Improvement of Identification Method for Isotropic Vector Play Model

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In order to accurately estimate the iron loss for rotating machinery, this paper proposes the novel identification method for the hysteresis model by using the isotropic vector play model so as to accurately represent the rotational hysteresis loss of magnetic materials. The numerical results are compared with the conventional identification method to demonstrate the effectiveness of the proposed identification method.

***Index Terms*—Electromagnetic fields, finite element methods, magnetic hysteresis.**

I. Introduction

In order to accurately estimate the iron loss of rotating machinery, it is necessary to consider not only the alternating hysteresis loss but also the rotational hysteresis loss of magnetic materials in the magnetic field analyses. For example, the Preisach model [1], [2] and its extended versions have been widely used to represent the various hysteretic characteristics such as magnetic hysteresis and vector properties.

In this paper, we adopt the isotropic vector play model [3], which is mathematically equivalent to the Preisach model, to represent the vector hysteretic properties of electrical steel sheets. Although the play model needs to be identified from dc symmetric loops [4] due to its rate-independent properties, it is difficult to accurately measure and estimate the dc hysteretic properties. A measurement error can result in inadequate representation accuracy of hysteresis models such as the rotational hysteresis loss. In order to improve the representation accuracy of the rotational hysteresis loss, this paper proposes the novel identification method for the isotropic vector play model. We demonstrate the effectiveness of the novel identification method compared with the conventional identification method under alternating and rotational flux density conditions.

II. Play Model

A. Property of Play Model

A discretized form of the isotropic vector play model [3] can represents the hysteretic properties with an output of magnetic field $\boldsymbol{H}$ from an input of magnetic flux density $\boldsymbol{B}$ because finite element analysis using magnetic vector potential as an unknown variables requires the calculation of $\boldsymbol{H}$ from $\boldsymbol{B}$.

$$\boldsymbol{p}_{\zeta n}(\boldsymbol{B}) = \boldsymbol{B} - \frac{\zeta_n(\boldsymbol{B} - \boldsymbol{p}^*_{\zeta n})}{\max\left(\left|\boldsymbol{B} - \boldsymbol{p}^*_{\zeta n}\right|, \zeta_n\right)}, \tag{1}$$

$$\boldsymbol{H} = \sum_{n=0}^{M-1} f_{\zeta_n}\left(\left|\boldsymbol{p}_{\zeta_n}(\boldsymbol{B})\right|\right)\frac{\boldsymbol{p}_{\zeta_n}(\boldsymbol{B})}{\left|\boldsymbol{p}_{\zeta_n}(\boldsymbol{B})\right|}, \tag{2}$$

where $\boldsymbol{p}_{\zeta n}$ is the play hysteron operator with a width of ζ_n, $\zeta_n = nB_{\max}/M$, $B_{\max}$ is the maximum measurable magnetic flux density, $\boldsymbol{p}_{\zeta n}^*$ is the play hysteron operator at previous time step, M is the number of hysterons, and $f_{\zeta n}$ is the shape function for the play hysteron operator $|\boldsymbol{p}_{\zeta n}|$. The identification method for the Preisach model can be applied to the play model [5] because the play model is mathematically equivalent to the Preisach model [1], [2].

The shape function $f_{\zeta n}$ is assumed to be piecewise linear as follows:

$$f_{\zeta n}\left(\left|\boldsymbol{p}_{\zeta n}(\boldsymbol{B})\right|\right) = f_{\zeta n}\left(p_{\zeta n,m}\right) + \mu\left(\left|\boldsymbol{p}_{\zeta n}(\boldsymbol{B})\right|, \zeta_n\right)\left(\left|\boldsymbol{p}_{\zeta n}(\boldsymbol{B})\right| - p_{\zeta n,m}\right), \tag{3}$$

$$p_{\zeta n,m} \le \left|\boldsymbol{p}_{\zeta n}(\boldsymbol{B})\right| \le p_{\zeta n,m+1}, \tag{4}$$

$$p_{\zeta n,m} = \frac{B_{\max}}{M}2m - B_{\max} + \zeta_n \quad (m = 0, \ldots, M-n), \tag{5}$$

where μ is the slope of the shape function $f_{\zeta n}$.

B. Hysteresis Losses

For alternating and rotational flux density input with amplitude B_{m}, the play model provides the alternating hysteresis losses W_{alt} and the rotational hysteresis loss W_{rot} by shape function $f_{\zeta n}$ as follows:

$$W_{\mathrm{alt}}(B_{\mathrm{m}}) = -4\sum_{n=1}^{N} f_{\zeta_n}(B_{\mathrm{m}} - \zeta_n)\zeta_n, \tag{6}$$

$$W_{\mathrm{rot}}(B_{\mathrm{m}}) = -2\pi\sum_{n=1}^{N} f_{\zeta_n}\left(\sqrt{B_{\mathrm{m}}^{\,2} - \zeta_n^{\,2}}\right)\zeta_n, \tag{7}$$

where $\zeta_N \le B_{\mathrm{m}} < \zeta_{N+1}$.

Fig. 1 shows the alternating and rotational hysteresis losses obtained from the play model, which is identified from the dc symmetric loops of an electrical steel sheet JIS: 50A470. The intervals ΔB_{m} (= $B_{\mathrm{m}}^{i} - B_{\mathrm{m}}^{i-1}$) of hysteresis loops is 0.01 T. The rotational hysteresis loss fluctuates remarkably at more than 1.5 T because some of μ in (3) in $n > 0$ is positive. Therefore, it is necessary to develop the identification method for the isotropic play model which satisfy the condition that all of μ in $n > 0$ are negative.

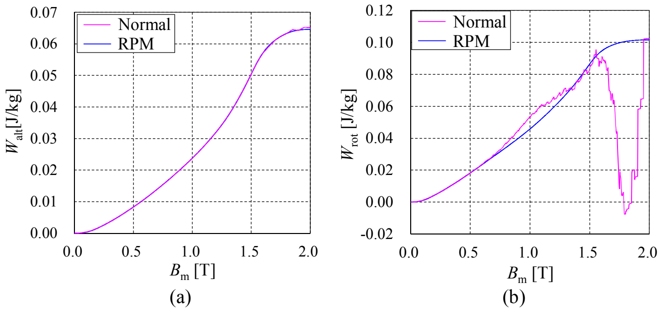

Fig. 1. Hysteresis losses per cycle for JIS: 50A470. (a) Alternating hysteresis loss. (b) Rotational hysteresis loss.

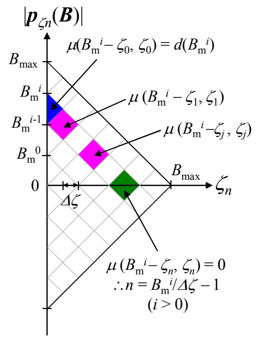

Fig. 2. Distribution function.

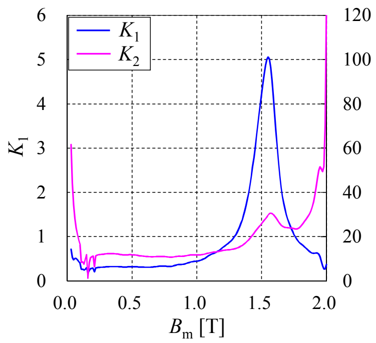

Fig. 3. K_1 and K_2 for JIS: 50A470.

III. Novel Identification Method for Play Model

A. Procedure of Novel Identification Method

In the play model, when an alternating flux density input

$$\boldsymbol{B}^i = (B_m^i \sin\omega t, 0), \tag{8}$$

is given, the initial magnetization curve is represented by:

$$H_b(B_m^i) = \sum_{n=0}^{N} f_{\zeta_n}(B_m^i - \zeta_n), \tag{9}$$

where B_m^i is the maximum magnetic flux density for the i-th symmetric loop as shown in Fig. 2. Substituting (3) into (9), the increment of the magnetic field H_b from B_m^{i-1} to B_m^i under alternating flux density conditions is given by:

$$H_b(B_m^i) - H_b(B_m^{i-1}) - d(B_m^i) = \sum_{n=1}^{N} \mu(B_m^i - \zeta_n, \zeta_n), \tag{10}$$

where d is the incremental permeability and d corresponds to $\mu(B_m^i - \zeta_0, \zeta_0)$.

Substituting (3) into (6), the increment of the alternating hysteresis loss W_{alt} from B_m^{i-1} to B_m^i is given by:

$$W_{alt}(B_m^i) - W_{alt}(B_m^{i-1}) = -4\sum_{n=1}^{N} \mu(B_m^i - \zeta_n, \zeta_n)\zeta_n. \tag{11}$$

In this paper, it is assumed that μ changes exponentially as follows:

$$\mu(B_m^i - \zeta_n, \zeta_n) = -K_1(B_m^i) e^{-K_2(B_m^i)\zeta_n} \quad (n > 0), \tag{12}$$

where K_1 and K_2 is the variables depending on B_m^i. As shown in Fig. 2, $\mu(B_m^i - \zeta_n, \zeta_n)$ is equal to 0 in $n = B_m^i/\Delta\zeta - 1$ and $i > 0$ [5]. Substituting (12) into (10) and (11), the variables K_1 and K_2 are solved by the Newton-Raphson method. In this paper, the play model is identified from the variables K_1 and K_2 depending on B_m^i, which is called "Robust Play Model (RPM)."

B. Numerical Results

Fig. 3 shows the variables K_1 and K_2 calculated from the dc hysteresis loops of electrical steel sheet JIS: 50A470. The intervals ΔB_m of hysteresis loops is 0.01 T. Fig. 4 shows the simulated hysteresis loops of the electrical steel sheet under alternating flux density conditions. The RPM gives an accurate representation of the hysteretic properties. As shown in Fig. 1, the rotational hysteresis loss obtained from the RPM forms a smooth curve. Futermore, the RPM can be applied the identified method from the measured rotational hysteresis loss [6] to represent the saturation property under rotational flux density conditions. The detail of the proposed identification method and further numerical results will be reported in the full paper.

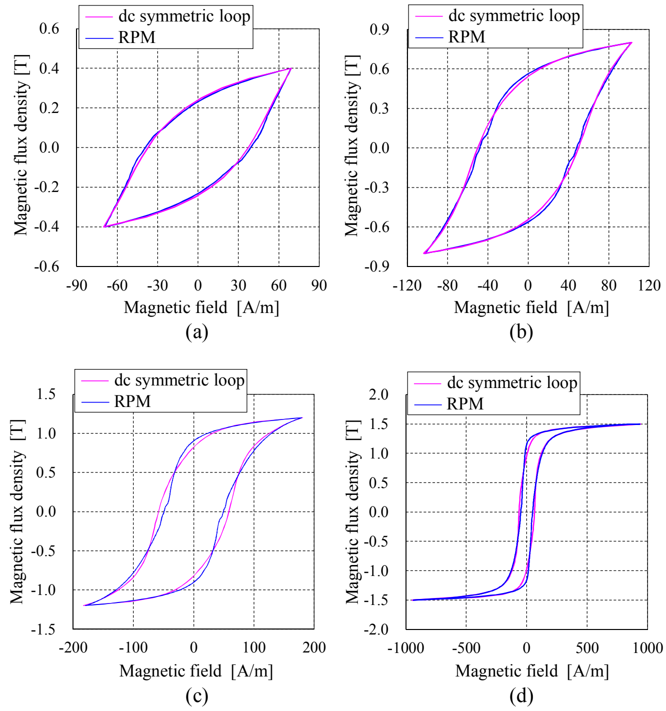

Fig. 4. Simulated symmetric hysteresis loops for alternating flux density. (a) $B_m = 0.4$ T. (b) $B_m = 0.8$ T. (c) $B_m = 1.2$ T. (d) $B_m = 1.5$ T.

IV. References

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