Modeling of one Dimensional Hysteresis Properties Based on Preisach Model

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Abstract. The B-based Preisach model, which employs magnetic induction intensity B as input and magnetic field intensity H as output, is proposed to overcome limitations and imperfections of the classical Preisach model (H-based model). Based on measured data of major hysteresis loop, first order reversal curves were created by numerical method, and Everett function was then established. Thus B-based model can be realized. Finally, the B-based and H-based model is applied to simulate the concentric hysteresis loops of soft magnetic materials and the high order reversal curves of hard magnetic materials, respectively. And the validity and accuracy of B-based Preisach model are verified by comparing with the experimental data measured under DC conditions.

1. Introduction
Hysteresis phenomenon is one of the important characteristics inherent in ferromagnetic and ferrimagnetic materials. The hysteresis characteristics of different magnetic materials are mainly represented by the shape of the hysteric loops. Magnetic materials are widely applied in almost all electrical equipment, such as power transformer cores, generators, inductors in electronic circuits and so on. Therefore, hysteresis simulation of ferromagnetic materials plays a critical role in design of electrical apparatus. However, the complex influence of hysteresis phenomenon is often ignored in the design of current electrical equipment, leading to increasing the error of the simulation results of excitation current and fault current. Therefore, in order to improve the accuracy of the magnetic field analysis in the engineering application, the hysteresis of the magnetic materials should be taken into account.

In order to accurately describe the hysteresis characteristics of the materials, hysteresis model needs to be established. At present, there are many kinds of hysteresis models, among which Preisach model and J-A model are widely used and the simulation results are more accurate. However, there are many parameters in the differential equations established by the J-A model, thus compared with the J-A model, the identification procedure of the Preisach model is easier a lot. In the paper, the hysteresis characteristics of ferromagnetic materials are simulated and analyzed based on the Preisach model.
2. Hysteresis Modeling Based on the Scalar Preisach Model

2.1. The B-based model

Among many types of Preisach models, the classical Preisach model provides a good compromise between accuracy, simplicity, and efficiency. Therefore, it has been widely popular in hysteresis models. The classical Preisach model employs the magnetic field intensity $H$ as the input and the magnetic induction intensity $B$ as the output. Hence, it is also referred to as the H-based Preisach, which is represented by equation (1).

$$B(t) = \int_{\alpha<\beta} \mu(\alpha, \beta) \gamma_{\alpha \beta}(t) d\beta d\alpha$$

Where $\alpha$ and $\beta$ correspond to the increasing and decreasing values of the input $H$, and $\gamma_{\alpha \beta}$ is the hysteresis operator controlled by the increasing $\alpha$ and decreasing $\beta$ corresponding to the input $H$; $\mu(\alpha, \beta)$ is a distribution function related to the hysteresis operator. When integrated over $\alpha$ and $\beta$ in the Preisach plane $\Omega$, the relationship between Preisach distribution function $\mu(\alpha, \beta)$ and Everett function $E(\alpha, \beta)$ is as follows:

$$E(\alpha, \beta) = \int_{\Omega(\alpha, \beta)} \mu(\alpha, \beta) d\alpha d\beta$$

In most magnetic materials, the change of magnetic field intensity $H$ ($dB/dH$) is relatively large near the coercivity $H_c$. Hence, most reversal points are located near the coercive field, that is, the input values of most reversal points approach $H_c$. And thus the congruency problem would appear. The congruence property of Preisach model can be expressed as that when the input value varies between the same maximum value and the minimum value, the corresponding output value is equal. For H-based model, the values of starting points of each first order reversal curve are close to the coercive field $H_c$. In other words, the corresponding input value variation intervals approximate. As a result of congruency, the difference of corresponding output value is slight, which will affect the accuracy of identification procedure. In a word, the larger hysteresis loops near saturation region can be simulated relatively accurately based on H-based model, while for the smaller loops near the coercivity, the congruence property has seriously hindered the application of the H-based model.

In order to avoid the errors caused by the congruency problem in H-based model, it is necessary to use an inverse Preisach hysteresis model, also called B-based model, in which $B$ is the input and $H$ becomes the output in the numerical modeling of hysteretic properties. On the basis of the formula (1), the numerical implementation of the B-based model based on the Everett function $E$ can be presented as follows:

$$H(t) = -E(B_0,b_0) + 2 \sum_{k=1}^{n} [E(B_k,b_{k-1}) - E(B_k,b_k)]$$

where $B_k$ and $b_k$ are the increasing and decreasing values of the input $B$, respectively, and $n$ denotes the total number of reversal points on the FORCs; $E(B_0,b_0)$ is the saturation value of inverse Everett function; $E(B_k,b_{k-1})$ is the value of inverse Everett function at reversal point $k=1,2,\ldots,n$.

It can be seen from (3) that the key of realizing H-based model depends on the calculation of the Everett function. By means of the first order reversal curve, the value of the Everett function can be calculated by the following formula (4):
\[ E(B, b) = \frac{1}{2} (H_{forc}(B, b) - H_{forc}(B)) \]  

where \( H_{forc} \) refers to the values of \( H \) on the first order reversal curves. The first order reversal curve can be obtained by either experimental measurement or numerical method. In the paper, based on the experimental data of the descending branch of the major hysteresis loop, the first order reversal curves are generated by numerical method.

Because the magnetic flux density corresponding to each reversal point is uniformly distributed in the whole interval, the change speed of the magnetic field near the coercive field has little effect on the Preisach model. Therefore, the B-based model can avoid the congruency problem caused by the H-based model.

2.2. The simulation of concentric hysteresis loops

The concentric hysteresis loop is the static hysteresis loop formed in a period of magnetic induction intensity \( B \) and magnetic field strength \( H \) of ferromagnetic material at a certain peak induction \( B_m \). When different \( B_m \) values are applied, the corresponding static hysteresis loops with respect to centrosymmetry can be obtained. They are called concentric hysteretic loops.

According to the above numerical methods, the concentric hysteretic loops of grain-oriented (GO) silicon steel sheet(27ZDKH90) are simulated based on H-based model and B-based model, respectively. And then the simulated loops are compared with the measured ones to verify the accuracy of the two models. Fig. 1 and Fig. 2 depict the simulated and measured concentric hysteresis curves of the GO silicon steel sheet based on H-based model and B-based model, respectively.

![Simulated and measured concentric hysteresis loops of silicon steel sheet(27ZDKH90) based on H-based model.](image)
As shown in these figures, it can be found that the simulated results based on B-based model are agree well with the experimented ones, which verifies the proposed measuring method of numerical modeling for hysteric characteristics.

2.3. The simulation of high order reversal curves
In the following, the high order reversal curves of the toroidal-shape specimen(C19) are simulated. According to the above analysis, the high order reversal curves corresponding to the Preisach model based on variable H and variable B are calculated and compared with the experimental data to verify the accuracy of the two models.

Fig. 3 and Fig. 4 depict the simulated and measured high order reversal curves of the toroidal-shape specimen based on H-based model and B-based model, respectively.

**Figure 2.** Simulated and measured concentric hysteresis loops of silicon steel sheet(27ZDKH90) based on B-based model.

**Figure 3.** Simulated and measured high order reversal curves of toroidal-shape specimen(C19) based on H-based model.
Measured results
Simulated results

Figure 4. Simulated and measured high order reversal curves of toroidal-shape specimen (C19) based on B-based model.

By comparing the simulated results of Fig. 3 and Fig. 4, it can be seen that the B-based model can simulate the high order reversal curves of toroidal-shape specimen (C19) more accurately than H-based model.

When the magnetic field is near saturation region, the errors of the two models are acceptable and the result is relatively accurate. However, when the magnetic field H is close to 0, the H-based model has a serious deviation and the influence of the congruency property is obvious, while the B-based model is still accurate.

3. Conclusion
The numerical implementation of the B-based Preisach model is presented to simulate the hysteresis curves of magnetic materials. The B-based model as well as H-based model is identified based on the numerically generated FORCs and used for the modeling of the concentric hysteresis loops and high order reversal curves. There is a good agreement between the measured results and simulated ones. Not affected by the congruency problem, the B-based model could achieve more accurate prediction of hysteresis properties than H-based model. In addition, it contributes to analyzing the dynamic hysteretic properties and loss characteristics of electrical equipment through numerical computation of magnetic fields.

References
[1] Dai Xinrui, Li Tian. Demagnetization skills of Hall magnetization Curve and hysteretic Circuit Experimental instrument [J]. College physics, 2007, 26 (6): 42-43.
[2] Mayergoyz, I.D. Mathematical Model of Hysteresis [M]. Springer, 1991, 45-87.
[3] Jia Qimin, Zheng Yongling, Chen Jiyao. Electromagnetics [M]. Higher Education Press (HEP), 2001.
[4] Shi Hong, Song Daojun, Liu Yu. Research on the Magnetization Model of the Core Based on the J-A Theory and Its Improvement [J]. Electrical logging and instrument, 2013, 50 (6): 4-7.
[5] E Dlala. Efficient algorithms for the inclusion of the Preisach hysteresis model in nonlinear finite-element methods [J]. IEEE Trans. Magn., vol. 47, no. 2, pp. 395-408, 2011.