

A Improved Method of Determining Everett Function with Logarithm Function and Least Square Method

Sun-Ki Hong*

Abstract

For Preisach model, Everett function from the transient curves is needed to simulate the hysteresis phenomena. However it becomes very difficult to get the function if the it would be made only from experiments. In this paper, a simple and stable procedure using least square method and logarithm function to determine the Everett function which follows the Gauss distribution for interaction field axis is proposed. The characteristics of the parameters used in this procedure are also presented. The proposed method is applied to implement hysteresis loops. The simulation for hysteresis loop is compared with experiments and good agreements could be shown.

Key Words : Everett Function, Gaussian distribution, Least square method, Logarithm function, Preisach model

1. Introduction

The Preisach model is well known as a most appropriate hysteresis model to represent the magnetic hysteresis phenomena [1]. It is needed, however, to know the distribution function or the Everett function information to describe or simulate any hysteresis loops. In order to obtain the needed functions, lots of first order transition curves are required and these can be obtained experimentally. However, it is very complex and boring things to carry out this procedure, because it needs lots of time. Of those formulations to

simplify the procedure, Gaussian function [2] is usually used and the previously proposed technique [3] using least square method and the Gauss distribution function for the interaction axis showed good agreements with experiments.

In this study, an improved method is proposed adopting logarithm function to increase the stability when the magnetization is near to the saturation. That is to say, the logarithm function is applied to the nearby saturation region for interpolation rather than a linear or high-order polynomial interpolation and this makes the Everett function more stable. The characteristics of the parameters used in this method are also presented to clear the proposed method. With the Everett function made by the proposed method, hysteresis phenomena including minor loops are simulated. From the comparison between simulations and

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experiments, we could get good agreements.

2. Formulation of the Everett function

2.1 Modeling of the Everett Function

It is well known that the Preisach distribution function or Everett function for the interaction field axis has Gaussian distributions [3]. Therefore the Gaussian function is adopted for the interaction field to formulate the Everett function. Equation (1) shows the proposed function which uses the Gaussian function to get the analytical formulation of the Everett function [3].

$$f(H_i, H_c) = k(H_c) G(H_i, \sigma_i(H_c)) + B_{nd}(H_c) \quad (1)$$

Where $G(H_i, \sigma_i(H_c))$ is the Gaussian function, H_i is the interaction field, $\sigma_i(H_c)$ is standard deviation of the Everett function according to the coercive force field H_c . The coefficient k , B_{nd} and σ_i^2 are the function of H_c . Because there are 3 variables of scale k , base B_{nd} and variance σ_i^2 , three equations are needed to determine the values of these parameters. Equation (2) shows the Gaussian function G which has three parameters of k , B_{nd} and σ_i^2 .

$$G(H_i, \sigma_i(H_c)) = \frac{1}{\sqrt{2\pi}\sigma_i} \exp\left[-\frac{(H_i - \mu_i)^2}{2\sigma_i^2}\right] \quad (2)$$

where the average μ_i becomes zero because the distribution of the Everett function for H_i is symmetric. Unfortunately, the Everett function distribution for H_c is not followed to Gaussian distribution and even there is no known adequate

function for H_c , this Gaussian function is needed to be discrete for H_c to make the Everett function table. Fig. 1 explains the relation of those parameters for interaction field as explained with (1). With 3 known points, the 3 parameters can be strictly determined. If the values of more than 3 points of the Everett function are known for $f(H_i, H_c)$ like in the figure, the parameters of k , B_{nd} and σ_i^2 can be determined using least square method minimizing errors from exact values.

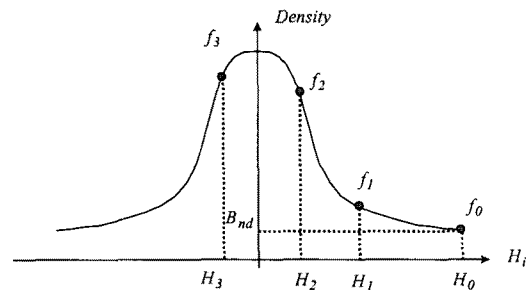


Fig. 1. Everett function for the interaction field

If there are enough known points to get 3 parameters in (2), there is no problem to get the Everett function. However, the more the field approaches to the saturation region, the less the known points become. Fig. 2 (a) shows the Everett plane. In the figure, the three vertical lines are correspond to the transition curves and line 1 becomes the initial magnetization curve of Fig. 2 (b). Line L_i crosses the vertical lines and from these points the parameters can be determined using (1).

If the coercive force field increases from a to c along the line 1 and if the line L_i becomes as the Fig. 2 (a), the number of cross points is less than 3, which means the state is underdetermined and the parameters can't be determined explicitly. In this case, area A and B correspond to the interpolation part of Fig. 2 (b). If linear function is

applied to approximate the residual line in this region, it can't satisfy to be the Gauss distribution for the distribution of the Everett function. If a polynomial function is used, the value of the

function may decrease like Fig. 2 (c) which can not be the real situation. Therefore the logarithm function looks better than polynomial function and the Everett function is formulated with high stability and the parameters can be determined at the region B.

2.2 Calculation of Everett Function

In Fig. 2 (a), if the line L_i crosses lines 3-6, there are 4 points which can make 4 equation with (1). In this kind of over determined problem, the parameters can be determined with least square method. If the coercive force axis is divided by n for discretization, and H_c is larger than some field where the cross points is less than 3, the interpolation of the initial magnetization curve becomes as Fig. 2 (b). If the values at the point b and c are given, logarithm function can be applied. If logarithm function is expressed as (3), (3) can be simplified to (4).

$$f(H) = p \log qH + r \tag{3}$$

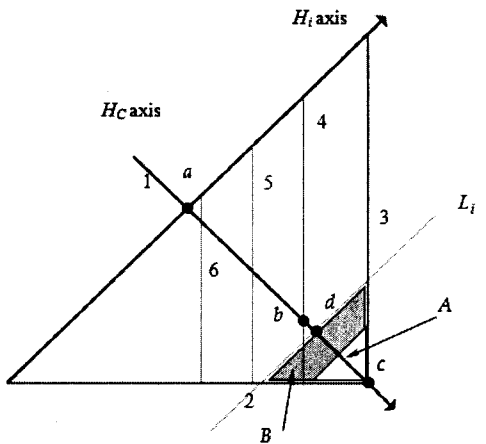
$$f(H) = p \log H + r' \tag{4}$$

where, $r' = p \log q + r$

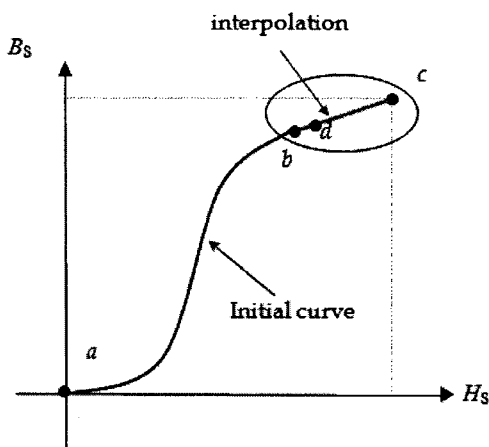
As a result, just 2 point data is enough to determine the unknown variable p and r' . As previous explained, it never happen that the values of the interpolated magnetization decrease according to the increasing H_c and a stable Everett function can be determined with this proposed method.

3. Simulation and results

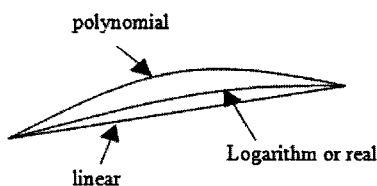
Fig. 3 shows the experimental hysteresis transient curves. The sample is a semi hard



(a) Everett function plane



(b) Initial curve and interpolation area



(c) Fitted curve

Fig. 2. Everett function plane, corresponded hysteresis initial curve

magnetic material which is used as a hysteresis ring of hysteresis motor. The coercivity is 7,200 (AT/m) and the remanent flux density is 1.41 (T). The sample is toroidal and has 1st and 2nd winding to apply the magnetic field and measure the flux density. In that figure, there are many transient curves with which the Everett function table is prepared. If the conventional method [4] is used, these data are not enough for the Everett function especially near the saturation region.

However, with the proposed method, 4 or 5 transient curves are enough to get the Everett function. Fig. 4 shows the 3D Everett function

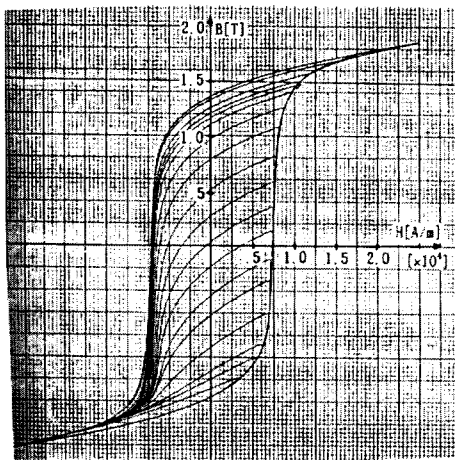


Fig. 3. Hysteresis first order transient curves of a semi hard magnetic material

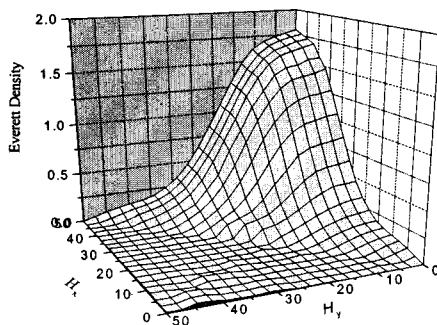
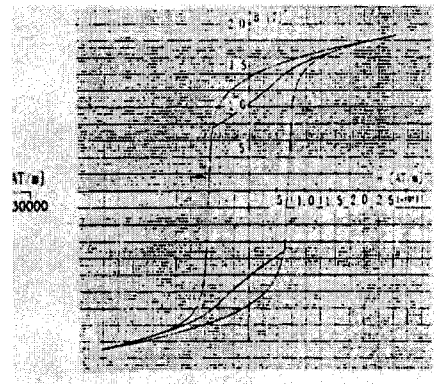
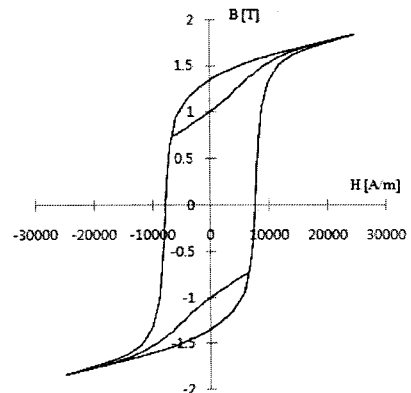


Fig. 4. Everett function formulated with the proposed method

table made from the transient curves. This table is made just with 4 transient curves using the proposed method. With this table, hysteresis phenomena are simulated.



(a) Experiment

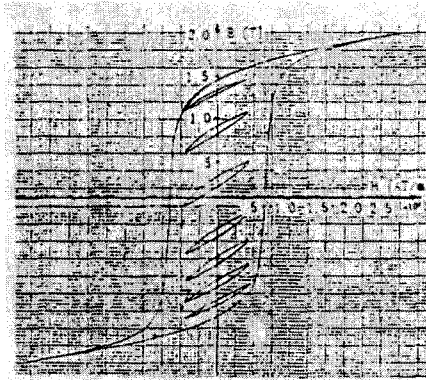


(b) Simulation

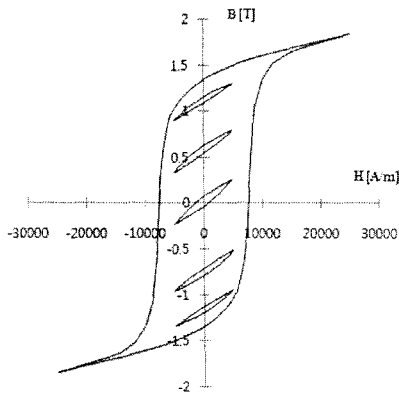
Fig. 5. Initial magnetization curve and first order transient curves which are reversed from the increasing and decreasing saturation hysteresis loop

Fig. 5 shows a measured and simulated minor hysteresis loops. At first, the magnetic field intensity increases to saturation and decreases to some negative values. And then it increases again to the positive saturation point. The field decreases again to negative saturation point and repeats the similar procedure with the positive

region. As can be seen in the figure, the variations are well corresponded with each other.



(a) Experiment



(b) Simulation

Fig. 6. Minor hysteresis loops with same extreme magnetic field

Fig. 6 shows some minor loops of which the variations of the applied field are same. According to the classical Preisach model, if the variations of the applied magnetic fields are equal, the shapes of the minor loops should be same. As can be see, however the real shapes are different according to their histories. This phenomena can be explained through the magnetization dependent model [5] and the simulation with the model has good agreement with the experiments.

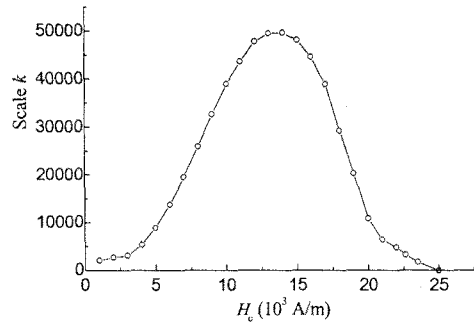


Fig. 7. Variation of parameter k

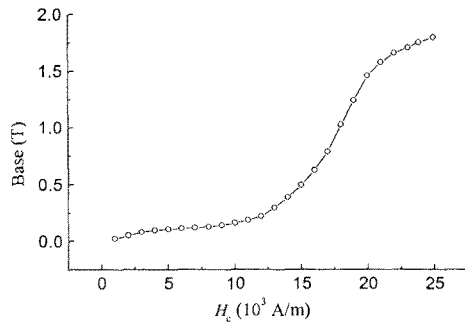


Fig. 8. Variation of base B_{nd}

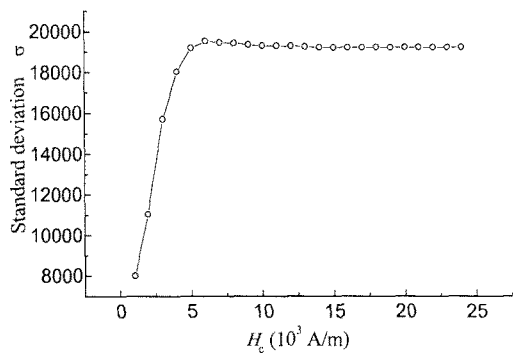


Fig. 9. Variation of standard deviation σ

Fig. 7, 8 and 9 show the variations of k , B_{nd} and σ . The circles in the figures show that the points of calculated values. The x axis is the coercive force field. The variation of the values of

scale k is similar to Gauss distribution. The values of B_{nd} increase according to the coercive force because this model is assumed to follow the Gauss distribution as Fig. 1. The standard deviation increases abruptly at the beginning, and it saturates to some value.

4. Conclusion

For easy and stable formulation of Everett function, a simple method which follows the Gauss distribution for interaction field axis using logarithm function and least square function is proposed. The characteristics of the parameters used in this procedure are also presented. The proposed method is applied to implement hysteresis loop simulation and the results are compared with experimental results and good agreements could be shown.

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Biography

Sun-Ki Hong

Sun-Ki Hong was born in Seoul, Korea, on January 24, 1965. He graduated from the Department of Electrical Engineering, Seoul National University in 1987. He received his M.S. and the Ph.D in electrical engineering from Seoul National University in 1989, 1993. He became a Member of IEEE in 1993 and worked as a researcher at REX industrial Co., Ltd. from 1993 to 1995. Then he has been teaching at the School of Electrical Engineering, Hoseo University since 1995. His special interests is the modeling and computation of hysteresis and present interests are the fields of design and analysis of electric and field analysis of magnetic field system with finite element method considering hysteresis.