Analysis of a SPM Motor Model Core Considering Vector Magnetic Property under High Magnetic Flux Density Conditions

Takeru Sato, Takashi Todaka, and Masato Enokizono
Dept. of Electrical and Electronic Engineering, Faculty of Engineering, Oita University
700 Dannoharu, Oita 870-1192, Japan
v08f1003@mail.cc.oita-u.ac.jp

Abstract — To make clear magnetic phenomena in a SPM motor model core under high flux density conditions over 1.3T, the integral-type dynamic E&S modeling is employed. The magnetic property database for this analysis is newly prepared in the measurements of the vector magnetic properties of the core material under the high magnetic flux density conditions up to 1.8T, and then the magnetic reluctivity and hysteresis coefficients of the integral-type dynamic E&S modeling are derived. The results show that there is an applicable region of the integral-type dynamic E&S modeling to obtain a good convergence. We show the magnetic phenomena in the stator core of SPM motor model core under high magnetic flux conditions.

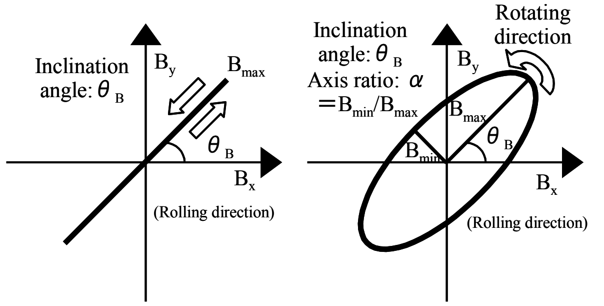
I. INTRODUCTION

Consideration of nonlinear vector magnetic properties is needed to express magnetic anisotropies and rotational iron losses of magnetic materials in numerical simulations [1]-[2]. For this purpose, we have developed the integral-type dynamic E&S modeling [3]-[4]. This modeling is based on a database prepared by vector magnetic property measurements. However, the magnetic properties under the high magnetic flux density conditions [5] are very difficult to measure accurately because of nonlinearity and anisotropy of magnetic materials. So far, we could not perform magnetic field analysis under high magnetic flux density conditions due to lack of database of vector magnetic properties over 1.6T. To solve this problem, we have developed a new vector magnetic property measurement system, which can magnetize a sample sheet up to 1.9T and prepared vector magnetic property database of the integral-type dynamic E&S modeling.

This paper presents results of magnetic characteristic analysis of a surface permanent magnet (SPM) motor model core by using the finite element method considering the integral-type dynamic E&S modeling. We show the magnetic phenomena in a stator core of SPM motor model core under high magnetic flux condition calculated by using the integral-type dynamic E&S modeling.

II. VECTOR MAGNETIC FLUX DENSITY

In the measurements of the two-dimensional magnetic properties, the flux density waveform (B_x, B_y) is controlled to be a sinusoidal waveform because of the criterion of measurement. Fig.1 shows definition of the magnetic flux density conditions. Figs.1 (a) and (b) are the alternating flux condition and the rotating flux condition, respectively. These conditions are expressed with three parameters. They are the magnitude of the maximum magnetic flux density B_{max}, and the angle between the rolling direction and the maximum magnetic flux density vector θ_B, and the ratio of the maximum magnetic flux density and the minimum magnetic flux density α. The precise circular rotating flux means that α is one, and the alternating flux condition means α is zero. Because the vector magnetic property can express relationship between the magnetic flux density and the magnetic field strength, the magnetic anisotropies and the rotating magnetic flux density are made clear.



(a) Alternating flux condition (b) Rotating flux condition

Fig.1 Definition of alternating and rotating flux conditions

III. INTEGRATION-TYPE DYNAMIC E&S MODELING

The integral-type dynamic E&S modeling can be defined as follows,

$$\begin{aligned} H_x(\tau) = {} & \nu_{xr}(B_{\max},\theta_B,\alpha,f_0,\tau)B_x(\tau) \\ & + \nu_{xi}(B_{\max},\theta_B,\alpha,f_0,\tau)\int B_x(\tau)d\tau \\ & + \frac{\pi(f-f_0)\sigma d^2}{6}\frac{\partial}{\partial\tau}B_{1x}(\tau+\gamma_x) \\ & + \frac{\pi(f-f_0)\sigma d^2}{6}\frac{\partial}{\partial\tau}\left\{\sum_{n=3}^{N}B_{nx}\left(\tau+\frac{\gamma_x}{n}\right)\right\} \end{aligned} \tag{1}$$

where, ν_{jr} and ν_{ji} are the magnetic reluctivity coefficients and the magnetic hysteresis coefficients, respectively. Especially, the third and fourth terms mean the magnetic field strength waveforms generated by eddy currents in higher harmonic components.

IV. MODEL MOTOR AND CALCULATED RESULTS

Fig.2 shows the SPM motor model core. The rolling direction of the non-oriented silicon steel sheet used in the model is shown with the arrow in Fig.2. Table I show the

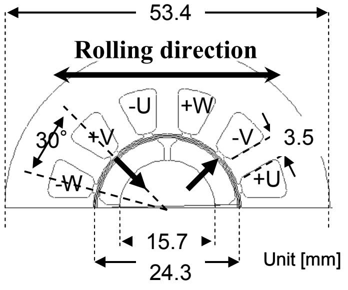
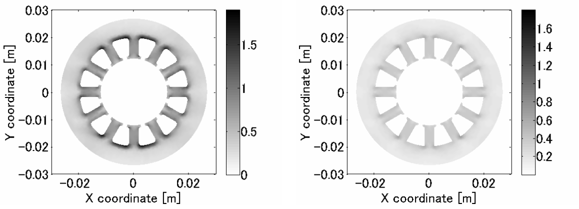


Fig.2 SPM motor model core

TABLE I
SPECITICATION OF THE SPM MOTOR MODEL CORE

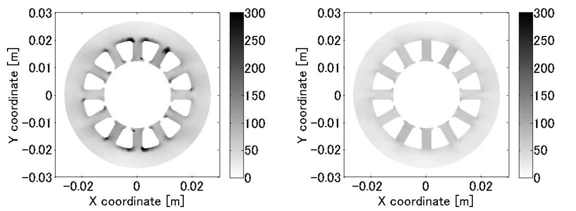
Model diameter [mm]		ϕ 53.4
Length of air gap [mm]		3
Number of Poles		4
Number of Slot		12
Speed [rpm]		1500
Permanent magnet	Magnetization [T]	0.4 or 0.8
	Direction N [deg]	45
	S	315
Magnetic silicon steel		35A440

design data of the SPM motor model core. The exciting conditions were assumed to be 0.4T and 0.8T. Fig.3 and Fig.4 show the distribution of the magnetic flux density and the magnetic field strength. In the calculated results by using the integration-type dynamic E&S modeling, the distributions of the magnetic flux density and the magnetic field strength are difference, because the magnetic flux density and the magnetic field strength is expressed as vectors in this modeling. Fig.5(a) and (b) show the distribution of α. The rotating magnetic flux density is generated around the roots of teeth in 0.8T and 0.4T model. When the exciting condition was changed, the distributions of α change as shown in Fig.5(a) and (b). Especially, in comparison between 0.8T and 0.4T model, the large change of α was shown at the point A. Fig.6 shows the shapes of the magnetic flux density vector loci at 0.8T and 0.4T model at the point A in Fig.5. The rolling direction is x-direction in this indicated case. Because the magnetic anisotropy become strong under the high magnetic flux density, the magnetic flux density was easy to increase in the rolling direction and hard to increase in the transverse direction to the rolling direction.



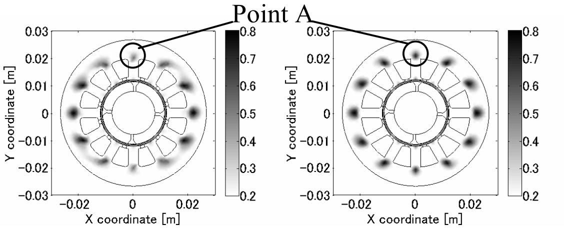
(a) 0.8T model (b) 0.4T model

Fig.3 Distribution of maximum magnetic flux density [T]



(a) 0.8T model (b) 0.4T model

Fig.4 Distribution of maximum magnetic field strength [A/m]



(a) 0.8T model (b) 0.4T model

Fig.5 Distribution of α

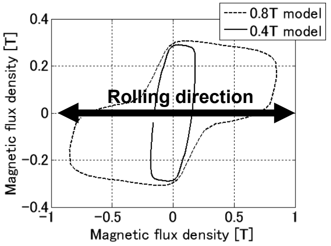


Fig.6 Distribution of B vector loci (α)

V. CONCLUSION

In this paper, the SPM motor model core was analyzed by using the integration-type dynamic E&S modeling. When the magnetic flux density become larger in the model core, the magnetic anisotropy become strong. As a result, the magnetic flux density was easy to increase in the rolling direction and hard to increase in the transverse direction to the rolling direction due to the magnetic anisotropy.

VI. REFERENCES

[1] M. Enokizono, “Two-Dimensional Magnetic Properties” , *Journal of the Magnetics Society of Japan*, Vol. 27, No. 2, pp. 50-58 (2003).

[2] M.Enokizono, K.Fujiwara, S.Yanase, “Two-Dimensional Vector Magnetic Property” , *The Papers of Technical Meeting on Magnetics*, IEE Japan, MAG-04-224, pp.27-31 (2003).

[3] S.Urata, T.Todaka, M.Enokizono, H.Shimoji, ”Magnetic Field Analyses Considering Dynamic E&SS Model under Distorted Flux Density Conditions”, *The Papers of Technical Meeting on Msgnetics*, IEE Japan, MAG-05-106 (2005).

[4] T.Matsuo, Y.Terada, M.Shimada, ” Representation of AC Hysteric Characteristics of Silicon Steel Sheet Using Simple Excess Eddy - Current Loss Approximation", *IEEE Transactions on Magnetics*, Vol.41, No.5, pp. 1544-1547 (2005).

[5] Zurek.S, Meydan.T, ” Rotatinal Power Losses and Vector Loci Under Controlled High Flux Density and Magnetic Field in Electrical Steel Sheets, *IEEE Trans*, Vol.42, No.10, pp. 2815-2817 (2006)