Analysis on Electromagnetic Losses of High-Speed Permanent Magnet Synchronous Motor according to Current Waveform

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Abstract — This paper accomplished the electromagnetic losses prediction, for instance core losses and rotor eddy current losses of 5kW class high speed PM synchronous motor using analytical method and finite element method. Especially, electromagnetic loss analysis is performed using actual current wave according to driving method, namely, sinusoidal drive and square wave, of high-speed PM synchronous motor. From the obtained analytical solution, the necessity of electromagnetic losses analysis considering driving method can be confirmed.

I. INTRODUCTION

Nowadays, high speed electrical machines are becoming more attractive in many industrial applications. In general, the electromagnetic losses appeared in high speed machines are widely classified into copper loss, core losses, and rotor eddy current losses. In particular, in high speed PM machines, core losses and eddy current losses occupy larger proportion of the total losses than those of other machines. In order to estimate accurate performance characteristics, the prediction of the core losses and rotor eddy current losses is essential. Moreover, since both core loss and rotor loss are highly affected by time harmonics included in input current, analysis with the consideration of driving method should be performed. Therefore, this paper accomplishes the electromagnetic losses prediction, for instance core losses and rotor eddy current losses, according to the driving method, namely, sine wave drive and square wave drive, of 5kW class high speed PM synchronous motor as shown in Fig. 1 using process of losses calculation method as shown in Fig. 2.

II. CORE LOSSES ANALYSIS

For electrical machine designers, core loss data are usually provided in the form of tables or curves of core loss versus flux density or frequency. So, designers normally use core loss data obtained from the Epstein test as a basis on which to predict the core loss of each part of a particular machine with corresponding assumed flux density there. This method has been proved to have good precision in predicting core loss in transformers where alternating field is dominant. However, complex flux distribution, flux density harmonics, and the rotational field in rotating machines bring great difficulties for the evaluation of core loss[1][2]. Therefore, this paper proposed core loss analysis method considering magnetic field behavior and flux density harmonics. Fig. 2 (a) shows the detail process of calculating core loss by proposed method. As shown in the

Fig. 1. Target model for losses analysis.

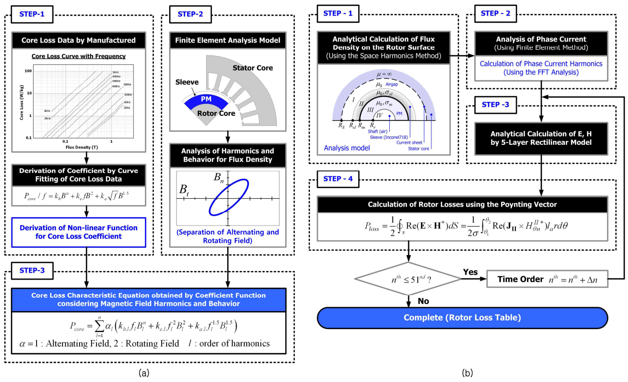

Fig. 2. Process of proposed loss calculation method : (a) core loss and (b) rotor loss

figure, the process of proposed method is listed as follows [3][4][5].

▪ *Step-1 : Rearrangement of core loss data.*

The core loss data provided by manufacturers are rearranged and plotted as a function of P_{core}/f *vs. B*.

▪ *Step-2 : Deduction of core loss coefficient by curve fitting.*

The data of core loss vs. frequency are plotted by the curve fitting of P_{core}/f *vs. B* plot. The derivation of non-linear curve fitting functions for core loss coefficients.

▪ *Step-3 : Time harmonic analysis and the separation of rotating and alternating magnetic field region under every harmonic by the analysis of FFT and magnetic field behavior.*

Using the nonlinear FEA, magnetic field distribution in each region of stator core is analyzed. As fast Fourier transform (FFT) analysis of the obtained results is performed; we obtained the time harmonic component of radial and tangential flux density. In addition, as the axis ratio of radial and tangential flux density at every harmonic is calculated, the rotating and alternating magnetic field are separated.

▪ *Step-4 : Calculation of core loss based on the obtained core loss coefficients and time harmonics analysis results .*

III. ROTOR EDDY CURRENT LOSSES ANALYSIS

This paper predicted the rotor eddy current losses in sleeve and PM region generated by the magnetic field of

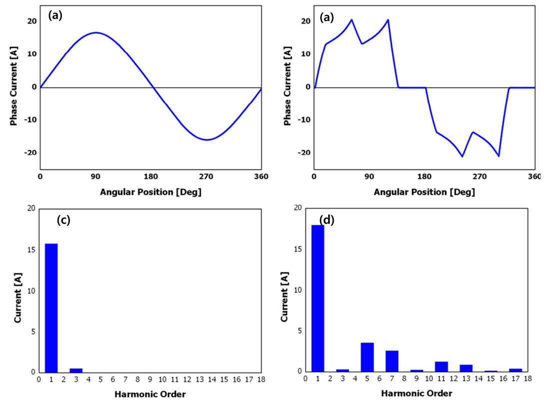

Fig. 3. Phase current waveform and FFT analysis results of high speed synchronous motor according to (a),(c) sinusoidal drive and (b),(d) square wave drive.

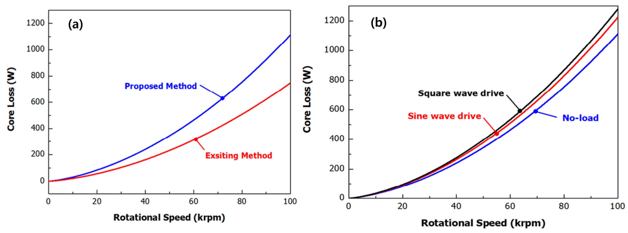

Fig. 4. Core loss calculation results : (a) Comparison of analysis result by proposed method and existing method not considering harmonics and behavior of magnetic field, (b) analysis results according to driving method and load condition.

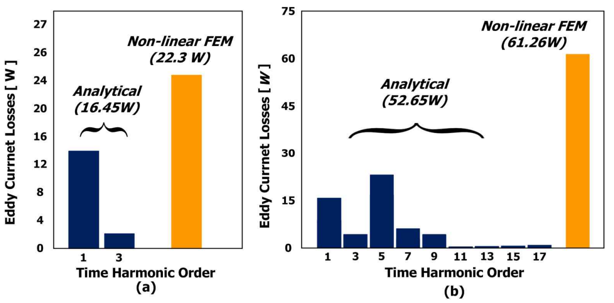

Fig.5. Rotor loss analysis results according to harmonic component in both sinusoidal and square current waveform.

both PM and armature reaction field. It is performed from analysis of the flux density in sleeve and PM region using 2-dimensional polar coordinate system. In particular, the rotor eddy current loss by the magnetic field in no-load condition is derived by magneto static analysis considering slotting, and the loss by armature reaction field is calculated considering eddy current reaction field. In general, the eddy current reaction field by no-load field distribution is generally negligible, and the slotting effect in the field distribution by armature reaction field is not considerable [6]. The loss analysis by magnetic field in no-load condition does not consider eddy current reaction field, and the loss analysis by armature reaction field does not include slotting effect in this paper. Fig. 2 (b) shows the process of rotor eddy current loss analysis [7].

IV. ELECTROMAGNETIC LOSSES ANALYSIS RESULTS ACCORDING TO CURRENT WAVEFORM

Fig. 3 (a) and (b) are the phase current waveform of high speed synchronous motor according to sinusoidal voltage and square voltage operation, and Fig. 3 (c) and (d) is the FFT analysis result of phase current waveform. As shown in Fig. 4 (a), the results of core loss analysis method suggested in this paper is compared existing method not considering harmonics and behavior of magnetic field showing the necessity of core loss analysis considering harmonics and behavior of magnetic field. In addition, as shown in Fig. 4 (b), this paper performed core loss prediction considering operating condition, and it is noticed that the smallest core loss emerges in the load condition of sinusoidal current. Fig. 5 shows the rotor loss according to harmonic component in both sinusoidal and square voltage operation, and the compared analysis results of the suggested analysis method and FEM is presented.

V. CONCLUSION

This paper accomplished the electromagnetic losses prediction, for instance core losses and rotor eddy current losses of 5kW class high speed PM synchronous motor using analytical method and finite element method. Especially, electromagnetic loss analysis is performed using actual current wave according to driving method, namely, sinusoidal drive and square wave, of high-speed PM synchronous motor. From the obtained analytical solution, the necessity of electromagnetic losses analysis considering driving method can be confirmed. It is expected that the losses analysis techniques proposed in this paper can be applied to initial design of high-speed PM synchronous motor.

VI. REFERENCES

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