Magnetic Field Analysis of Window-shaped Core for Verifying Accuracy of Isotropic Vector Hysteresis Model

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This paper proposes a verification model for examining the accuracy of modelling methods of isotropic vector hysteresis. The model has a window-shaped structure made of cold-rolled steel sheets, which can easily generate rotational magnetic field. First, alternating and rotational magnetic properties of the cold-rolled steel sheets are measured and their anisotropy is assessed. Then, the magnetic measurement of the verification model is carried out. The accuracy of isotropic vector play model is examined by comparing the analysis and measurement results of the proposed model.

***Index Terms*—Isotropic vector play model, magnetic hysteresis, verification model**

I. INTRODUCTION

IN ORDER to design the high-efficiency electrical machinery and apparatus, a more detailed magnetic field analysis considering hysteretic properties of magnetic material is requested. Many isotropic vector hysteresis models have been proposed and investigated. However, there is no standard model for verifying the accuracy of isotropic vector hysteresis models.

In this paper, we propose a verification model for examining the accuracy of modelling methods of isotropic vector hysteresis. The model is named “Window-shaped Core model” (WSC model). The WSC model has a simple structure with closed magnetic paths and can easily generate rotational magnetic field. The accuracy of the isotropic vector play model [1] is verified by comparing the analysis and measurement results of the WSC model.

II. WINDOW-SHAPED CORE MODEL

A. *Structure of the Model*

Fig. 1 shows the structure of WSC model. There are two pairs of coils and each pair is composed of two coils. Coil A1 and A2 (coil A), coil B1 and B2 (coil B) are connected in series, respectively. The number of turns of each coil is 43. The diameter of coil wire is ϕ 1.0 mm. A rotational magnetic field can be easily generated at the center of the core by setting the phase difference of 90 degrees between the excitation voltage of coil A and that of coil B. A cold-rolled steel sheet called SPCC is adopted as a magnetic material of the window-shaped core. Magnetic properties of the cold-rolled steel sheet seem to be nearly isotropic by annealing.

The thickness of the cold-rolled steel sheet is 0.5 mm. The cores are stacked in three layers at the interval of 3.25 mm. The top and bottom cores have a role as magnetic shield. This structure improves the uniformity of the magnetic field in the thickness direction between the layers.

The window-shaped core has four slits as shown in Fig. 1. The length and width of each slit are 7.1 mm and 0.2 mm, respectively. The slits can make magnetic fields concentrate at the center of the core. The absolute value of magnetic flux density over 1.4 T is realized as shown later.

The area for detecting magnetic flux density and magnetic field strength is 20 mm × 20 mm at the center of the core. The magnetic flux density at the center of the core of the middle layer is measured by using a single-turn search coil set in the *x*- and *y*-directions. The magnetic field strength is measured by means of the H coil method. The thickness of base plate for H coil is 2.0 mm and the diameter of coil wire is ϕ 0.05 mm. The distance between the center of the H coil and the surface of the core of the middle layer is 1.5 mm.

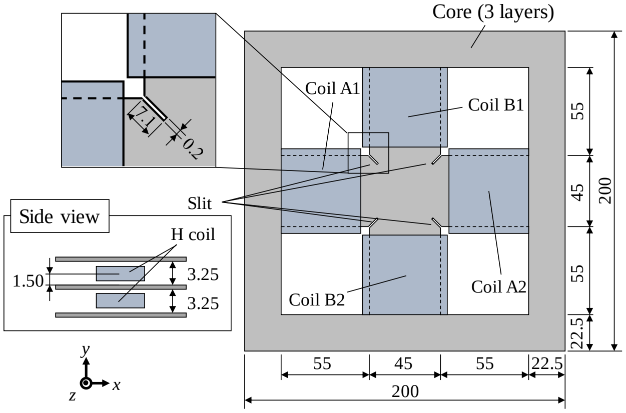


Fig. 1. Structure of the window-shaped core model.

B. *Magnetic Properties of Cold-rolled Steel Sheet*

We prepared three kinds of specimens to get magnetic properties used in the magnetic field analysis. They are cut out from the same lot of the core material: rectangular specimens (360 mm × 60 mm) of which the longitudinal direction is the rolling direction (RD) and transverse direction (TD), and round specimens (ϕ 99 mm). The round specimens are used for measuring rotational hysteresis loss [2], which is required for identification of parameters in the vector play model.

The results of measurements revealed that there are some differences in the magnetic properties among measured specimens. Hence, we carried out measurement of magnetic properties by using the WSC model. Fig. 2 shows the schematic diagram of the measurement. For the hysteretic magnetic field analysis, the measurement results of the specimen showing the closest properties to the WSC model are selected. Figs. 3 and 4 show the measurement results of the WSC model and the specimens. The magnetic properties in

RD and TD were measured at 50 Hz. B_m and H_b denote the maximum magnetic flux density of each symmetric loop and the magnetic field strength at the instance of B_m, respectively. The magnetic properties in RD and TD of the WSC model are similar to each other. The specimen showing the closest properties to the WSC model is the rectangular specimen cut out in TD (yellow lines in Figs. 3 and 4). Fig. 3 (b) also shows the measurement results of the round specimen showing the closest alternating hysteresis loss to the WSC model (an orange line (RD) and a purple line (TD)). Fig. 5 shows the rotational hysteresis loss measured by using the round specimen. The average property is used for identification.

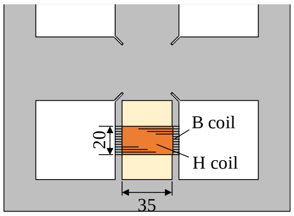
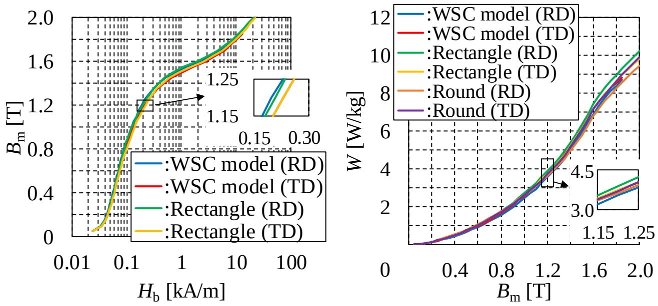


Fig. 2. Magnetic measurement of the window-shaped core model.



(a)

(b)

Fig. 3. Magnetic properties of cold-rolled steel sheet. (a) B_m-H_b curve. (b) Iron loss property.

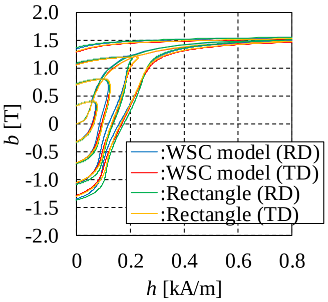


Fig. 4. Symmetric loops and B_m-H_b curve.

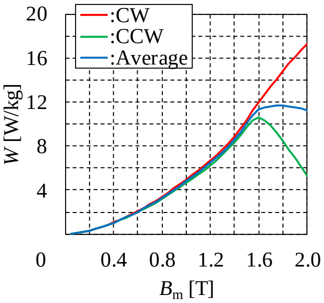


Fig. 5. Rotational hysteresis loss.

III. COMPARISON OF ANALYSIS AND MEASUREMENT RESULTS

A. Analysis Condition

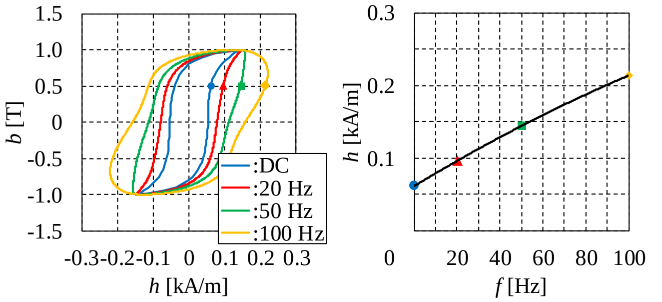
The hysteretic magnetic field analysis applying an isotropic vector play model was carried out on the WSC model. Table I shows the analysis condition. The number of time steps per period in the transient analysis is 160 and three periods are calculated. The TP-EEC method is applied to obtain a steady-state solution rapidly [3].

The magnetic field analysis applying the play model needs dc hysteretic properties. We approximated dc hysteretic properties from symmetric loops measured at 20, 50, 100 Hz by assuming that magnetic field strength has quadratic change with frequency. Fig. 6 shows the estimated dc symmetric loop at B_m = 1.0 T.

TABLE I

ANALYSIS CONDITION

Core material	Cold-rolled steel sheet (TD)
Conductivity [S/m]	9.28×10^6
Excitation frequency [Hz]	50
Voltage of coil A1, A2 [V]	$2.75\cos\omega t$
Voltage of coil B1, B2 [V]	$2.75\sin\omega t$
Number of turns of each coil	43



(a)

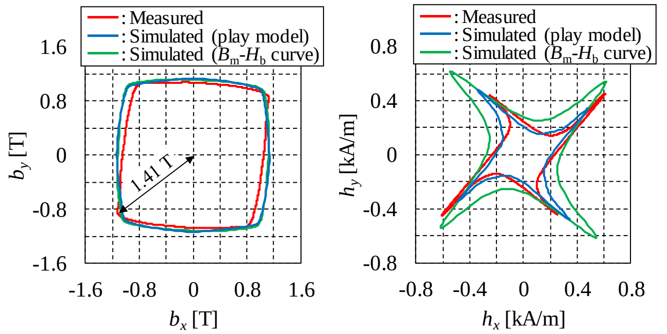
(b)

Fig. 6. Estimation of dc symmetric loop. (a) Symmetric loop at B_m = 1.0 T. (b) h-f characteristic at b = 0.5 T.

B. Numerical Results

Fig. 7 shows the comparison of the analysis and measurement results of the WSC model. There are differences between the analysis and measurement results. Under the rotational magnetic field, the effect of anisotropy is much larger than that under the alternating magnetic field.

Details of the measurement results and further investigation on the differences between the analysis and measurement results will be reported in full paper.



(a)

(b)

Fig. 7. Comparison of the analysis and measurement results. (a) Magnetic flux density. (b) Magnetic field strength.

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