

Study on the Reduction of Eddy Current Loss of Permanent Magnet Synchronous Motor considering PWM

Ye-Seo Lee¹, Ik-Sang Jang², In-Jun Yang³, Sung-Hyun Yoon⁴, and Won-Ho Kim⁵

¹Dept. of Next Generation System Convergence, Gachon University, Seongnam 13120 South Korea

²E-Drive Unit Development Team, Hyundai Mobis, Uiwang 16082 South Korea

³Dept. of Electrical Engineering, Hanyang University, Seoul 04763 South Korea

⁴Dept. of Electrical Engineering, Wonkwang University, Iksan 54538 South Korea

⁵Dept. of Electrical Engineering, Gachon University, Seoul 13120 South Korea, wh15@gachon.ac.kr

Synchronous motors with PWM control are the main ones. When a motor is driven through PWM control, the current waveform considering PWM control shows a different waveform from the sinusoidal current waveform used for general Finite Element Method (FEM) analysis. It is a waveform with harmonics in a sinusoidal current waveform, and this harmonic component has a great effect on eddy current loss generated in permanent magnets, and this eddy current loss causes demagnetization in permanent magnets and affects motor performance. In this paper, the magnet division method is selected as a method to reduce eddy current loss per unit volume, and the reduction of eddy current loss per unit volume according to the decrease in length of the magnet is confirmed. In addition, the effect of harmonics on the eddy current loss of the permanent magnet is confirmed by comparing the current waveform considering PWM with the sinusoidal current waveform. The validity of the above points is verified through FEM.

Index Terms—Synchronous motors, eddy current losses, Pulsewidth modulation, Finite element analysis.

I. INTRODUCTION

RECENTLY, permanent magnet synchronous motors to which PWM (Pulse Width Modulation) control is applied are mainly used. PWM control is a technique that can modulate not only the frequency of the output voltage but also the magnitude, and is a control method that generates pulses for turning on and off each phase switch. In addition, it is a technology that uses switching to control analog circuits with digital output, which is effective for motor control.

In general, when designing a motor using FEM (Finite Element Method), a sinusoidal current waveform is used. When the motor is driven through PWM control, it shows a different waveform from the current waveform considering PWM control. Current considering PWM control contains harmonic components compared to sinusoidal current, and these harmonic components have a great influence on eddy current loss generated in permanent magnets. When designing a motor, it is possible to obtain more accurate analysis results by using a current waveform considering PWM control instead of using a conventional sinusoidal waveform.

Previously, various studies on eddy current loss generated in magnets have been conducted. Since the eddy current loss generated in the magnet causes a thermal deterioration in the permanent magnet, leading to a decrease in performance, research on ways to reduce eddy current loss is essential[1]. In [2], a design was carried out to divide the permanent magnet to reduce the eddy current loss of the permanent magnet. The effect of reducing the eddy current loss and demagnetization of the permanent magnet was derived by reducing the length of the magnet through the dividing of the permanent magnet. In this regard, it is necessary to confirm the effect of the harmonic component of the PWM current on the eddy current loss by conducting a study with a current waveform considering PWM control rather than a sinusoidal current waveform.

In this paper, the eddy current loss of the permanent magnet, which has a great effect on the performance of the motor, is compared using the division of the permanent magnet, and the eddy current loss of the permanent magnet is derived and compared using the sinusoidal current waveform and the current waveform considering PWM control.

II. ANALYSIS OF EDDY CURRENT LOSS THROUGH MAGNET DIVIDING

When a magnetic flux that varies with time is generated in a conductor at rest, this change in magnetic flux creates a voltage, and the voltage generates a current, which is called eddy current. Eddy current losses generated from permanent magnets cause magnet demagnetization, which has a fatal effect on motor performance.

The eddy current loss generated in the permanent magnet by the path of the magnetic flux can be expressed by the following formula.

$$p = \frac{c^2}{12\rho} \left(\frac{dB}{dt} \right)^2 \quad (1)$$

where, p is eddy current loss per unit volume, c is the length of the magnet, R is the resistivity, and B is the magnetic flux density. Accordingly, the eddy current loss can be reduced by reducing the length c of the magnet.

Table 1 shows the specifications of the motor models, and Figure 1 shows the shapes of the model without dividing the existing magnet and the model with the magnet divided. The model that divides the magnet divides the magnet into four pieces parallel to the axial direction. According to the FEM results, the eddy current loss of the model in which the magnet was not divide was 5.79W, and the eddy current loss of the model in which the magnet was divided into 4 pieces was 0.41W, a difference of about 1/16 times, which was verified by comparison with Equation (1).

TABLE I
SPECIFICATIONS OF THE MODEL

Item	Type Size (points)	Unit
Pole / Slot	8 / 12	-
Power	5	kW
Rotating Speed	6000	rpm
Input Current	20	A
Number of Turns	76	-

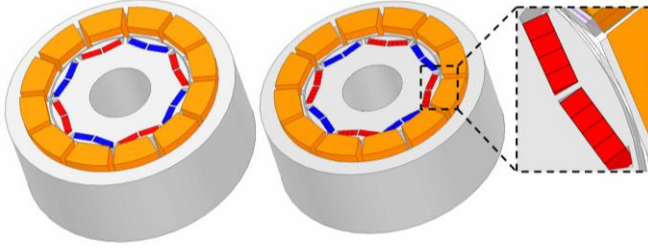


Fig. 1. The Shapes of the Model without Dividing And Model with Dividing

III. ANALYSIS OF EDDY CURRENT LOSS THROUGH PWM CURRENT

In a synchronous motor, since the rotating speed of the rotor and the speed of the stator rotating magnetic field are the same, eddy current loss for the fundamental wave does not occur. However, when harmonics exist, eddy current loss of permanent magnets occurs due to harmonics. The eddy current loss due to harmonics is calculated by the following formula[3].

$$W_{mag} = \sum_n \left\{ \int_{magnet} \frac{J_n^2}{2\sigma} dv \right\} \quad (2)$$

where J_n is the amplitude of nth time-harmonic eddy currents.

Accordingly, when designing a PMSM to which PWM control is applied, a current waveform considering PWM control must be used for more accurate analysis results.

Figure 2 shows the sinusoidal current waveform according to the current phase angle of the model without dividing the magnet and the model with dividing the magnet, and the current waveform considering PWM control. Table 2 shows the comparison of eddy current loss of each model for two current waveforms. Due to the harmonic components of the PWM current, the Total Harmonic Distortion(THD) of the line-to-line voltage under load increased by about 167% compared to the simulation result through the sinusoidal current waveform in comparison to the existing sinusoidal current waveform, and the torque ripple also increased by about 33%.

In addition, to confirm the effect of the harmonic components of the PWM current on the eddy current loss of the permanent magnet, the eddy current loss of the permanent magnet was compared. When the magnet was not divided, the model using a sinusoidal current waveform measured 5.79W, and the model using a current waveform considering PWM measured 7.26W. When the magnet was divided, the model using a sinusoidal

current waveform measured 0.416W and PWM The model using the considered current waveform measured 0.604W. Differences of 23% and 34% were shown between the case of using a sinusoidal current waveform and the case of using PWM current, respectively.

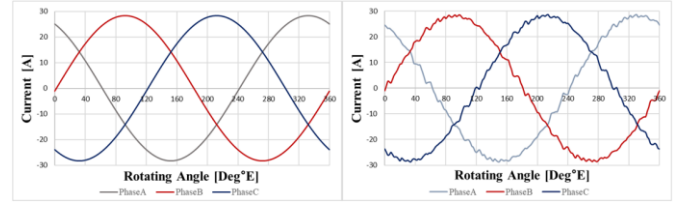


Fig. 2. The Sinusoidal Current Waveform and The Current Waveform Considering PWM Control

TABLE 2
COMPARISON OF EDDY CURRENT LOSS FOR TWO CURRENT WAVEFORMS

Item	Eddy Current Loss	Unit
0Div with sinusoidal current waveform	5.79	W
0Div with PWM current	7.26	W
4Div with sinusoidal current waveform	0.416	W
4Div with PWM current	0.604	W

IV. CONCLUSION

When PWM control is considered, since harmonic components exist, current considering harmonics should be used instead of ideal sinusoidal current. This harmonic component also affects the eddy current loss that occurs in the permanent magnet. Since the eddy current loss generated in the permanent magnet causes a thermal demagnetization in the permanent magnet and has a great fatal on the performance, it is necessary to study a method to reduce the eddy current loss and a method to obtain an accurate value of the eddy current loss.

In this paper, a method for reducing eddy current loss in permanent magnets through magnet dividing is presented, and a method for analyzing eddy current loss due to harmonics using current waveforms considering PWM control is proposed. Validate analysis results through FEM (Finite Element Analysis).

REFERENCES

- [1] K. Yamazaki, Y. Fukushima and M. Sato, "Loss Analysis of Permanent-Magnet Motors With Concentrated Windings—Variation of Magnet Eddy-Current Loss Due to Stator and Rotor Shapes," in IEEE Transactions on Industry Applications, vol. 45, no. 4, pp. 1334-1342, July-aug. 2009
- [2] B. -C. Kim, J. -H. Lee and D. -W. Kang, "A Study on the Effect of Eddy Current Loss and Demagnetization Characteristics of Magnet Division," in IEEE Transactions on Applied Superconductivity, vol. 30, no. 4, pp. 1-5, June 2020.
- [3] K. Yamazaki and A. Abe, "Loss Investigation of Interior Permanent-Magnet Motors Considering Carrier Harmonics and Magnet Eddy Currents," in IEEE Transactions on Industry Applications, vol. 45, no. 2, pp. 659-665, March-april 2009.