A Research on the Demagnetization and Demagnetizing Factors for Normal Shape of Magnetic Materials

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Many recent studies have made it possible to determine the demagnetizing factors of the magnetic materials of various Shape. However, in the case of the non-ellipsoid, the actual internal demagnetizing factors are distributed differently in the body, and the study is insufficient. There is also a lack of research on the demagnetizing factors of hollow cylinders. Therefore, in this study, the distribution of the internal demagnetizing factors of the magnetic body was analyzed and compared with the results of the previous research. Also, new calculation method was proposed to determine demagnetizing factors of hollow cylinder model.

***Index Terms*— Demagnetizing factor, ellipsoid, square, cylinder, hollow cylinder.**

I. Introduction

Demagnetizing factors for both ellipsoidal and non-ellipsoidal bodies have been studied for more than 100 years. In the ellipsoid, the magnetic field inside the model is constant, so that the demagnetizing factor can be represented by one value. However, in the case of non-ellipsoid, since the magnetic field inside the body is non-uniform, it is difficult to represent the demagnetizing factor as one value. [1]

Through the previous studies, the demagnetizing factor for square shape cans be represented by theoretical equations. However, the demagnetizing factor inside the object are distributed differently depending on the position. Since the demagnetizing factor depending on equations are determined by certain assumptions, they have errors with the actual results. Therefore, it is needed to analyze the demagnetizing factor considered distribution inside body and compare with the values according to previous studies.

In addition, there is lack of study on the demagnetizing factor for cylinder and hollow cylinder shape. Especially, it is needed to calculate the demagnetizing factor for hollow cylinder shape since it is often used in research for demagnetization of submarine. The demagnetization requires very precise application and control of the magnetic field. If the demagnetizing factor of the submarine is not correct, a magnetic field of unexpected magnitude was applied to the submarine. Then, it will be not fully demagnetized and it can be easily exposed to fatal damage by magnetic mines. Therefore it is necessary to represent the demagnetizing factor as one value in consideration of the internal distribution for hollow cylinder. In this paper, the distribution of the demagnetizing factor inside the non-ellipsoid shape is analyzed by FEM simulation, and compared with results of other studies. Also, the method of determining the demagnetizing factor for the hollow cylinder model is proposed and verified according to the simulation results.

II. Demagnetizing Factor in Ellipsoid and Square

If external magnetic field was applied, the total magnetic field that is really applied to the object is reduced by demagnetizing fields. In addition, it is represented by (1).

$$\overrightarrow{H_d} = -N_d \overrightarrow{M} \tag{1}$$

where N_d is the demagnetizng factor.
Factors influencing the demagnetizing factor are shape and permeability, but mainly determineed byt the shape of the object. Fig. 1 shows the relation between demagnetizing field and magnetization in ellipsoid and square shape.

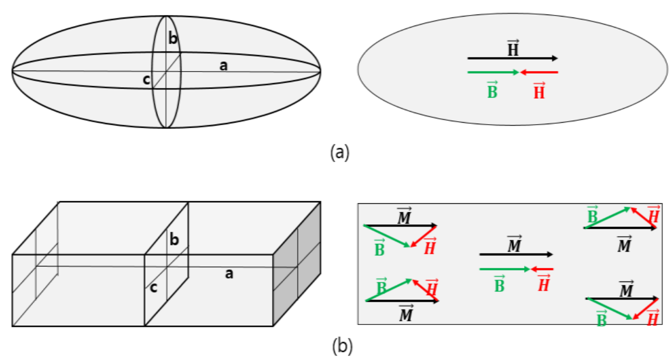

Fig. 1. Effect of a demagnetization field of Ellipsoid and square shape.
(a) Ellipsoid shape. (b) Square shape.

For ellipsoid, if a uniform magnetic field was applied from the outside, the magnetic field inside is uniformly distributed, and the demagnetizing factor has a constant value irrespective of the position. Therefore, the demagnetizing factor of ellipsoid is calculated by (2) when b is infinitely long and m is a/c [1].

$$N_d = \frac{1}{m+1} \tag{2}$$

For square model, since the magnetic field inside is non-uniformly, it is difficult to determine the demagnetizing factor. It is expressed as one value by Amikam and when b is infinitely long, demagnetizing factor is calculated by (3) [2].

$$N_d = \left[\frac{1-m^2}{2m} \ln(1+m^2) + m\ln(m) + 2ac\tan(\frac{1}{m}) \right] / \pi \tag{3}$$

Although the demagnetizing factor of a square model is represented as one representative value, it can’t confirm the demagnetizing factor distribution in the model. Fig.2 shows the demagnetizing factor distribution in the ellipsoid and square shape by FEM simulation when m is 2. For the ellipsoid, the demagnetizing factor is constant. However, in the case of the square model, it is largest at both corner positions and becomes smaller as it is located at the center. Table I shows the maximum, minimum, and average values of the demagnetizing factor in the square according to the aspect ratio. The average value and calculated value are similar, but the demagnetizing factor inside it is largely different by about 3times

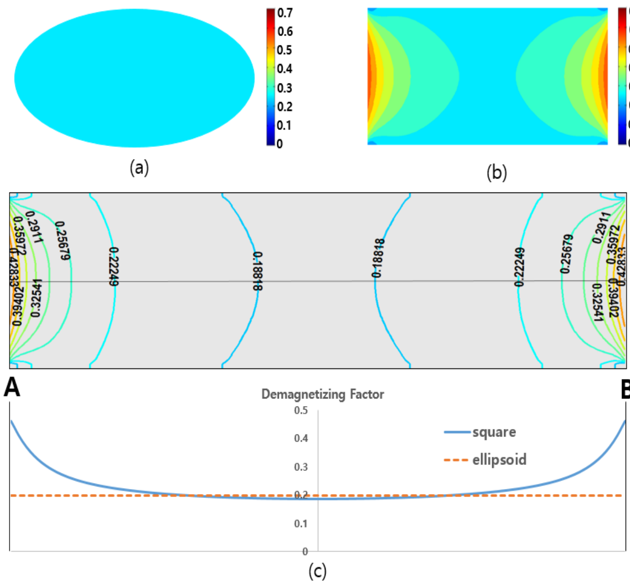

Fig 2. Demagnetizing factor distribution. (a) Ellipsoid (m=2). (b) Square (m=2). (c) Square (m=4) and middle line distribution

Table I
Simulation Result and Amikam's constant

m(a/c)	Simulation result Min	Max	Average	Amikam's constant	Error ratio
0.5	0.315602	0.806872	0.627969	0.647787	3.1%
1	0.247971	0.704669	0.473198	0.5	5.4%
2	0.189287	0.586717	0.330072	0.352213	6.3%
3	0.158709	0.514268	0.258252	0.276683	6.7%
4	0.153873	0.462636	0.221144	0.230093	3.9%

III. Demagnetizing Factor in Cylinder and Hollow Cylinder

In case of cylinder shape, as shown in Fig. 3(a), the demagnetizing factor was expressed by the ratio of the length to the diameter of the cylinder. Previously, it was represented by Brown and experimented by Graham and Lorenz [3]-[4]. In addition, research has been carried out to show the demagnetizing factors by various methods [5]-[7]. In order to validate Brown's values, the demagnetizing factor distribution of the cylinder was analyzed by FEM simulation. Demagnetizing factors of cylinder shape were analyzed by length ratio. There are some differences between the analysis results and the Brown's values. There are largely 23% errors between the results by two methods. The detailed results are shown in the full paper.

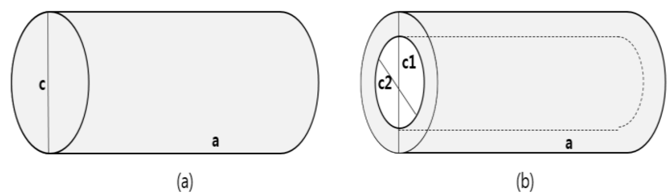

Fig. 3 Cylinder and hollow cylinder shape

For ellipse, square, cylinder, the demagnetizing factor is represented by one value according to many studies although it has some errors. But, it is difficult to determine the value for the hollow cylinder as shown in Fig. 3(b). Previously, timothy Malcolm baynes proposed a method of calculating the demagnetizing factor of a hollow cylinder by subtracting the values of two ellipses from each other. However, there was a lack of verification of the results.

It is very important to define a demagnetizing factor of hollow cylinder shape. Because it was usually used for demagnetization of submarine. Since demagnetization requires very precise control, it is necessary to know the exact demagnetizing factor of the object. Therefore, in this study, a method for calculating the values of this shape was proposed.

In the full paper, the results obtained from the previous research and the results from the newly proposed method were compared. The results of the two methods showed errors due to the length radio. Also, it was verified through the simulated results by FEM analysis.

IV. Conclusion

In this paper, demagnetizing factor and distribution for various shape was analyzed by FEM simulation. The simulated demagnetizing factors have errors with the results of the theoretical and numerical calculations. Moreover, the results of hollow cylinder are significantly different from the value of previous research. Therefore, in this paper, precise demagnetizing factors are analyzed and this result will be useful in fields that it is important such as demagnetization.

References

[1] B. D. Cullity and C. D. Graham, Introduction to Magnetic Materials, 2nd ed. New York : Wiley, 2009, ISBN 978-0-471-47741-9.
[2] B. K. Pugh, D. P. Kramer, and C. H. Chen, "Demagnetizing Factors for Various Geometries Precisely Determined Using 3-D Electromagnetic Field Simulation," *IEEE Trans. Magn.* Vol. 47, no. 10, October 2011
[3] Amikam Aharoni, "Demagnetizing factors for rectangular ferromagnetic prisms", *journal of Applied Physics* 53, 3432(1998)
[4] W. F. Brown, "Magnetostatic Principles in Ferromagnetism (North Holland, Amsterdam, 1962), Appendix.
[5] C.D. Graham and B. E. Lorenz, "Experimental demagnetizing factors for disk samples magnetizing along a diameter," *IEEE Trans. Magn.*, vol. 43, no. 6, pp. 2743-2745, Jun. 2007.
[6] M. Sato and Y. Ishii, "Simple and approximate expressions of demagnetizing factors of uniformly magnetized rectangular rod and cylinder," Journal of applied physics, Vol. 66, No. 2, 15 July 1989.
[7] R. I. Joseph, "Demagnetizing Factor in Uniformly Magnetized Cylinders," Journal of applied physics, Vol. 37, No. 13, December 1966.