Electro-magnetic Losses Calculation and Reduction of High-speed Permanent Magnet Synchronous Motor using Measured Load Current Waveform with Harmonics and 2-D FEM

Seok-Myeong Jang[1], Cheol Han[1], Jang-Young Choi[1], Yong-Bok Lee[2]
[1] Dept. of Electrical Engineering, Chungnam Nat'l Univ., 220, Gung-dong, Yuseong-gu, Daejeon, Korea
[2] Korea Institute of Science and Technology
hchol86@cnu.ac.kr

Abstract — This paper deals with calculation and comparison of electromagnetic losses for high-speed PMSM according to phase current with/without time harmonics and suggests methods to decline stator core and rotor eddy current losses. Through measured current wave, various losses are calculated and compared with losses according to current sine wave. Then it is verified to decrease stator core and rotor eddy current losses as improved model. Two-dimensional (2-D) nonlinear time-domain finite-element analysis has been used to investigate the losses of high-speed permanent magnet machine.

I. INTRODUCTION

Nowadays, high speed permanent magnet synchronous motors (PMSM) are becoming more attractive in many industrial applications because of the increasing need for low weight, high efficiency, and high power density. High speed PMSM has time harmonics of very high frequency because it's driven on high speed performance. In general, electromagnetic losses such as stator core, rotor eddy current and copper by AC resistance losses are highly affected by time harmonics included in input current. The faster Speed of PMSM, the bigger these losses are. Besides they may cause significant heating of the PM, due to relatively poor heat dissipation from the rotor, and result in partial irreversible demagnetization. For these reasons, analysis considering actual current waveform should be performed and re-analysis for decrease of losses is needed. This paper deals with comparison and analysis of electromagnetic losses for high-speed PMSM according to phase current with/without time harmonics and suggests methods to reduce stator core and rotor eddy current losses.

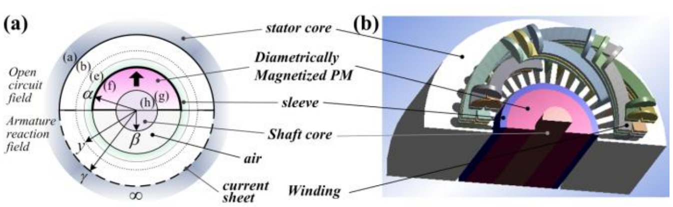

Fig. 1. (a) Cross-sectional diagram (b) Concept model

II. ANALYTICAL PROCESS AND LOSSES DECREASE METHOD

First, current shown in Fig. 2 (a) is measured under rated condition. Time harmonics are obtained using Fast Fourier transform (FFT) analysis shown in Fig. 2 (b). Then, influence of time harmonics on electromagnetic losses are calculated. In particular, in order to calculate stator core losses and eddy current losses, non-linear finite element (FE) analyses are employed. And copper losses are analyzed through resistance applied valid coil area considering skin-depth which is affected by AC current. As shown in Fig. 3, electromagnetic losses according to current with/without time harmonics are calculated and compared. The eddy-current loss W_e and hysteresis loss W_h of the core can be calculated from the time series data of the flux density distribution as follows:

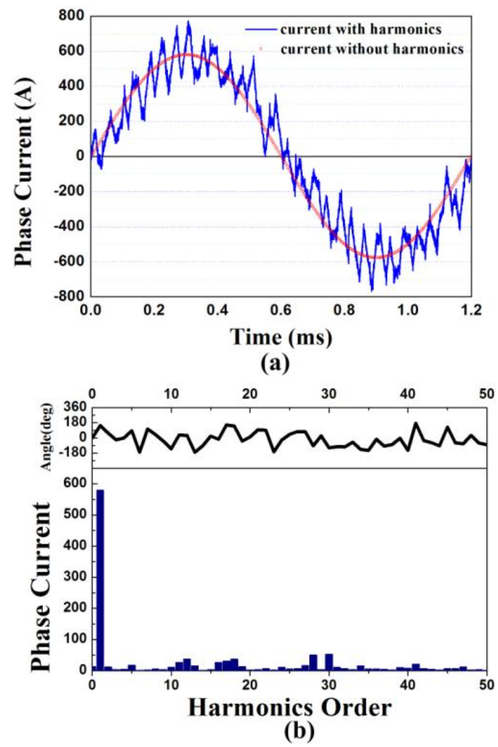

Fig. 2. (a) Measured input-current wave and sine-wave (b) FFT Spectrum of Measured input-current

$$W_e = \frac{K_e D}{2\pi^2}\int \frac{1}{N}\sum_{k=1}^{N}\left\{\left(\frac{B_r^{k+1}-B_r^k}{\Delta t}\right)^2+\left(\frac{B_\theta^{k+1}-B_\theta^k}{\Delta t}\right)^2\right\}dv \quad (1)$$

$$W_h = \frac{K_h D}{T}\sum_{i=1}^{NE}\frac{\Delta V_i}{2}\left(\sum_{j=1}^{Npr^i}\left(B_{mr}^{ij}\right)^2+\sum_{j=1}^{Np\theta^i}\left(B_{m\theta}^{ij}\right)^2\right) \quad (2)$$

where D is the density of the core, N is the number of time steps per one time period, Δt is the time interval, ΔV_i is the volume of i th finite element, B_r and B_θ are the radial and peripheral component of the flux density, B_{mr}^{ij} and $B_{m\theta}^{ij}$ are the amplitude of each hysteresis loop. K_e and K_h are the experimental constant obtained by Epstein frame [1]-[3].

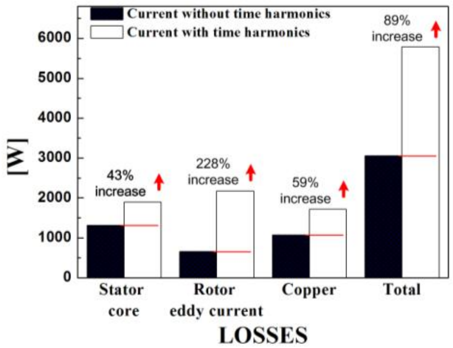

Fig. 3 Result losses by FEM

Then, in order to decrease stator core loss, slot shape is remodeled as maintain same slot area. Five models shown in Fig. 4 (a) are analyzed by changing width of teeth and yoke [4]. In order to decrease rotor eddy current loss, nine models with different material and mix ratio of sleeve are remodeled as maintain same thick. Double sleeves which are made up inconel and copper with different conductivity are used [5].

III. Result and Discussion

It can be seen that stator core, rotor eddy current and copper losses produced by current with time harmonics are 43%, 228% and 59%, respectively, each value is larger than those without time harmonics in Fig 3. Finally it can be seen that total losses produced by current with time harmonics is 89% larger than those without time harmonics. However as like shown in Fig. 5, as slot shape and sleeve material of model are changed, stator core and rotor eddy current losses is decreased again each 5% and 40.5% respectively. Fig. 6(a) shows that for magnetic flux density of yoke with lowest stator core loss improved model is lower than original model. Moreover Fig. 6 (b) shows that for rotor eddy current loss density of lowest rotor eddy current loss improved model is lower than original model. As this result of our paper, losses of high speed PMSM according to time harmonics is investigated and improved model for the reduce of losses is valid. The discussion for these results will be stated clearly in final full paper. The methods and the procedures for calculation of losses will be also fully in final full paper.

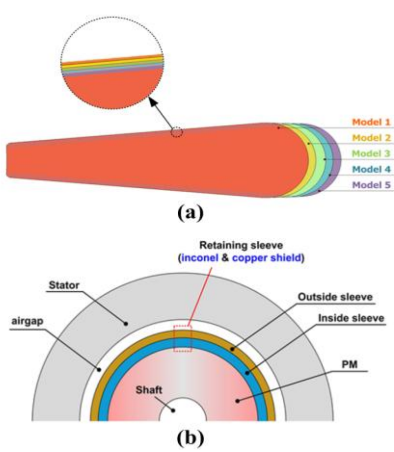

Fig. 4. (a) Slot modeling for decrease in stator losses (b) Rotor modeling for decrease in rotor eddy current loss

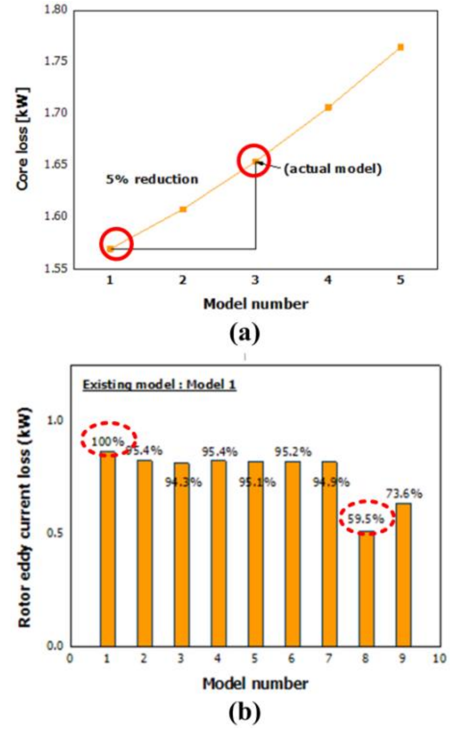

Fig. 5. According to model (a) Stator core loss (b) Rotor eddy current loss

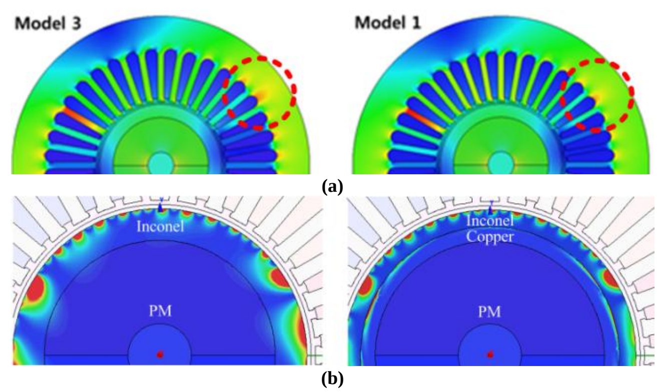

Fig. 6. (a) Compare Magnetic flux density of original model and improved model (b) Compare rotor eddy current loss of original model and improved model

IV. References

[1] Zhu, Z.Q., Ng, K., Schofield, N., and Howe, D, "Analytical prediction of rotor eddy current loss in brushless machines equipped with surface-mounted permanent magnets, Part I : magneto static field model" fifth international conference on electrical machines and systems 2001.

[2] Zhu, Z.Q., Ng, K., Schofield, N., and Howe, D, "Analytical prediction of rotor eddy current loss in brushless machines equipped with surface-mounted permanent magnets, Part II : accounting for eddy current reaction field" fifth international conference on electrical machines and systems 2001.

[3] Yamazaki K, Watari S. "Loss analysis of permanent-magnet motor considering carrier harmonics of PWM inverter using combination of 2-D and 3-D finite element method" Magnetics, IEEE Transactions on 2005

[4] H.Y. Lee, H.B. Lee, H.K. Jung, S.Y. Hahn, K.S. Lee, I.H. Park, G.S. Park, and D. Son, "shape design of stator slot for the reduction of stator core loss in the induction motor" Electric Machines and Drives Conference Record, 1997. IEEE International

[5] Zhou. F., Shen. J., Fei. W., Lin. R., "Study of Retaining Sleeve and Conductive Shield and Their Influence on Rotor Loss in High-Speed PM BLDC Motors " Magnetics Conference, 2006. INTERMAG 2006. IEEE International