A Vector Jiles-Atherton Hysteresis Model and Its Application to Finite Element Analysis of Iron Loss

Wei Li, Minkyu Seo, Inhyun Kim, and Chang-Seop Koh, *Senior Member, IEEE*
School of Electrical Engineering, Chungbuk National University
410 Seongbong-ro, Cheongju, Chungbuk 361-763, Korea
liwei@chungbuk.ac.kr

***Abstract* — Scalar Jiles-Atherton hysteresis model is improved for a better fitness between the measured and modeled hysteresis loops. A vector Jiles-Atherton hysteresis model is also developed to model the hysteresis phenomena. The developed vector model will be combined with finite element method to analyze the iron loss distribution of a three-phase transformer model.**

I. INTRODUCTION

Several hysteresis models have been developed and applied to take into account hysteresis in finite element analysis. The Jiles-Atherton (J-A) hysteresis model is a physically based approach for modeling magnetic hysteresis. It has been widely employed due to its advantages of small number of parameters and low computation cost [1], [2]. To describe the magnetic behavior more accurately, several vector J-A models have also been investigated. In [3] Bergqvist presented a vector J-A model through modifying the differential equation to a vector model. In [4] an inverse J-A vector model was proposed and the anhysteretic magnetization function was improved.

In this paper, the scalar J-A hysteresis model is improved for a better fitness especially in saturated region. A vector J-A hysteresis model is also developed based on Bergqvist model concentrating on the improvement of anhysteretic magnetization function. The developed vector model, finally, is combined with the finite element method to calculate the iron loss of a three-phase transformer model.

II. SCALAR J-A HYSTERESIS MODEL

A. Improved Scalar J-A Hysteresis Model

The differential equation of the original J-A model has the following form [5]:

$$\frac{dM}{dH}=\frac{\delta_M\left(M_{an}-M\right)+k\delta c\dfrac{dM_{an}}{dH_e}}{k\delta-\alpha\left\{\delta_M\left(M_{an}-M\right)+k\delta c\dfrac{dM_{an}}{dH_e}\right\}} \tag{1}$$

where M_{an} is the anhysteretic magnetization calculated by the Langevin's equation

$$M_{an}\left(t\right)=M_s\left[\coth\frac{H_e\left(t\right)}{a}-\frac{a}{H_e\left(t\right)}\right]. \tag{2}$$

The five parameters M_s, a, c, k, α are obtained from the experimental data using particle swarm optimization technique [6]. The measured data cannot be fitted quite well by the original J-A hysteresis model in saturated region, as shown in Fig. 1.

As parameter a is related with the curve shape, we take parameter a as a variable on several points in the saturated region. The optimized values of parameter a on the several points is also obtained by using particle swarm optimization. Finally the function of parameter a for the whole loop is constructed by using Bezier interpolation of the optimized values of parameter a, as shown in Fig. 2. At the same time, to improve the fitting accuracy, parameter k is also made a function of the magnetic field, as shown in (3).

$$k=k_0+k_1*e^{-(|H|-k_2)^2/2\sigma^2} \tag{3}$$

where k_0, k_1, k_2, σ are parameters determined by optimization [7]. The fitting accuracy is much improved comparing to the original J-A hysteresis model

B. Parameter Identification for Multiple loops

The optimized model for major loop is usually not suitable for minor loops [8]. In [9] a multiple loops optimization method was proposed. However, for our material it is difficult to describe all the loops accurately using only one set of parameters. Therefore, we divide the B-H loops into several groups according to the magnetic flux density value, for each group the multiple loops optimization is applied and only generates one optimized result. Finally the whole magnetic property of the material can be described by several sets of J-A hysteresis parameters as shown in Table. I. The optimized results for different B-H loops are shown in Fig. 3.

III. VECTOR J-A HYSTERESIS MODEL

In Bergqvist model [3], original anhysteretic magnetization functions (4) and (5) were used.

$$M_{anx}=M_{sx}\left[\coth\frac{H_{ex}}{a_x}-\frac{a_x}{H_{ex}}\right] \tag{4}$$

$$M_{any}=M_{sy}\left[\coth\frac{H_{ey}}{a_y}-\frac{a_y}{H_{ey}}\right] \tag{5}$$

TABLE I
SCALAR J-A HYSTERESIS MODEL PARAMETERS

B_Range (T)	M_s	a	K	c	α
0.0 ~ 0.6	920057	106.43	70.19	0.4009	1.65e-4
0.6 ~ 1.0	1290489	401.60	138.84	0.6440	7.57e-4
1.0 ~ 1.5	1344336	447.86	281.97	0.7813	8.29e-4

where M_{sx}, a_x, and M_{sy}, a_y are the parameters of rolling direction (RD) and transverse direction (TD), respectively.

The vector model should be able to describe the B-H behavior along any excitation direction by using the parameters of RD and TD. When the excitation is $\theta°$ shifted from RD, the proposed anhysteretic magnetization function is as follows,

$$M_{anx\theta} = M_{sx} f_{mx\theta}\left[\coth\frac{H_{ex}}{a_x f_{ax\theta}} - \frac{a_x f_{ax\theta}}{H_{ex}}\right] \quad (6)$$

$$M_{any\theta} = M_{sy} f_{my\theta}\left[\coth\frac{H_{ey}}{a_y f_{ay\theta}} - \frac{a_y f_{ay\theta}}{H_{ey}}\right] \quad (7)$$

where $f_{mx\theta}$, $f_{my\theta}$, $f_{ax\theta}$, $f_{ay\theta}$ are scale factors. The definition and calculation of scale factors will be discussed in the full paper.

The inverse vector J-A hysteresis model is adopted. For an ideal isotropic material, the B-H behavior should be same for excitation in any direction. Fig. 4 shows the locus of the magnetic flux density under rotating excitation, and the corresponding loci of magnetic field obtained from original and proposed anhysteretic models. The proposed model gives the same B-H behavior along any excitation direction. An anisotropic material is analyzed under the alternating excitation applied in 45° shifted from RD. The calculated results from proposed and original models are compared with the measured one as shown in Fig. 5.

In the version of the full paper, the suggested vector J-A hysteresis model will be combined with the finite element method to analyze a three-phase transformer model. The calculated results will be compared with the measured one in detail.

IV. REFERENCES

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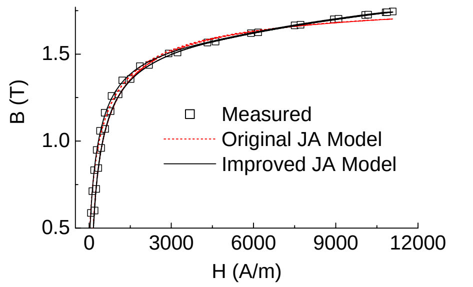


Fig. 1. Measured and modeled B-H major loop with original and improved scalar J-A hysteresis model.

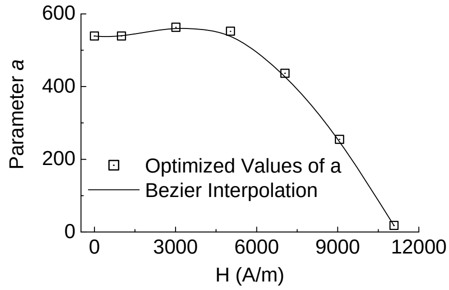


Fig. 2. Distribution of parameter *a* by Bezier interpolation.

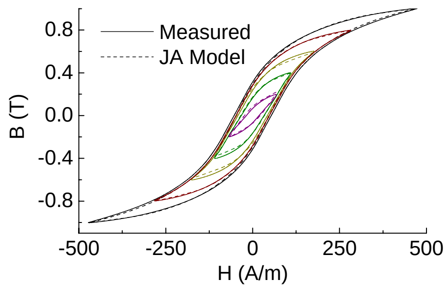
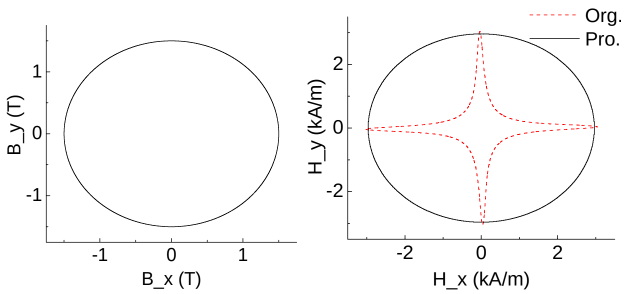
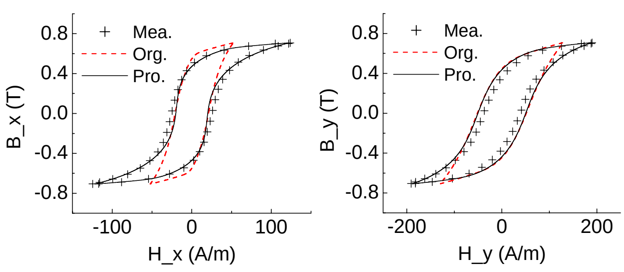


Fig. 3. Measured and modeled B-H loops from 0.2 T to 1.0T.



(a) magnetic flux density (b) magnetic field

Fig. 4. B-H behavior obtained by original and proposed anhysteretic models under rotating excitation for an ideal isotropic material.



(a) B-H loop in RD (b) B-H loop in TD

Fig. 5. B-H behavior obtained by original and proposed anhysteretic models under 45° alternating excitation for an anisotropic material.