# Determination of the Distribution of the Preisach Density Function With Optimization Algorithm

**Sun-Ki Hong* and Chang Seop Koh****

**Abstract** - The Preisach model needs a distribution function or Everett function to simulate the hysteresis phenomena. To obtain these functions, many experimental data obtained from the first order transition curves are usually required. In this paper, a simple procedure to determine the Preisach density function using the Gaussian distribution function and genetic algorithm is proposed. The Preisach density function for the interaction field axis is known to have Gaussian distribution. To determine the density and distribution, genetic algorithm is adopted to decide the Gaussian parameters. With this method, just basic data like the initial magnetization curve or saturation curves are enough to get the agreeable density function. The results are compared with experimental data and we got good agreements comparing the simulation results with the experiment ones.

**Keywords**: Gaussian function, Preisach density function, Genetic algorithm, Transition curve.

## 1. Introduction

The Preisach model is known as a appropriate one to represent magnetic hysteresis [1]. It is necessary, however, to know the distribution function or Everett function to describe any hysteresis loops. To obtain those things, many first order transition curves are required and it is desirable to obtain these curves by experiments. However, it is difficult or boring thing to carry out these measurements. To reduce these experimental efforts, some mathematical formulations like the Gaussian function [2] have been used and some methods make it much easier to get the distribution function. That is to say, with a few hysteresis curves, agreeable function table can be composed. Recently, with the help of computational power, the optimization methods like genetic algorithm or evolution strategy are used and some paper [3-5] shows good results to get the distribution functions. In this study, a new technique of mathematical formulation using the genetic algorithm and the Gauss distribution function for the interaction axis is proposed to enhence the accuracy and reduce the calculation efforts. The proposed method needs only the initial magnetization curve or saturation cuves and it is shown that the method can describe the hysteresis characteristics with satisfaction.

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## 2. Formulation of the Everett function

### 2.1 Preisach density function

The first order transition curves obtained from experiments are used to make Everett function directly. The Everett function is defined as follows.

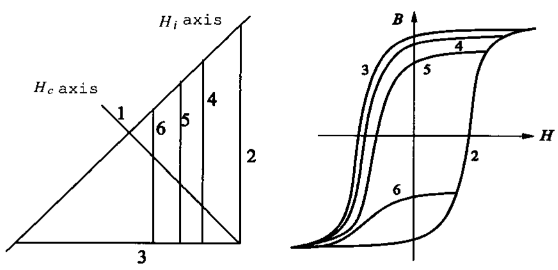
$$E(\alpha,\beta)=\frac{1}{2}(M_\alpha-M_{\alpha\beta}) \tag{1}$$

where, α and β are the upper and lower switching fields, $M_\alpha$ is the magnetization increased from the negative saturation to the input field α, and $M_{\alpha\beta}$ is the one decreased from α to the field β. Interaction field $H_i$ and coercive force field $H_c$ defined by (2) are used in mathematical formulation of the Preisach density function. $H_\alpha$ and $H_\beta$ in (2) are the increasing and decreasing fields in the Preisach or Everett plain as shown in Fig. 1. From (1), the Preisach or Everett plain is constructed by experiments.

$$H_i=\frac{H_\alpha+H_\beta}{2}, \qquad H_c=\frac{H_\alpha-H_\beta}{2} \tag{2}$$

In many cases, formulating the Everett function is more convenient than the Preisach distribution or density function [5]. Fig. 1 shows the relationship between Everett function plane and hysteresis loops. The line 2 and 3 in Fig. 1(a) correspond to the hysteresis saturation curve 2, and 3 in Fig. 1(b). The line 1 in Fig. 1(a) indicates the initial magnetization curve. The line 4, 5 and 6 also correspond to the each transient curve 4, 5 and 6 in Fig. 1(b). If the saturation loop and a few transient curves are measured, the data of the Everett table corresponding to the lines 2 through 6 can be obtained.

If we can get enough transient curves without measurement errors through the experiments, the exact hysteresis analysis and simulation could be realized. However it is very difficult and boring thing to measure the data, mathematical formulations were tried to reduce these efforts. It is well known [3] that the distribution of the Preisach distribution function for the interaction field is Gaussian, but that for the coercive force field is not. Therefore the Gaussian distribution is applied only to that of the interaction field. The relation between the Preisach density function and Everett function is shown in (3) or (4).




(a) (b)

**Fig. 1** Everett function plain and corresponded hysteresis loop

$$\rho(\alpha,\beta) = -\frac{\partial^2 E(\alpha,\beta)}{\partial\alpha\partial\beta} \tag{3}$$

$$E(\alpha,\beta) = \int_\beta^\alpha \int_\beta^y \rho(x,y)dxdy \tag{4}$$

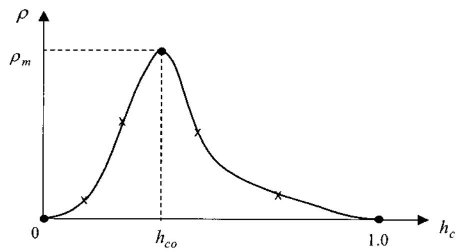
## 2.2 Formulation of Preisach distribution function

To simulate the hysteresis phenomena, Everett function is commonly used. If the Preisach density is prepared, the Everett function can be composed with (4). As mentioned before, the distribution according to the coercive force axis is not Gaussian as shown in Fig. 2(a) although that for the interaction field axis is Gaussian.

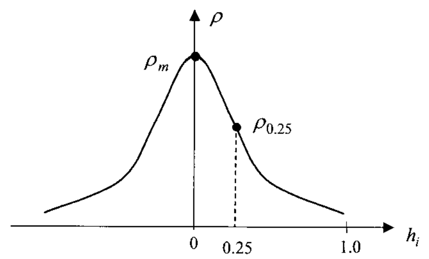
Because the density distribution for coercive axis is not Gaussian, the curve can not be formulated with one function. As can be seen in Fig. 2, however, the curve has non-symmetrical bell shape and it looks the curve can be formulated with spline function by dividing two curves. One is from 0 to $h_{co}$ and the other is from $h_{co}$ to 1.0 where $h_{co}$ is the normalized coercive force field intensity. Fig. 2(b) shows the distribution of the Preisach density for normalized interaction field $h_i$ axis, which has Gaussian distribution.

According to the $h_i$ axis, the distribution curve is determined [4] just with two points $\rho_m$ and $\rho_{0.25}$ using equation (5) and (6),

$$\rho(H_c,H_i) = \rho_m(H_c)e^{\left\{\frac{-(H_i-\mu_i)^2}{2\sigma^2(H_c)}\right\}} \tag{5}$$




(a) Density for coercive force axis




(b) Density for interaction axis

**Fig. 2** Preisach density distribution for coercive and interaction field axis

$$\sigma^2(H_c) = -\frac{H_{im}^2(H_c)}{32\log\{\rho_{0.25}(H_c)/\rho_m(H_c)\}} \tag{6}$$

where $H_{im}$ is the maximum interaction field for $H_c$ and $\mu_i = 0$. The number of variables or control points according to the $h_c$ is 5 which means the one summit and 4 x points. Each curve has 4 points including 0 at zero and 1 on $h_c$ field axis. This curve is separated at $h_{c0}$ and becomes two curves. With 4 points for each curve, two splined curves can be produced and they are monotonous increasing or decreasing curves.

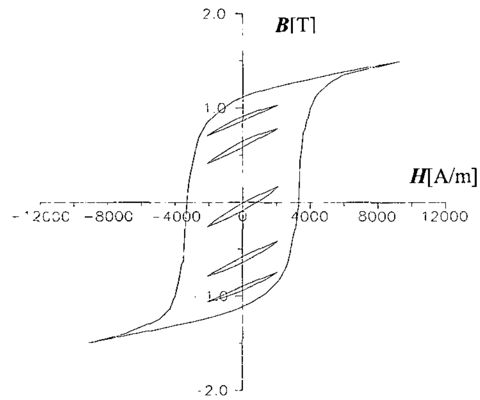
In this paper, the genetic algorithm [6] is adopted to get the control points and a important criterion is the characteristics of the curves for $H_c$. They have monotonous increasing or decreasing curves. If the vertex $\rho_m$ is determined then the other points are smaller than $\rho_m$

and have monotonous increasing or decreasing characteristics. The number of variables becomes 10 because each curve for $h_i$ needs just two points. 10 variables may require huge calculation time to converge to determine the control points, however with the tip of the monotonous characteristics, the calculation time is reduced remarkably. Equation (7) shows the objective function to be minimized in this study.

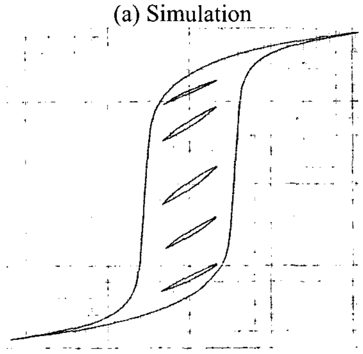
$$F_{obj}(E) = \sum_{i=1}^{N} (B_m(H_a) - B_{sim}(H_a))^2 \qquad (7)$$

Where $N$ is the number of data, $B_m$ and $B_{sim}$ are the measured and simulated data and $H_a$ is the applied field at each point. In this study, the equation (3) is combined with an optimizer genetic algorithm which is nondeterministic method to determine the 10 parameters. If the variables are determined, the Preisach density function and the Everett function can be calculated with (5) and (4).

## 3. Results




(a) Simulation

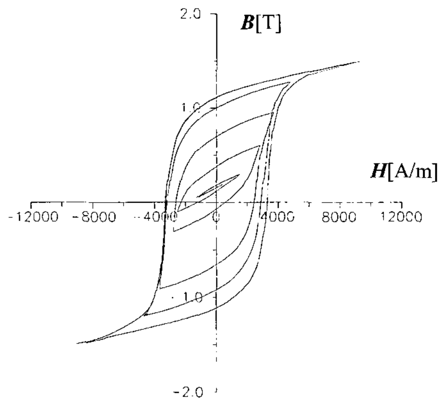


(b) Experiment

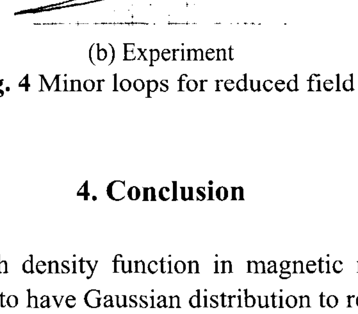
**Fig. 3** The measured and calculated minor hysteresis loops

The sample is a semi-hard magnetic material that the coercive force is 3,500[AT/m] and the remanent flux density is 1.14[T]. Fig. 3 and 4 shows the measured and simulated hysteresis loops of the test material. Fig. 3 shows the minor loops which shows the non-congruency the the magnetization-dependent model [3]. As we can see in the figure, although the input field is same, the shapes of the minor loops are different because the variance of the magnetization depends on the history of the magnetization state.

Fig. 4 shows the minor loops when the applied field decreases from the saturation state to some negative values and repeats this process as reducing its amplitude. From the well-posed Everett table, the magnetization can be computed using the magnetization-dependent Preisach model according to the variation of the magnetic field. It is remarkable that fairly acceptable hysteresis loops can be made only using a few experimental measurements like saturation curve.




(a) Simulation



(b) Experiment

**Fig. 4** Minor loops for reduced field

## 4. Conclusion

The Preisach density function in magnetic materials is often assumed to have Gaussian distribution to represent the hysteresis because of the difficulties of getting the functions in experiments. However it is shown that the Gauss function does not express the distribution function correctly for the coercive force axis. To overcome this problem, a simple method to determine the Preisach density function is presented and the Everett function also can be made from the Preisach density function. The proposed algorithm using Gaussian function and genetic algorithm with the tip of the monotonous characteristics could determine the parameters with ease and reliability. Through the comparison between the simulations and experiments, the proposed method shows the usefulness in simulating the hysteresis characteristics.

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