

PWM Core-loss Analysis of Permanent Magnet Motor Using Current-Waveform

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In this paper, we propose the use of the fast finite element method (FEM) for the nonlinear analysis of a pulse-width modulation (PWM) current source. Using FEM analysis, PWM current analysis is time consuming because it has many steps, unlike the case with a sinusoidal current. In this paper, we perform the FEM analysis in two steps. First, the sinusoidal current is applied to the nonlinear analysis and each permeability value is saved in memory. Second, we perform the linear analysis using the saved permeability value. To verify the effectiveness of this approach, the core loss of the proposed method is compared with that of the full-FEM result.

Index Terms— PWM current, current harmonic, finite element analysis, PWM losses, core-losses

I. INTRODUCTION

The development of advanced power electronic switching devices has enabled high-frequency switching operation and has improved the performance of PWM inverters for driving. Magnetic circuit analysis methods have also developed significantly in recent years. The magnetic flux density that is applied to the PWM source uses the analysis of the core losses and the estimation of the efficiency of electric machines. It takes much time to perform the FEM with a PWM current, however, because there are too many steps.

Several papers have published the iron loss calculation in the PWM inverter excitation in a recent study [1][2]. The magnet iron loss is investigated via PWM modulation. It is calculated using the magnetic flux density and the efficiency of the electric motor with a PWM inverter. This method takes much time, though [3]. As an alternative, the hysteresis model using Preisach modeling of the PWM source is being investigated. Fast PWM analysis is required for accurate magnetic circuit design.

In this paper, fast PWM analysis is performed using a combination of nonlinear analysis and linear analysis. The sinusoidal current is applied to the nonlinear analysis to determine the permeability of the operation B-H curve. Then the permeability is saved to the memory by angle step. Next, the linear analysis is performed to analyze the PWM source. At this time, the saved permeability is used to consider the saturation effect. There are several techniques for getting an effective result; but they differ between sinusoidal analysis and PWM analysis. Therefore, interpolation is needed to adjust the permeability of the PWM result from the sinusoidal permeability. This method is useful to quickly determine the iron losses and efficiency of the motor with a PWM source.

II. ANALYSIS METHOD AND MODEL FOR PWM CIRCUIT

A. Analysis model

Analytical model was applied to the three phase ac synchronous motor of 400W. Fig. 1 and Table I show the quarter cross-section and brief specifications of the analysis model.

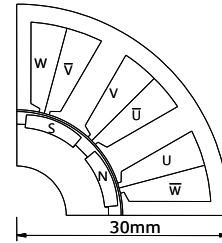


Fig. 1. The cross-section of analysis model

TABLE I
BRIEF SPECIFICATIONS OF 3-PHASE SYNCHRONOUS MOTOR

Item	Value	Item	Value
Phase number	3	Pole number	8
Input voltage (V)	220	Rated current (A)	2.5
Output power (W)	400	Rated speed (rpm)	3000
PWM frequency (kHz)	8	Connection	Y

B. Methodology of a fast PWM analysis

Fig. 2 shows the flow chart for the fast finite element analysis using the combined the sinusoidal and PWM signal. Fig. 3 shows the PWM current of the test motor. In order to reduce the analysis time, the sinusoidal current is applied to first moving analysis by nonlinear analysis. At that time, the permeability is saved in memory according to the moving angle. After the moving angle is finished, the linear analysis is applied to the PWM analysis. The PWM step is very much than the sinusoidal analysis and the moving step is different from previous sinusoidal analysis. The spline interpolation is used for adjust the permeability form the sinusoidal analysis to PWM step.

C. Iron losses

In PWM mode ac machine theory the iron loss is viewed as being caused mainly by the fundamental frequency and the harmonic flux density. In this paper, the flux density is dividing into 2 directions of tangential component and normal component. The iron loss is calculated using the harmonic component analysis method [3].

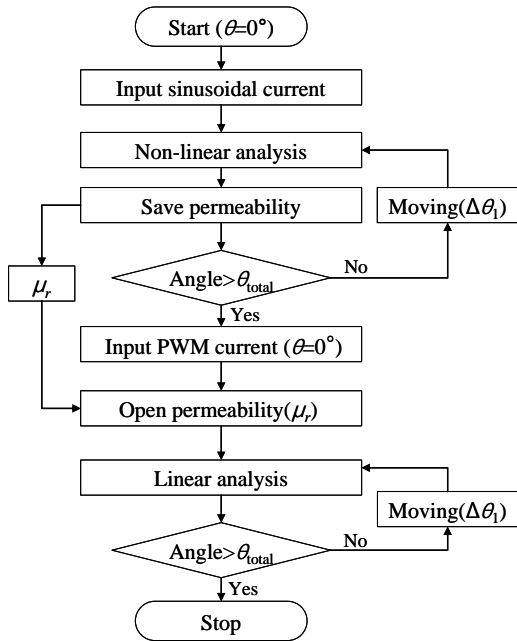


Fig. 2. The analysis flowchart of the combination method of nonlinear analysis and linear analysis

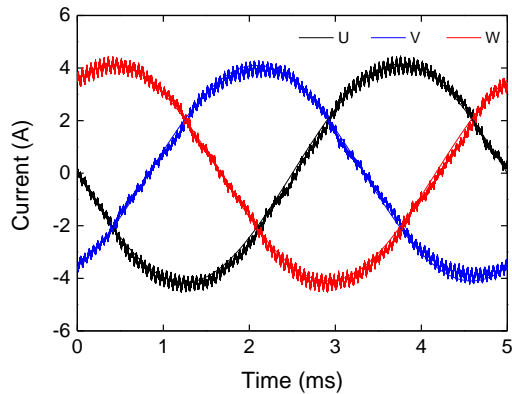


Fig. 3. Sinusoidal current and 8 kHz PWM current at 3000 rpm

III. EXPERIMENT & RESULT

Fig. 4 and Fig. 5 show the core loss distribution for the sinusoidal current and PWM current, respectively, at the rated speed (3000 rpm). The distribution of the core loss is very similar for both analysis results. However, the magnitude of the core loss is different for the sinusoidal and PWM modes. For a clockwise (CW) rotational direction, the maximum core loss density is shown at point C. There is no core loss in the rotor part because there is no alternating or rotating flux.

A comparison of the results obtained for the full PWM analysis and fast PWM simulation show that the core loss error rate is 3% or less. The fast PWM result is close to that of the full PWM analysis. This error is caused by the inclusion of the PWM harmonic components to determine the permeability

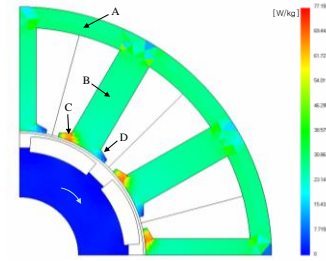


Fig. 4. Core loss distribution in sinusoidal mode at rated speed

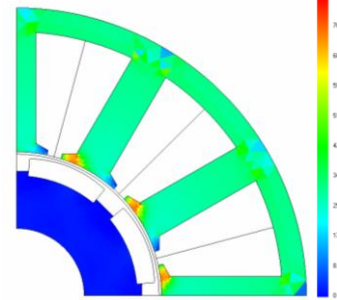


Fig. 5. Core loss distribution in PWM mode at rated speed

IV. CONCLUSION

In this paper, a fast FE method with PWM was presented. Combined nonlinear and linear analysis was performed to reduce the simulation time. The simulation result compared the conventional FEM methods and the combination method of the PWM current. This method is more useful in the analysis of iron losses, including of the harmonic component of PWM. This method can be applied to the analysis of the iron losses in the time-stepping analysis and the steady-static analysis in FEM. Other interesting results and detailed descriptions of the conducted experiments and analyses will be included in the full paper.

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