MK0500055

The Analysis of the Permanent Magnet MotorUsing the New Magnetic Field Analysis.

Hiroyasu Shimoji, Masato Enokizono, and Takashi Todaka.
Dept. of Electrical and Electronic Engineering, Faculty Engineering, Oita University, 700 Dannoharu, Oita, 870-1192, Japan

Abstract. In this paper iron loss analysis of the permanent magnet motor considering anisotropy of magnetic material is carried out. Recently the magnetic material can be measured using of vector quantity technique. Non-oriented silicon steel sheets for the iron core material have the anisotropy. Therefore, it is necessary to carry out the analysis considering the anisotropy of the magnetic material. We 'used the magnetic field analysis, which consider the anisotropy by combining finite element method with the E&S (Enokizono & Soda) modeling

1. INTRODUCTION

A high-efficient motor can be designed, since the direct analysis of the iron loss becomes possible by using this method. The relation between magnetic flux density **B** and magnetic field **H** has not only non-linearity of the size but also spatial angle which is clarifies by non-linearity. However, the non-linearity of the spatial angle could not be considered in the magnetic field analysis.
Then, we carried out the magnetic field analysis considering the non-linearity of size and spatial angle by using finite element method and E&S modeling[1][2]. In the magnetic material, the non-linearity of the spatial angle is that an existence of directions in which magnetic flux density passes easily and with difficulty. The direction in which the magnetic flux density is passes easily is called the easy axis direction, and the direction in which the magnetic flux density passes with difficulty is called the difficult axis direction.
Easy axis direction and difficult axis direction occur in Non-oriented silicon steel sheet mainly used as a stator core material of the motor. The iron loss tends to decrease in easy axis direction and increase in difficult axis direction. Therefore, the shape, which can reduce iron loss by the magnetic field analysis considering the easy axis direction and the difficult axis direction, can be designed.
In this paper, magnetic field analysis of the permanent magnet motor using the assembled core is carried out. The manufacturing is easy, when the assembled core is used, and it is possible to reduce the copper loss by the improvement in occupancy rate of copper wire. In addition, it is possible to reduce the iron loss by choosing the easy axis direction, which is the optimum part in every stator core. The iron loss distribution of the assembled core is compared with one of the conventional core models.

2. The Material Property using Two-dimensional Magnetic Measurement

2.1. Two-dimensional Magnetic measuring apparatus

Figure 1 shows the outline of two-dimensional magnetic measuring apparatus.

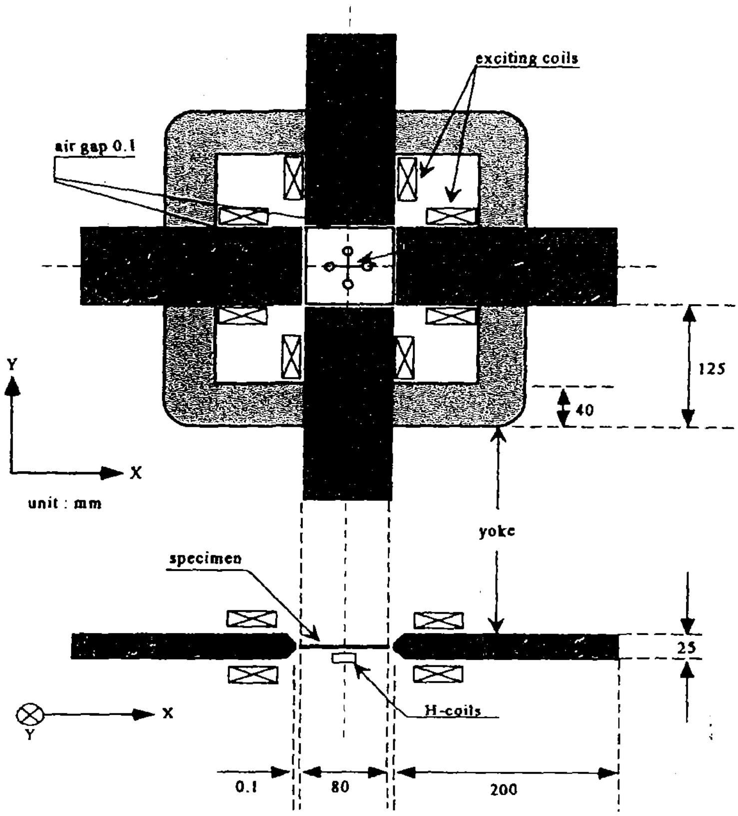


Fig. 1. Two-dimensional Magnetic measuring apparatus.

The yoke for the excitation is placed for the two-dimensional excitation in X axis direction and Y-axis direction. The tip of the excitation yoke for equalizing a magnetic flux is inside the sample. In addition, the air gap is made by putting 0.1 mm sheet between sample and excitation yoke for equalizing a magnetic flux inside of the sample. The rotational magnetic flux of the optional direction is produced by the two-dimensional magnetic measurement equipment.

3. THE FINITE ELEMENT METHOD WITH THE E&S MODELING

3.1. E&S modeling

The E&S modeling considering the easy axis direction is defined in the following equation.

$$\begin{cases} H_x = \upsilon_{xr} B_x + \upsilon_{xi} \dfrac{\partial B_x}{\partial \theta} \\ H_y = \upsilon_{yr} B_y + \upsilon_{yi} \dfrac{\partial B_y}{\partial \theta} \end{cases}, \qquad (1)$$

where υ_{xr}, υ_{xi}, υ_{yr} *and* υ_{xr} are the reluctivity. This reluctivity is obtained from the result of the two-dimensional magnetic measurement. The magnetic flux density and magnetic field becoming following equations by the Fourier transformation

4. FORMULATION FOR MAGNETIC ANALYSIS.

Substituting (2) into Maxwell's equation of a two-dimensional quasi-static magnetic field problem, we can obtain the following equation.

$$J_0 + J_m = \frac{\partial}{\partial x}\left(a_3 \frac{\partial A_z}{\partial y} - a_4 \frac{\partial A_z}{\partial x} \right) - \frac{\partial}{\partial y}\left(a_1 \frac{\partial A_z}{\partial y} - a_2 \frac{\partial A_z}{\partial x} \right)$$
$$+ \frac{\partial}{\partial t}\left\{ \frac{\partial}{\partial x}\left(b_3 \frac{\partial A_z}{\partial y} - b_4 \frac{\partial A_z}{\partial x} \right) - \frac{\partial}{\partial y}\left(b_1 \frac{\partial A_z}{\partial y} - b_2 \frac{\partial A_z}{\partial x} \right)\right\},$$

(2)

where J_0 is the exciting current density, M is the magnetization. A (=A_z) is the magnetic vector potential.

Because the components of reluctivity coefficients υ_{xr}, υ_{xi}, υ_{yr}*and* υ_{xr} have non-linearity, it is necessary to calculate iteratively until those values become constant. We can carry out the non-linear magnetic field analysis considering the hysteresis.

The iron loss and total iron loss can be calculated directly from the analyzed results by using the following equation:

$$P_t = \frac{1}{\rho T}\int_0^T \left(H_x \frac{dB_x}{dt} + H_y \frac{dB_y}{dt} \right) dt \text{ [W/Kg]}, \quad (3)$$

$$Pt_{total} = \rho \cdot Dp \cdot Nos \cdot \sum_{i=1}^{Nes} Pt_i \cdot S_i , \quad (4)$$

where T is the period of exciting waveform and ρ is the material density.

5. RESULTS AND DISCUSSINOS.

Figure 2 shows the model of permanent magnet motor. The stator core is constructed of non-oriented silicon steel sheet. The permanent magnet has been placed in the rotor surface. Table 1 shows the easy axis direction of each teeth and detailed analytical result. The phase difference for the relationship between magnetic field **H** and magnetic flux density **B** is shown in figures 3. The magnetic field analysis, which considered phase difference of magnetic flux density **B** and magnetic field **H** by using this method, became possible. Figures 4 are obtained results for direct iron loss. Total loss of model 1 is 0.43537 [W], and model 2 is 0.42659 [W]. It is known that the total iron loss can be reduced by the change of the easy axis direction. It cannot be judged in quantity, since the iron loss also increases when magnetic flux density increases. Therefore Figure 5 shows the distribution of the iron loss divide the square of magnetic flux density. It is proven that model 2 has been improved further than model 1.

Table 1

	Model 1 (degree)	Model 2 (degree)
Teeth 1	0	28
Teeth 2	0	119
Teeth 3	0	89
Teeth 4	0	59
Teeth 5	0	88
Teeth 6	0	58
Teeth 7	0	28
Teeth 8	0	118
Teeth 9	0	89
Teeth 10	0	120
Teeth 11	0	88
Teeth 12	0	118
Element number	34314	34314
Node number	17242	17242
Total iron loss [W/Kg]	0.43795	0.42659
The average of B_{max}	0.5800	0.5764

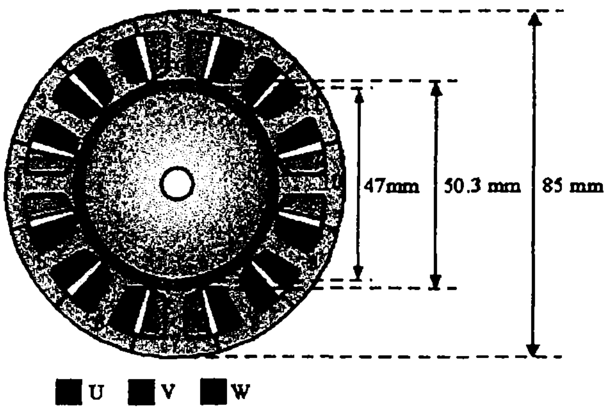
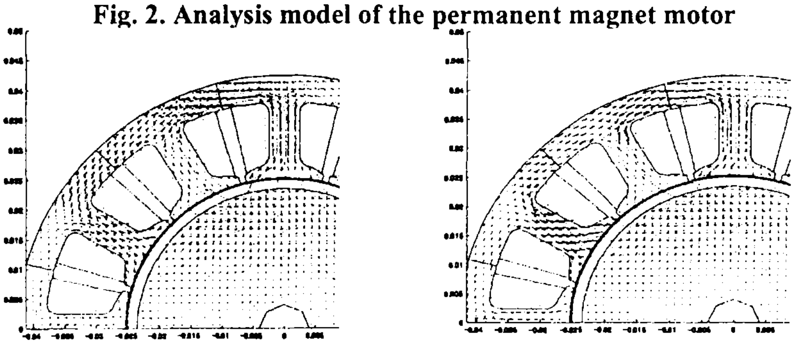
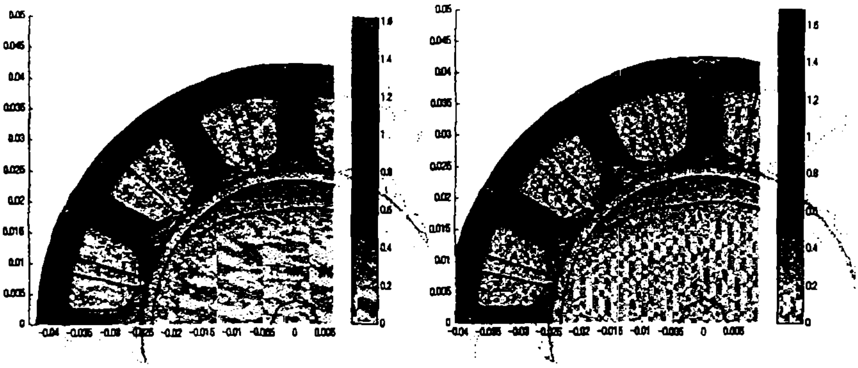


Fig. 2. Analysis model of the permanent magnet motor



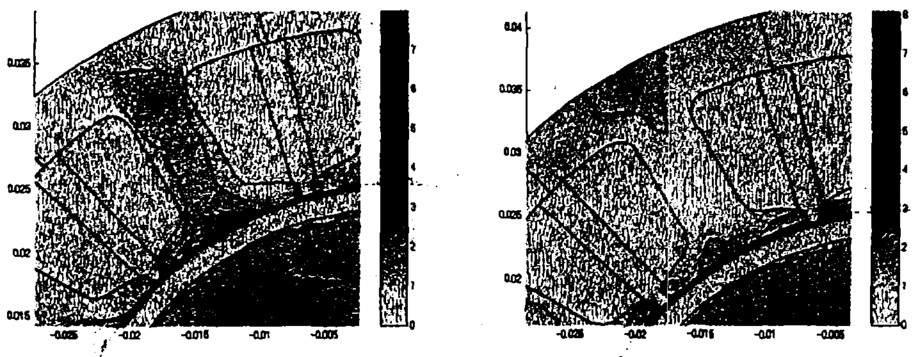
(Model 1) (Model 2)

Fig.3. Distribution of B and H vector.



(Model 1) (Model 2)

Fig.4. The core loss distribution. [W/Kg]



(Model 1) (Model 2)

Fig. 5. The distributions of the iron loss divide the square of magnetic flux density

6. CONCLUSION

(1) The non-linearity of the spatial angle of magnetic flux density and magnetic field can be considered.

(2) The direct analysis of the iron loss became possible if we handle as a vector magnetic flux density B and magnetic field H it as a vector.

(3) It was shown that the reduction of the iron loss was possible by the easy axis direction's optimization.

7. References

[1] M.Enokizono and N.Soda, " Iron loss Analysis of Three-Phase Transformer by using Finite Element Method" Proc. WEE '8, Vol. 1, 1998, pp. 852-855.

[2] M.Enokizono and N.Soda, " New modeling of Vector Magnetic properties for Magnetic Field Analysis" Studies in Applied Electromagnetics and Mechanics, Vol. 13, pp. 418-421.