New implementation of Preisach model

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Abstract. This article presents a new numerical implementation procedure for the classical Preisach model. Implementation has numerical improvements time needed for simulations are improved. Identification is done for a set of 3 different measurements and results have a good accuracy. A specific search algorithm for 2 variables is implemented and optimum parameters values are determined for an analytic Preisach type density function.

1 Introduction

Hysteresis is a phenomenon wide spread in technical domains and applications. It appears for example in economy, physics, mathematics, medicine. When it was discovered in the XVIII century it was defined as a delay that influences input and output values. Due to its complexity many definitions tried to explain intrinsic facts of it.

For example, Della Torre begins to explain the process in a mathematical way starting from physical description. The author highlights connection between hysteresis and speed of input/output values. If the value of input over output rises, then hysteresis effect is more obviously and it vanishes when the speed becomes 0 [1].

Visintin defines it as a phenomenon closely connected with memory effects [2]. In magnetism, Barkhausen jumps are determined by a displacement of domain. In magnetism, input is represented by magnetizing force and output is magnetization. Barkhausen jumps of magnetization, that initiate hysteresis, are determined by domain walls displacement. Due to complexity of phenomenon delay effects can’t be determined only by time [3, 4]. Bertotti defines it as a complex phenomenon including delay between applied field and magnetization. Also thermal effects influence heat losses which are strongly related to hysteresis.

Many works contain details about numerical implementation of hysteresis models. For example Newton-Raphson method is studied and numerically implemented for materials with hysteresis. Although it is very old, classical Preisach model is still implemented due to its simplicity and speed passing its known limits [7, 8].

2 Classical Preisach model

Classical Preisach model considers the material composed from elemental dipoles, characterized by a rectangular cycle [9]. It was developed starting from an idea of Weiss and Freudenreich.

Magnetization is determined using the following formula:
\[ M = \iint_{S_+} p(a, b) \, da \, db - \iint_{S_-} p(a, b) \, da \, db \]  

(1)

In above relationship \( p(a, b) \) represents probability density function which is defined as probability of an elemental particle to have \( a \) and \( b \) switching fields. Determination of probability density function is a difficult task that hasn’t been solved in a very good manner for now. Identification of Preisach function can be done analytically or numerically. Analytically identification can be done using Everett function \([10]\), or Gauss-Gauss distribution).

In written code, Preisach density function, after calculations, is considered to have this form:

\[ p(a, b) = \frac{128^N}{128 + 16(a+b) + (a+b)^2} \]  

(2)

Where the parameters \( A \) and \( B \) are given by:

\[ A = (a - b - 2)^2 \]  

(3)

\[ B = (a + b)^2 \]  

(4)

In above relationships \( a \) and \( b \) represent the 2 switching values of classical Preisach model. This way of determining density function can lead to strange errors because it does not have a real physical signification. This formulation it is still used for its simplicity and speed in determining density function for a certain category of materials.

3 New implementation method

Density function has a few unknown parameters which are correlated and must respect minimum error criterion. In developed code error is determined using least squares method. Optimum parameters are determined using a recursively search algorithm and obtained results are plotted. The novelty of this article represents state line memorization technique using a specially coded matrix. State line modifications are taken into account using a certain codification. Determined magnetization values are compared with measured ones and optimum Preisach function parameters are plotted. A recursive implementation method is used which less time is consuming. For determination of Preisach density function parameters, a search algorithm based on dividing by 2 search interval is used.

Parameters are transmitted to functions using classes. A new hypothesis is made to original model: on the edges of Preisach triangle particles have also a rotation movement. Special programing techniques are used to speed up execution of program.

Although analytical approximation amplifies the inherent errors of noise and unpredictable graphics can be obtained, due to its simplicity and speed of execution it is still implemented and used in program. Basic idea was to identify main functions characteristics for tested materials which can be used in other research processes. Another improvement concerning speed is done using parallelization programing. In case of a big number of measured data time consuming is a special characteristic that should be improved.

Search algorithm is based on the following idea for each of the 2 parameters: first the total search interval is divided in equal sub-intervals and the algorithm searches for the best value witch has minimum error. After this there is a in depth search near that value for optimum value that suits well the input. The same thing is done for the second parameter, and after trying all the possible combinations with optimum values for first parameter, results are shown. This search
algorithm works for any form of Preisach density function. It is efficient for a small number of measured data.

4 Results and conclusions

Measurements were done using a Vibrating Sample Magnetometer Lake-Shore 7304. Samples were round in order to avoid demagnetization problems. Correction of measured data was done in order to characterize not only the tested probe but also the relationship between magnetic parameters. In order to determine magnetization a surface of 8 mm$^2$ was considered.

Results point out a comparison between initial magnetization curves for a transversal applied field at different angles and values. An homogenous magnetic medium (a diskette) was tested for comparison with non-homogenous magnetic medium (metro card).

Saturation values for a metro card with an applied field at 90 degrees are the following: $H_S=636500$ A/m and $M_S=29385$ A/m. Number of measured points of initial magnetization curve is equal to 81 and comparison between measured and calculate values in the hypothesis that material starts from a demagnetized state are:

![Figure 1: Comparison between measured and identified data for a metro card.](image1)

Optimum values of parameters are: $a=-429,385$ and $b=421,6252$. Minimum error obtained for these parameters is $6.2974e^{-13}$. Preisach plane represented for optimum values of parameters $a$ and $b$:

![Figure 2: Preisach plane for a metro card with applied field at an angle of 90 degrees.](image2)
In case of a floppy disk (homogenous magnetic medium) with saturation values of field and magnetization, $H_S=477488\ \text{A/m}$ and $M_S=883\ \text{A/m}$ with 61 measured points good identification results were obtained. For an applied transversal field of approximately $480\text{kA/m}$ the following identification was obtained:

![Graph](image1)

**Figure 3:** Comparison between measured and identified data for a floppy disk

Values of optimum parameters and minimum error obtained are $a=623.976$ and $b=-5406.9$. For these values the minimum error is equal to $2.8906 \times 10^{-13}$. Preisach plane obtained for these values is shown in figure 4:

![Graph](image2)

**Figure 4:** Preisach plane for a floppy disk.

Another test was done for a metro card with an applied field at 30 degrees that has the following saturation parameters: $H_S=636683\ \text{A/m}$ and $M_S=41330\ \text{A/m}$. Number of measured points for initial magnetization curve was $N=81$. Identification results are:
Optimum values of parameters obtained are: $a=4848$ and $b=3742.7$. With these values minimum error is: $9.6470 \times 10^{-13}$. For these optimum values the following Preisach plane was obtained:

In conclusion a new implementation of Preisach model was done with advantages concerning speed. Results point out that model suits well homogenous magnetic mediums. A new way of memorizing state line in Preisach triangle was presented. Also a method of searching optimum parameters of a function with 2 unknowns is included in code. Numerical improvements concerning precision can be done for Preisach density functions with one
extremum value. Identification results are promising and a vectorization of model is a future task.

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References