Magnetization Simulation of Permanent Magnets by using Three-Dimensional VMSW Method Taking Demagnetization Process Into Account

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***Abstract*— This paper presents results obtained in numerical simulation in magnetizing process of permanent magnets by using the three-dimensional Variable Magnetization and Stoner-Wohlfarth method (VMSW method) taking into account the demagnetization process. The calculation results were compared with the measured results to verify the accuracy of numerical simulation.**

I. Introduction

This paper presents results obtained in numerical simulation of magnetization process of permanent magnets by using the three-dimensional Variable Magnetization and Stoner-Wohlfarth method (VMSW method) taking account of demagnetization process.

Nowadays, progress of numerical simulation technique and increase in performance of computers makes it possible to use the three-dimensional magnetic field analysis. And permanet magnet are very important engineering elements widely used today in many applications such as information equipment, communication equipment, acoustic equipment, medical equipment, and so on. However, to perform detailed design of electrical and electronics equipment using permanent magnets, precise simulation of the magnetization process is required. Important point of the magnetizing process simulation is magnetic characteristic modeling of the permanent magnet. On the other hand, evaluation of the permanent magnets is still difficult, because we can not measure the residual magnetization distribution directly.

We have developed a three-dimensional VMSW method[1] by expanding the conventional 2D-VMSW[2] method. The 3D-VMSW method enable us to estimate magnetization distribution in magnetized magnets in three-dimensions. The results demonstrate that evaluation of magnetizing state under various conditions is very important to prevent incomplete magnetization and to make clear various of the magnetization after equipped.

II. Three-dimensional VMSW method

A. Initial magnetization process

When an external magnetic field H_0 is applied to a magnetic substance, we assume that the magnetization M is induced in average. The energy equation in the magnetic substance can be expressed as follows,

$$\begin{aligned} U =& \frac{M^2}{2\mu_0}\big(N_{\mathrm{x}}\sin^2\phi_{\mathrm{M}}\cos^2\theta_{\mathrm{M}} + N_{\mathrm{y}}\sin^2\phi_{\mathrm{M}}\sin^2\theta_{\mathrm{M}} \\ &+ N_{\mathrm{z}}\cos^2\phi_{\mathrm{M}}\big) + \frac{M^2}{2}\bigg(\frac{1}{\chi_{\mathrm{e}}}\cos^2\phi_{\mathrm{M}} \\ &+ \frac{1}{\chi_{\mathrm{h1}}}\sin^2\phi_{\mathrm{M}}\cos^2\theta_{\mathrm{M}} + \frac{1}{\chi_{\mathrm{h2}}}\sin^2\phi_{\mathrm{M}}\sin^2\theta_{\mathrm{M}}\bigg) \\ &- MH_0\big(\sin\phi_{\mathrm{M}}\cos\theta_{\mathrm{M}}\sin\phi_{\mathrm{H}}\cos\theta_{\mathrm{H}} \\ &+ \sin\phi_{\mathrm{M}}\sin\theta_{\mathrm{M}}\sin\phi_{\mathrm{H}}\sin\theta_{\mathrm{H}} + \cos\phi_{\mathrm{M}}\cos\phi_{\mathrm{H}}\big) \end{aligned} \tag{1}$$

where N_a, N_b and N_c are the demagnetizing factors: N_a denotes the major axis and N_b and N_c denote the minor axes. χ_e, χ_{h_1} and χ_{h_2} are the magnetic susceptibility in the easy axis and the hard axis.

B. Demagnetization process

At the maximum magnetization point $(H_{\mathrm{m}}, M_{\mathrm{m}})$ in the initial magnetization process, magnetization vector slopes θ_{m} from the direction of the easy magnetization axis. During the external magnetic field strength decreases from H_{m} to 0, the magnetization vector rotates until its direction coincides with the easy magnetization axis. Then it becomes the residual magnetization vector M_{m}. When the external magnetic field H, which has the angle of θ_{h} from the easy axis, is applied to magnetic substance, the total energy can be written as follows,

$$U = U_{\mathrm{demag}} + U_{\mathrm{mag}} + U_{\mathrm{aniso}} - M \cdot H_0. \tag{2}$$

The shape anisotropic energy U_{demag} can be expressed as follows

$$U_{\mathrm{demag}} = \frac{1}{2\mu_0}N_{\mathrm{a}}\big(M_{\mathrm{a}}^2 - M_{\mathrm{ar}}^2\big) + \frac{1}{2\mu_0}N_{\mathrm{b}}\big(M_{\mathrm{b}}^2 - M_{\mathrm{br}}^2\big), \tag{3}$$

$$\begin{aligned} M_{\mathrm{a}} = M\cos\theta, M_{\mathrm{b}} = M\sin\theta, \\ M_{\mathrm{ar}} = M_{\mathrm{r}}\cos\theta, M_{\mathrm{br}} = M_{\mathrm{r}}\sin\theta \end{aligned} \tag{4}$$

where, N_{a} and N_{b} are the demagnetizing factor: N_{a} denotes the major axis and N_{b} denotes the minor axis. The magnetization energy U_{mag} can be expressed as follows

$$U_{\mathrm{mag}} = \int_{M_{\mathrm{r}}}^{M} H_{\mathrm{eff}}dM = \frac{1}{2\chi_{\mathrm{rec}}}\big(M - M_{\mathrm{r}}\big)^2, \tag{5}$$

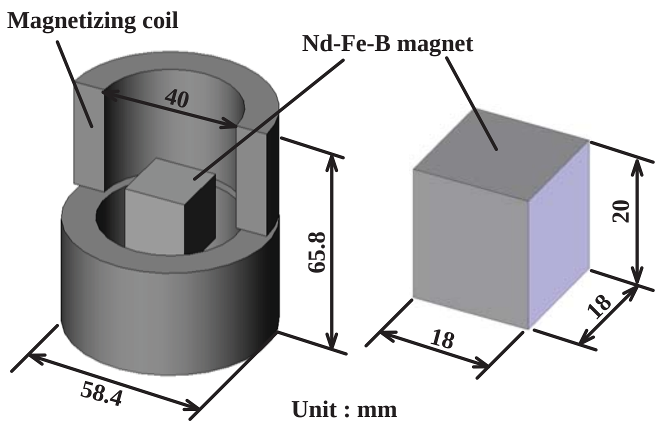


Fig. 1. Pulse magnetizer model.

where, χ_{rec} is gradient of demagnetization curve in easy magnetization axis. The anisotropy enegy U_{aniso} can be expressed as follows

$$U_{\text{aniso}} = \frac{1}{2} H_{\text{A}} M \sin^2\left(\theta - \theta_{\text{r}}\right), \tag{6}$$

where, H_{A} is anisotropy field. Therefore the energy equation in the magnetic material can be written by

$$\begin{aligned} U =& \frac{1}{2\mu_0} N_{\text{a}}\left(M^2 - M_{\text{r}}^2\right) \\ &+ \frac{1}{2\mu_0}\left(N_{\text{b}} - N_{\text{a}}\right) M^2 \sin^2\left(\theta - \phi\right) \\ &- \frac{1}{2\mu_0}\left(N_{\text{b}} - N_{\text{a}}\right) M_{\text{r}}^2 \sin^2\left(\theta_{\text{r}} - \phi\right) \\ &+ \frac{1}{2\chi_{\text{rec}}}\left(M - M_{\text{r}}\right)^2 + \frac{1}{2} H_{\text{A}} M \sin^2\left(\theta - \theta_{\text{r}}\right) \\ &- M H_0 \cos\left(\theta_{\text{h}} - \theta\right) \end{aligned} \tag{7}$$

Accordingly, the conditions of M, and θ can be calculated by the following simultaneous equation.

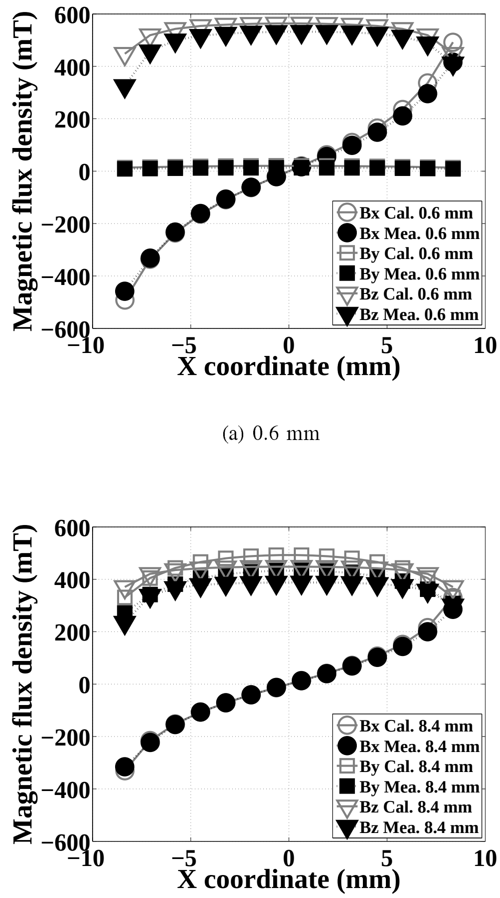
$$\begin{aligned} &\left[\frac{1}{\mu_0}\left(N_{\text{a}} + \left(N_{\text{b}} - N_{\text{a}}\right)\sin^2\left(\theta - \phi\right)\right)\chi_{\text{rec}} + 1\right] M \\ &= M_{\text{r}} + \chi_{\text{rec}} H_0 \cos\left(\theta_{\text{h}} - \theta\right) - \frac{1}{2}\chi_{\text{rec}} H_{\text{A}} \sin^2\left(\theta - \theta_{\text{r}}\right) \end{aligned} \tag{8}$$

$$\begin{aligned} &\frac{1}{2\mu_0}\left(N_{\text{b}} - N_{\text{a}}\right) M \sin 2\left(\theta - \phi\right) + \frac{1}{2} H_{\text{A}} \sin 2\left(\theta - \theta_{\text{r}}\right) \\ &- H_0 \sin\left(\theta_{\text{h}} - \theta\right) = 0 \end{aligned} \tag{9}$$

III. Results of Simulatons

Fig. 1 shows the pulse magnetizer coil and a rare-earth permanent magnet. In the finite element analysis, we assumed that the magnetization voltage was 1500V, the capacitance was 3000μF, and the conductivity of the permanent magnet was 0.694×10^6S/m, respectively. The easy axis of the permanent magnet was assumed to be parallel to the z-axis.

In verification of this method, we compared the calculated results and the measured one. We used a device (manufactured by IMS Co. Ltd.) to measure the 3-D magnetic-field distribution. The distance between the measured line and the magnet surface was 1mm. Fig. 2 shows the comparison between the measured amount of flux density and the calculated one. The calculated results agreed well with those measured near the center of the magnetic pole. However, the differences between the calculated and measured results increase near the edge parts. The effect of the demagnetizing field is larger at the edges of the magnet.



(a) 0.6 mm

(b) 8.4 mm

Fig. 2. Comparison between calculated and measured results. Magnet is 18×18×20 mm.

IV. Conclusion

This paper presented the formulation of a 3D-VMSW method taking into account the demagnetization process. The magnetization process was simulated to verify this method. The calculated results were compared with those measured near the magnetic pole in the verification. The results indicated good agreement near the center of the magnetic pole.

References

[1] Y. Nakahata, T. Todaka, and M. Enokizono, *Magnetization Process Simulation of Anisotropic Permanent Magnets by Using the Three-Dimensional VMSW Method*, IEEE Trans. on Magn., vol. 44, pp. 858-861, 2008.

[2] F.Mohri, *International Journal of Applied Electromagnetics in Materials* Vol.3, No.4 (1964), p. 241.