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An experimental study of the compensation coil method for thin magnetic films

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ABSTRACT: In order to measure the exact magnetization characteristics of thin magnetic films, we have systematically carried out an experimental study of the compensation coil method. The magnetization characteristics of thin magnetic films have been measured by the compensation coil as well as conventional toroidal core methods. Comparison of the B-H loops measured by these methods shows that there is an suitable length ratio between the excitation and pickup coils. The ratio between excitation coil length l and pickup coil length m should take a value smaller than $m / l = 0.033$ in order to reproduce the B-H loops obtained by means of toroidal core.

1 INTRODUCTION

Higher frequency operation of modern magnetic devices enables them to be lightweight as well as compact in shape as a part of the electric/electronic devices. This spurs on developments and investigations of thin magnetic films for high frequency use [1]. For example, small size power supplier is necessary for the modern electric/electronic devices such as a cellular phone and a notebook personal computer. In order to design them it is of paramount importance to measure the magnetization characteristics of thin magnetic films for higher frequency operation exactly. Because of the demagnetization factor, the measurement of magnetization characteristics of the thin magnetic films confronts with a serious difficulty. By means of deposition, major of the thin magnetic films are worked out. It is difficult to work out a toroidal ring-shaped specimen, which leads to the measurement of exact magnetization characteristics. The method with compensation coil along with the eight-figure coils has been proposed as one of the ways to measure the magnetization characteristics of thin magnetic films [2].

In this paper, we have experimentally examined an approach with compensation coil. Namely, we have examined the geometrical parameters of the compensation coil method in order to reproduce the B-H loops similar to that measured using toroidal core. As a result, it is revealed that a ratio between the excitation coil length l and pickup coil length m should take a value smaller than $m / l = 0.033$ in order to obtain the B-H loops similar to these by means of toroidal core.

2 MEASUREMENT BY COMPENSATION COIL METHOD

Magnetization characteristics measurement device by the compensation coil method is composed of excitation, compensation and pickup coils as shown in Fig.1. The measurement target, thin magnetic film, is located in the middle of pickup coil. The operation of compensation coil method is the same as the eight-figure coil one. Namely, the flux density in the sample is calculated from the differential voltage caused by the compensation and the pickup coils. The magnetic field is calculated from the output voltage of compensation coil. Thereby, it is possible to obtain the B-H loops of the target sample.

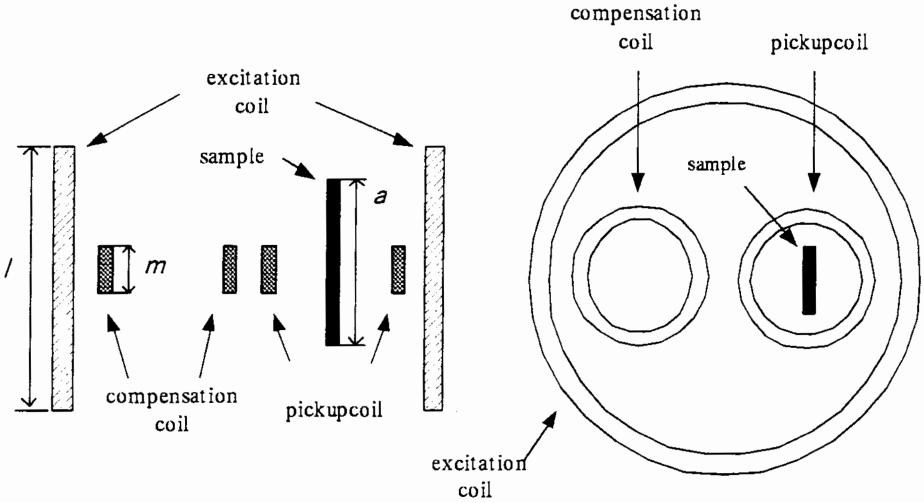


Fig.1 Magnetization characteristic measurement device by compensation coil method

Compensation and pickup coils have the differential connection. When a magnetic material sample exists in the pickup coil, the differential voltage v is given by

$$v = \{\mu_0 \mu_s N_s A_e \frac{dH}{dt} + \mu_0 N_s A_a \frac{dH}{dt}\} - \mu_0 N_c A_c \frac{dH}{dt} \qquad (1)$$

μ_0 : permeability in a vacuum,
μ_s : relative permeability,
A_e : cross-sectional area of the magnetic material,
N_s : number of turns of the pickup coil,
A_a : cross-sectional area of the pickup coil,
N_c : number of turns of the compensation coil,
A_c : cross-sectional area of the compensation coil,

If a condition $N_s A_a = N_c A_c$ is realized, then the differential voltage v of (1) reduces into

$$v = \mu_0 \mu_s N_s A_e \frac{dH}{dt} = N_s \frac{d\phi}{dt} \qquad (2)$$

Where ϕ in (2) is the magnetic flux in the magnetic material.

After time integrating the voltage v in (2), dividing the magnetic flux ϕ by the cross-sectional area of magnetic material sample gives the flux density B. The magnetic field H is obtained by the third term on the right in (1) [3].

3 EXPERIMENT

3.1 Experimental method

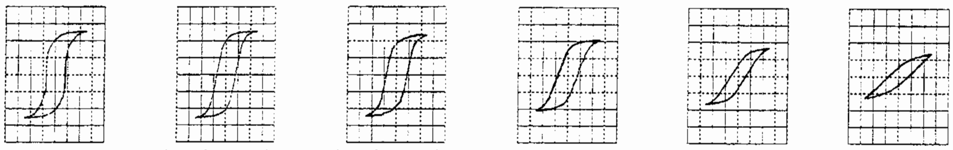
Comparison of the B-H loops measured by the conventional toroidal and by the compensation coil methods leads to the evaluation of the compensation coil method. The sample used for the measurement is a silicon steel sheet, and its width and thickness are 15mm and 0.3mm, respectively. Lamination of the thin ring-shaped ones constitutes a toroidal core, whose various constants are listed in Table.1.

Table.1 Various constants of the tested toroidal core

Thickness [mm]	Number of laminations	Outer diameter [mm]	Inner diameter [mm]	Cross-sectional area [mm^2]	Length of average magnetic flux path [mm]	Number of turns of excitation coil	Number of turns of pickup coil
0.35	29	100	80	100	282.7	1200	400

3.2 Length of the excitation and pickup coils

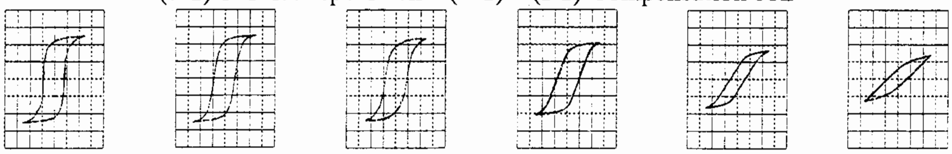
Because of the demagnetization factor, the measured B-H loop depends on the geometrical shapes of excitation as well as pickup coils. In order to determine these geometrical parameters, at first, we have examined on the relationship between excitation coil and pickup coil lengths. Let the lengths of excitation and pickup coils be l and m, respectively. Fig.2 shows the B-H loops when the coil length ratio m / l is changed. Fig.3(a) shows the correlation coefficients between the B-H loop of the compensation coil and that of the toroidal core methods. Fig.3(b) shows the relationship between the area of B-H loop and the coil length ratio. Observing the results in Fig.3 reveals that the B-H loops measured by the compensation coil method having m / l = 0.033 are well corresponding to that of toroidal core one.



(a-1) (b-1) m / l = 0.033 (c-1) m / l = 0.18 (d-1) m / l = 0.28 (e-1) m / l = 0.55 (f-1) m / l = 1

x : 286.6[A/m/div], y : 0.46[T/div], frequency = 50[Hz]

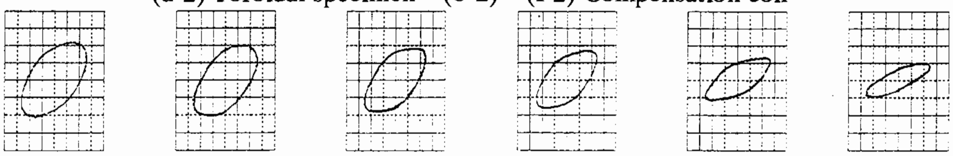
(a-1) Toroidal specimen (b-1) − (f-1) Compensation coil



(a-2) (b-2) m / l = 0.033 (c-2) m / l = 0.18 (d-2) m / l = 0.28 (e-2) m / l = 0.55 (f-2) m / l = 1

x : 286.6[A/m/div], y : 0.46[T/div], frequency = 100[Hz]

(a-2) Toroidal specimen (b-2) − (f-2) Compensation coil

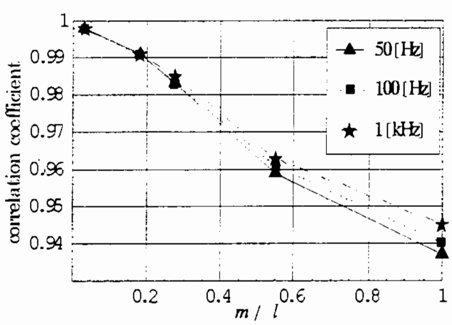


(a-3) (b-3) m / l = 0.033 (c-3) m / l = 0.18 (d-3) m / l = 0.28 (e-3) m / l = 0.55 (f-3) m / l = 1

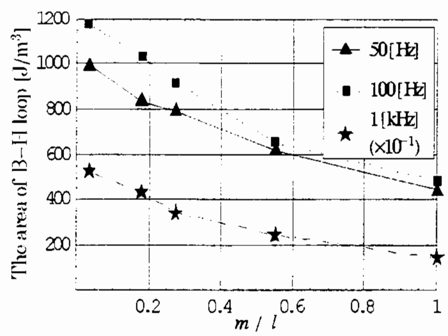
x : 38.9[A/m/div], y : 0.096[T/div], frequency = 1[kHz]

(a-3) Toroidal specimen (b-3) − (f-3) Compensation coil

Fig.2 B-H loop changing by coil length ratio *m / l*



(a) Correlation coefficient between the B-H loops by the compensation coil method and toroidal core method

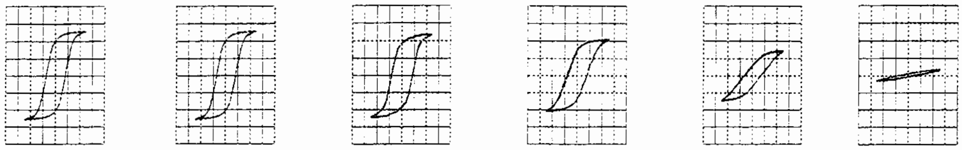


(b) Relationship between the area of B-H loops and coil length ratio m / l

Fig.3 Correlation coefficient and the area of B-H loops

3.3 Influence of the length of target sample

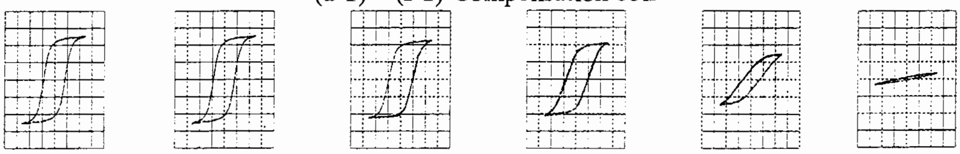
Next, we consider the influence of the target sample length. The length of the sample is a, The effect of length difference has been investigated by changing the ratio a / l at each case of m / l = 0.033 and 0.18. Figs.4 and 5 show The B-H loops when changing the ratio a / l are shown in Figs.4 and 5. Fig.6 shows the correlation coefficient between the B-H loops measured by the compensation coil and by toroidal core methods. Fig.7 shows the relationship between the area of B-H loop and ratio a / l. Figs. 6 and 7 suggests that the smaller value than the ratio a / l = 0.6 are not well corresponding to the B-H loops obtained by means of toroidal core. Moreover it is found that the B-H loops are not related with the length of pickup coil, but also the B-H loops depend only the ratio a / l.



(a-1) a / l = 1 (b-1) a / l = 0.6 (c-1) a / l = 0.41 (d-1) a / l = 0.32 (e-1) a / l = 0.25 (f-1) a / l = 0.18

x : 286.6[A/m/div], y : 0.46[T/div], frequency = 50[Hz]

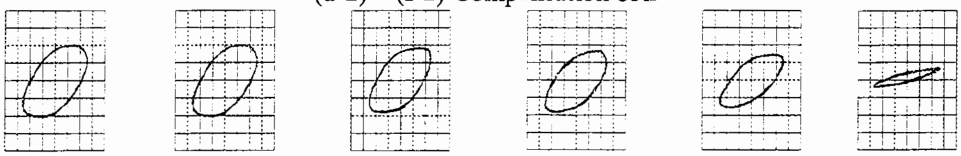
(a-1) − (f-1) Compensation coil



(a-2) a / l = 1 (b-2) a / l = 0.6 (c-2) a / l = 0.41 (d-2) a / l = 0.32 (e-2) a / l = 0.25 (f-2) a / l = 0.18

x : 286.6[A/m/div], y : 0.46[T/div], frequency = 100[Hz]

(a-2) − (f-2) Compensation coil

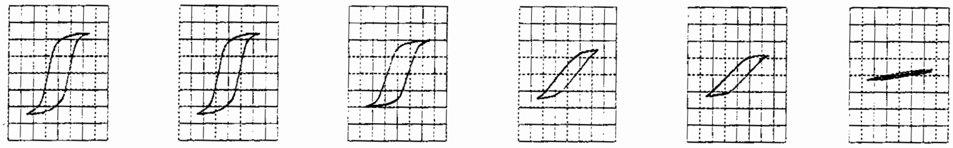


(a-3) a / l = 1 (b-3) a / l = 0.6 (c-3) a / l = 0.41 (d-3) a / l = 0.32 (e-3) a / l = 0.25 (f-3) a / l = 0.18

x : 38.9[A/m/div], y : 0.096[T/div], frequency = 1[kHz]

(a-3) − (f-3) Compensation coil

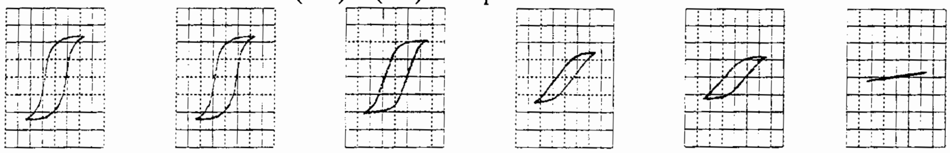
Fig.4 A change in the B-H loop by the ratio a l (m / l = 0.033)



(a-1) $a\,/\,l$ = 1 (b-1) $a\,/\,l$ = 0.6 (c-1) $a\,/\,l$ = 0.41 (d-1) $a\,/\,l$ = 0.32 (e-1) $a\,/\,l$ = 0.25 (f-1) $a\,/\,l$ = 0.18

x : 286.6[A/m/div], y : 0.46[T/div], frequency = 50[Hz]

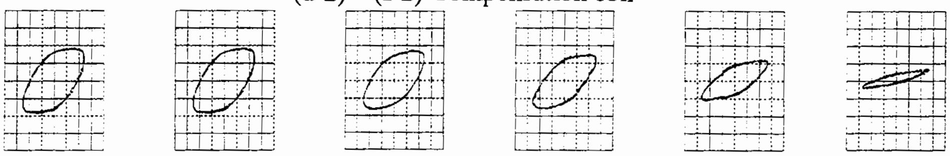
(a-1)－(f-1) Compensation coil



(a-2) a / l = 1 (b-2) a / l = 0.6 (c-2) a / l = 0.41 (d-2) a / l = 0.32 (e-2) a / l = 0.25 (f-2) a / l = 0.18

x : 286.6[A/m/div], y : 0.46[T/div], frequency = 100[Hz]

(a-2)－(f-2) Compensation coil

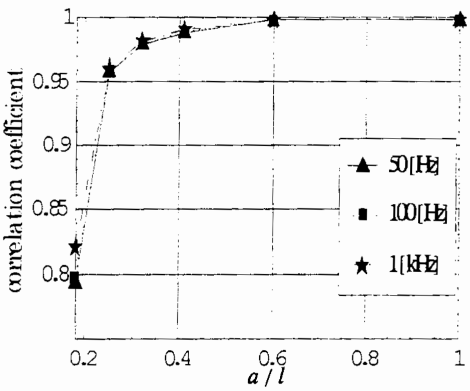


(a-3) a / l = 1 (b-3) a / l = 0.6 (c-3) a / l = 0.41 (d-3) a / l = 0.32 (e-3) a / l = 0.25 (f-3) a / l = 0.18

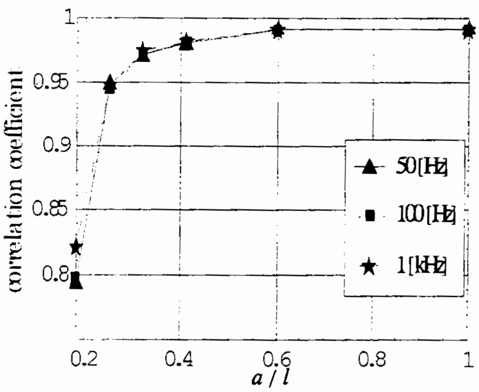
x : 38.9[A/m/div], y : 0.096[T/div], frequency = 1[kHz]

(a-3)－(f-3) Compensation coil

Fig.5 A change in the B-H loop by the ratio $a\,/\,l$ ($m\,/\,l$ = 0.18)



(a) $m\,/\,l$ = 0.033



(b) $m\,/\,l$ = 0.18

Fig.6 Correlation coefficient between the B-H loops by the compensation coil method and toroidal core method

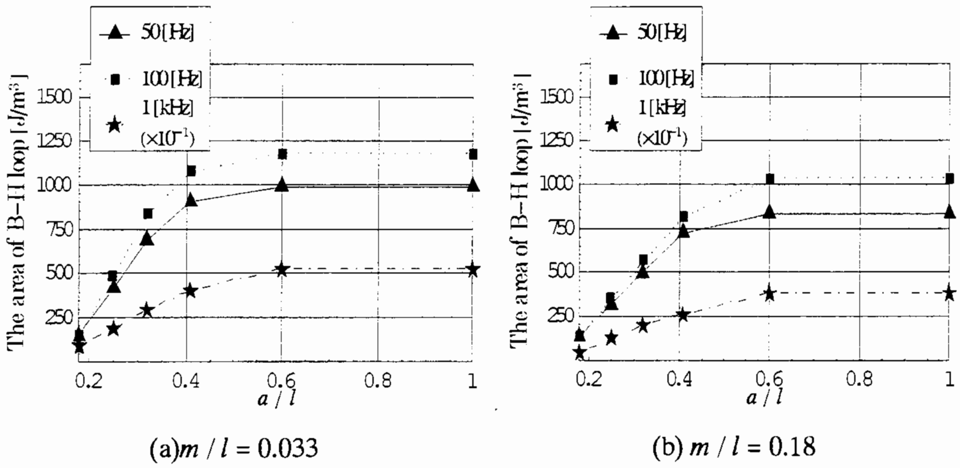


Fig.7 Relationship between the area of B-H loops and the ratio a / l

4 CONCLUSIONS

In this paper, we have examined the validity of the magnetization characteristics of thin magnetic films by means of the compensation coil. Though we have employed the iron sheets instead of magnetic films, it has been clarified. We have clarified the influence of the coil length ratio between excitation and the pickup coils. Furthermore, we have revealed that the relationship between the length of excitation coil length and those of pickup coil should take smaller than m / l = 0.033 in order to measure the B-H loops with high accuracy. Also, we have shown that the relationship between excitation coil length l and target sample length a should be larger than a / l = 0.6 to reproduce the exact B-H loops.

5 REFERENCES

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[2] S.Hayano, A.Miyazaki and Y.Saito, "Nonlinear phenomena in electromagnetic fields", Elsevier Studies in Applied Electromagnetics in Materials, vol3, pp.457-460, January 1992.

[3] A.Miyazaki, S.Hayano and Y.Saito, "A new magnetization characteristic measurement device for thin magnetic films", IEEE Trans.Magn., MAG-91-183, pp75-84, October 1991 (in Japanese).