diameter is 65.5Φ. The stacking length is 38.4Φ. The residual magnetic flux density for the analysis was 1.3T at 20°C at no load condition and 1.25T at 80°C at load condition, and the electromagnetic field analysis was performed.

Table 1. SPECIFICATION TABLE OF 1KW IPMSM BASE MODEL

Para.		Spec.	Units.
Max Power		1	kW
Max Torque		3.5	Nm
Speed (Base / Max)		2739 / 4500	rpm
Stator	Inner dia	66.7	Φ
	Outer dia	114	Φ
Rotor	Inner dia	15	Φ
	Outer dia	65.5	Φ
Poles / Slots		8 / 12	-
Airgap		1.2	mm
Stack Length		40	mm
Br		1.3 (20˚C)	T
		1.25(80˚C)	T

B. Select Optimal Design

Electromagnetic field analysis and FEM simulation were performed to select the optimal model. The values of cogging torque by skew angle, no-load back EMF, and harmonics of the model applying 2-step and 3-step skew were analyzed. The optimal model was selected through this analysis method. Table 2. shows the harmonics and cogging torques of the FEM-analyzed models under no load. Considering that one slot pitch is 30deg, FEM analysis was conducted by dividing 2-step skew and 3-step skew by 1 deg units. Fig. 2. shows the no-load back EMF waveform changes. In Table 2. the 3-step skew and 10deg model which has the lowest cogging torque value, was selected as the optimal model. Fig. 3. shows the THD (Total Harmonics Distortion) changes, and in Table 2, 3-step skew, 10deg, which has the lowest cogging torque value, was selected as the optimal model. As shown in Fig. 2, no-load back EMF of the 3-step, 10deg is smoother than that of the basic model. The THD shown in Fig. 3. decreased from 11.73% to 2.74%.

Table 2. HARMONICS AND COGGING TORQUE ACCORDING TO SKEW ANGLE

Para. \ Skew angle		7°	8°	9°	10°	11°
2-step	THD[%]	4.92	3.7	2.85	3.1	4.54
	$T_{cogging}$[Nm]	0.09	0.1	0.18	0.26	0.34
3-step	THD[%]	5.47	5.1	4.04	2.74	1.7
	$T_{cogging}$[Nm]	0.09	0.08	0.07	0.02	0.07

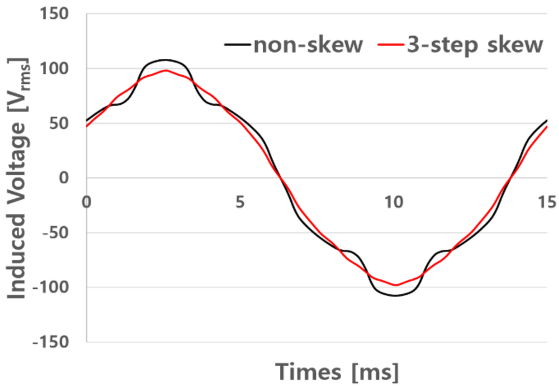


Fig. 2. Comparison 3-skew model with base model about no-load back EMF

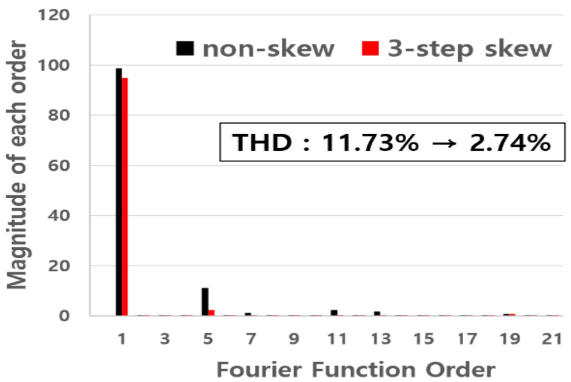


Fig. 3. Comparison 3-skew model with base model about THD

In consideration of one slot pitch, the back EMF and THD(Total Harmonics Distortion) were compared by dividing 1deg from 7deg to 11deg at no load. Through this process, skew was applied and the characteristic analysis model was selected as 3skew, 10deg model, confirming that the ripple of the back EMF waveform was reduced at no load and it was confirmed that the THD was reduced from 11.73% to 2.74%. Next, the reduction effect of cogging torque and torque ripple was shown by comparing the driving characteristics of the skew applied model and the basic model. We will confirm the improvement of torque ripple and cogging torque of the final model by analyzing the cogging torque and torque ripple of the basic speed and the maximum speed under the load condition.

III. FEA ANALYSIS

Table 3. shows the instantaneous rating of the comparative model and the conventional model and the comparison of the characteristics in the instantaneous maximum section. The battery limit voltage of the existing model is 280 Vdc, and the line voltage is 198Vrms. The torque ripple at the base speed of the non-skew model was 24.86% and 41.13% at the max speed. The cogging torque was also 0.44Nm and 0.40Nm, respectively. The torque ripple of the model given 3-skew by 10 deg is 6.41% at base speed and 3.1% at max speed. The base speed and max speed were reduced by 18.45% and 38.03%, respectively. The cogging torque of the 3-step skew model is 0.11Nm in the base speed and 0.03 in the max speed, respectively, which is 0.33Nm and 0.37Nm lower than the previous model.

Table 3. COMPARISON OF EXISTING MODEL AND SKEW APPLIED MODEL

	Non-skew		3-step Skew		Unit
	2739	4500	2860	4500	rpm
Ia	3.1	6.13	3.2	5.55	A
angle	7	75.2	7	72.5	deg
Vab	197.93	197.74	197.7	197.65	V_{rms}
Torque	3.51	2.1	3.51	2.09	Nm
Torque Ripple	24.86	41.13	6.41	3.1	%
Cogging Torque	0.44	0.40	0.11	0.03	Nm

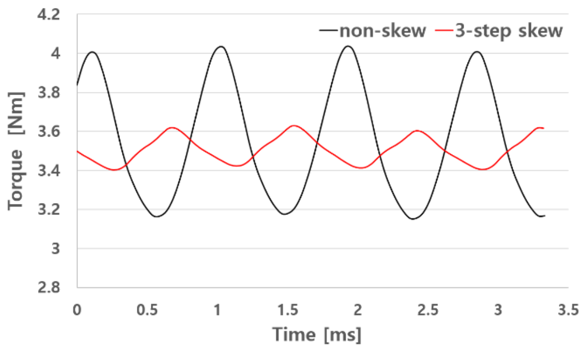


Fig. 4. Torque Comparison non-skew and 3-step skew at Base speed

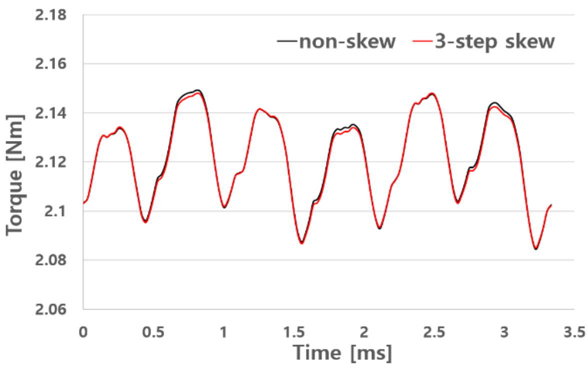


Fig. 5. Torque Comparison non-skew and 3-step skew at Max speed

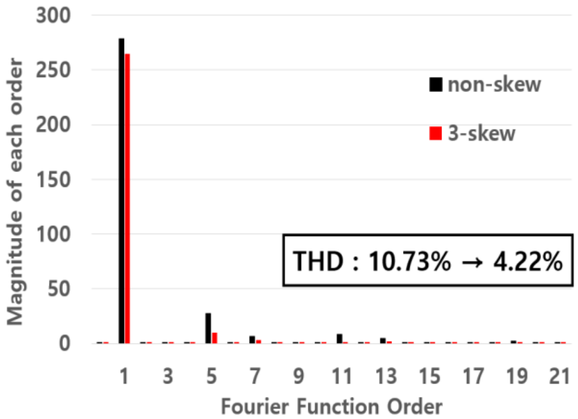


Fig. 6. THD Comparison non-skew and 3-step skew at Base speed

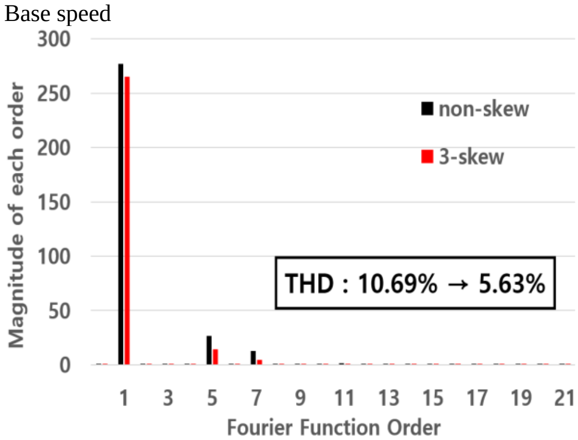


Fig. 7. THD Comparison non-skew and 3-step skew at Max speed

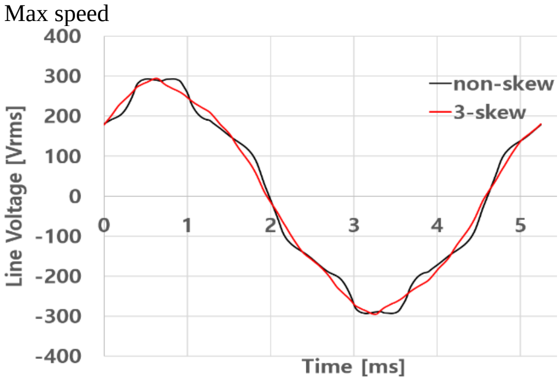
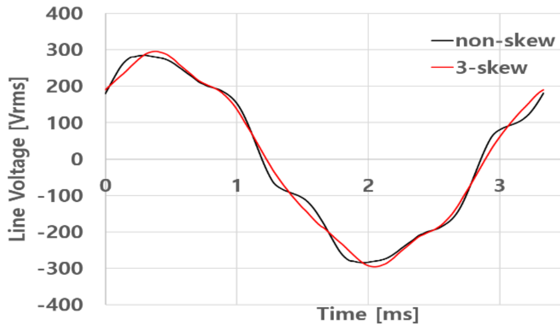


Fig. 8. Line Voltage Comparison non-skew and 3-step skew at Base speed



(b)

Fig. 9. Line Voltage Comparison non-skew and 3-step skew at Max speed

IV. Conclusion

In this paper, the characteristics of the base model and 3-step skew model were analyzed by applying the skew method. To confirm the reduction of cogging torque and torque ripple, a characteristic analysis was performed using the Finite Element Method. Among the models to which skew is applied for each angle in consideration of the one slot pitch in the no-load condition, the model with the most no-load back EMF and THD reduction was selected as the load analysis model. As a result, the torque ripple of the selected 3skew 10deg model was reduced by about 20% compared to the base model and the cogging torque was also significantly reduced.

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References

[1] Ki-Chan Kim. (2014). A Novel Method for Minimization of Cogging Torque and Torque Ripple for Interior Permanent Magnet Synchronous Motor. *IEEE transaction journal on magnetics,* 50(2*)*

[2] Xiao Ge, Z. Q. Zhu, Graham Kemp, David Moule, and Connel Williams.(2017). Optimal Step-Skew Methods for Cogging Torque Reduction Accounting for Three-Dimensional Effect of Interior Permanent Magnet Machines. *IEEE transaction on Energy Conversion*, 32(1), 222-232

[3] M. A. Alhamadi and N. A. Demerdash. (1994). Three Dimensional Magnetic Field Computation By A

Coupled Vector-Scalar Potential Method In Brushless DC Motors with Skewed Permanent Magnet Mounts-The No-Load And Load Results. *IEEE transaction journal on magnetics,* 9(1), 1-14

[4] Claudio Bianchini, Fabio Immovilli, Emilio Lorenzani, Alberto Bellini, and Matteo Davoli (2012). Review of Design Solutions for Internal Permanent-Magnet Machines Cogging Torque Reduction. *IEEE transaction journal on magnetics*, 48(10), 2685-2693

[5] W. Fei, and Z. Q. Zhu (2013). Comparison of Cogging Torque Reduction in Permanent Magnet Brushless Machines by Conventional and Herringbone Skewing Techniques. IEEE *transaction journal on magnetics*, 28(3), 664-674

[6] Byung-Il Kown. Byung-Taek Kim and Cha-Seung Jun, Seung-Chan Park. (1999). Analysis of Axially Non-uniform Loss Distribution in 3-phase Induction Motor Considering Skew Effect. *IEEE transaction journal on magnetics,* 35(3), 1298-1301

[7] W. Q. Chu and Z. Q. Zhu (2013). Reduction of On-Load Torque Ripples in Permanent Magnet Synchronous Machines by Improved Skewing. *IEEE transaction journal on magnetics,* 49(7), 3822-3825

[8] Min-Mo Koo, Jang-Young Choi, Key-yong Hong, and Kangsu Lee (2015). Comparative Analysis of Eddy-Current Loss in Permanent Magnet Synchronous Machine Considering PM Shape and Skew Effect Using 3-D FEA. *IEEE transaction journal on magnetics*, 51(11)

[9] Changliang Xia, Zhen Zhang, and Qiang Geng (2015). Analytical Modeling and Analysis of Surface Mounted Permanent Magnet Machines With Skewed Slots. *IEEE transaction journal on magnetics*, 51(5)

[10] Tae-Woo Kim and Jung Hwan Chang(2015). Analysis of Thrust Characteristics Considering Step-Skew and Overhang Effects in Permanent Magnet Linear Synchronous Motor. *IEEE transaction journal on magnetics, 51(3)*

[11] Panagiotis Lazari, Bhaskar Sen, Jiabin Wang, and Xiao Chen (2014). Accurate d–q Axis Modeling of Synchronous Machines With Skew Accounting for Saturation. *IEEE transaction journal on magnetics, 50(11)*