NON-EQUIDISTANT GRID IN PREISACH MODEL

Jakub Eichler, Miroslav Novák, Miloslav Košek

Institute of Mechatronics and Computer Engineering

Technical university of Liberec

Liberec, Czech republics
jakub.eichler@tul.cz, miroslav.novak@tul.cz, miloslav.kosek@tul.cz

Abstract

A main problem in the practical use of the Preisach hysteresis model is finding its parameters and time consumption of computation. The paper is focused to decreasing the computation complexity of the Preisach model using non-equidistant steps of the field strength. The implementation and comparison of the modified model with standard one is presented here. The reduced Preisach model leads to the same results as the original one. The computation speed increase is considerable as well as the measuring time is saved.

1 Introduction

The Preisach model [1], [2], is an old approach how to model hysteresis, but it is still object of study of many scientists. The main problem in its application is the determination of the weighting function that is key matrix of parameters of the model. The model implementation in software MATLAB is very simple, when we used conditional indexing. Other problem is computation complexity resulting in the time consumption. Model is based on matrix that is recalculated after each change of exciting field. Therefore, the response to excitation needs many repeated calculations. If the suitable parameters of acceptable weighting function in analytical form are searched by the errors and trials method, the calculation speed is important, since there are a lot of attempts. As the first solution appears the reduction of matrix size. But the results should not be degraded by the reduction.

The modern grain oriented magnetic materials used in the distribution transformers have almost “rectangular” and narrow hysteresis loop. The loop is very steep in region near the coercitive force and approaches unit relative permeability in the saturation region. Reduction of the matrix size negatively affects the model precision in steep part of the loop. The paper deals with simple method, how to optimize the matrix simplification in order to get the lowest degradation of accuracy.

Since the Preisach model in not usually well-known, we start with its simple explanation. Then the method for effective matrix reduction is explained and some examples confirm its applicability. Further methods for the increase of calculation speed are mentioned briefly.

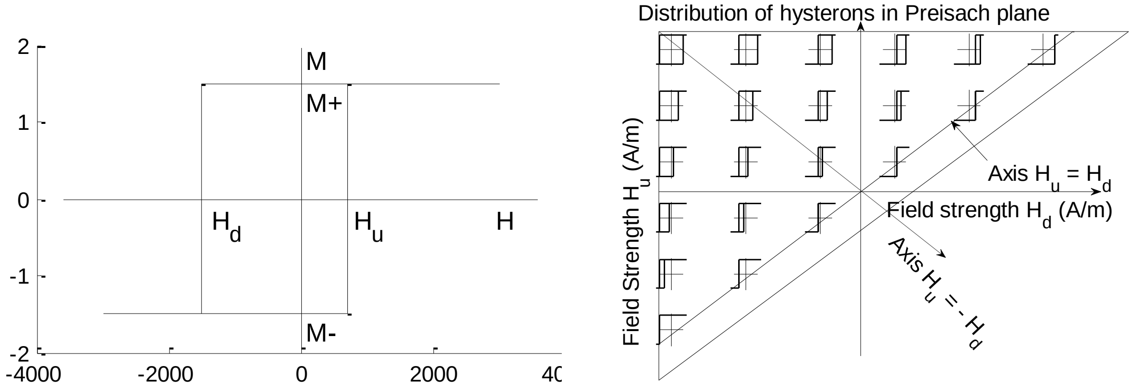
2 Preisach Model Parameters and Work

The Preisach model [1], [2] is based on hypothetical elementary hysterons with rectangular magnetizing loops with two switching levels H_u and H_d, see Fig. 1a. The third and the most important hysteron parameter is its magnetic dipole momentum M. Because of hysteresis, the model must be two-dimensional (2D) and considers the increasing excitation field H_u and decreasing field H_d as two independent variables. Practically they are parts of one excitation field $H(t)$. According the 2D model the hysterons are systematically located in Preisach plane, Fig. 1b, with field H_u in vertical direction and field H_d oriented horizontally. Their switching levels correspond to their geometrical position in Preisach plane. Since $H_u <= H_d$, only the upper part of matrix is used. The step of the increase for both the fields is the same; therefore the grid is regular and symmetric.

Since the excitation should start at minimum field value, the (1, 1) index is in the left low corner of Fig. 1b. The choice is opposite to the standard matrix presentation. In the main diagonal[1], there is no hysteresis, while at the secondary diagonal the hysteresis curves are symmetrical. For the non-linearity modeling the loops on main diagonal are sufficient, therefore the model is one-dimensional.

[1] The main diagonal line in Fig. 1b is little shifter in order to see hysteron on it well.

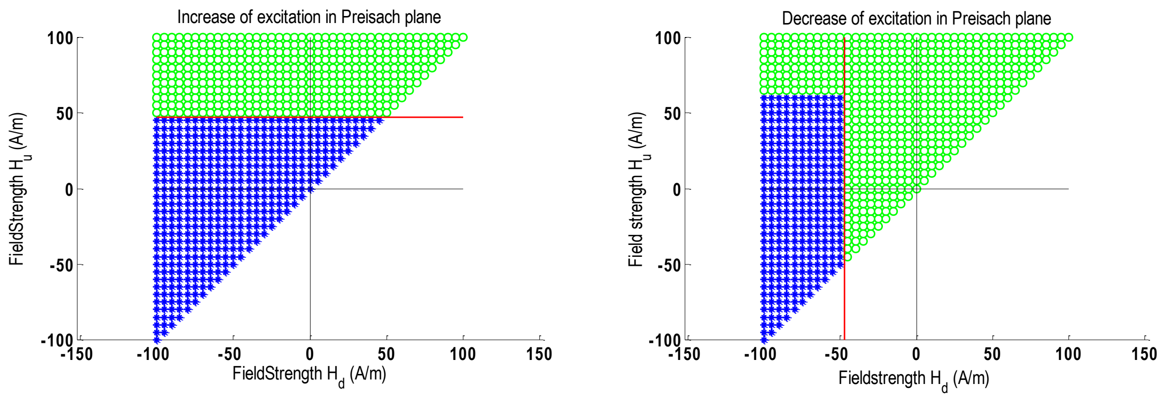
In this case the reduced loops can be considered as wavelets. The hysteresis needs two-dimensional model; therefore it is a very complicated material feature as for modeling.



a) b)

Figure 1. Basics of Preisach model. a) Elementary hysteron and its parameters, b) Hysterons systematically arranged in Preisach plane.

Exact Presiach model is continuous, but it is interesting only for mathematicians. For the practical use, the discrete Preisach model is used, as it was already shown in Fig. 1b. The function of Preisach model can be explained easily on the discrete presentation.



a) b)

Figure 2. Preisach model work. a) Hysteron are switched up (asterisk) for the increase of magnetic field given by horizontal line moving up. b) Hysterons are switched down (empty circles), when magnetic field decreases; vertical line moves from left to right.

The effect of the external excitation field is in Fig. 2. The Preisach model takes into account the sign of the excitation change. When the excitation increases, the excitation level is done by a horizontal line, Fig. 2a. All hysterons under the excitation level are switched up, others, above the line, remain unchanged. The line can move only up. When the excitation decreases, the excitation level has a form of a vertical line that can move only from right to left hand side, Fig. 2b. All the hysterons at the right hand side of the level are switched down, others, on the left hand side, are unchanged. The magnetization is the sum of the momentum of all the hysterons.

As an interesting example the demagnetization by standard method of decreasing switched current is shown in Fig. 3. The method does not lead to the full demagnetization practically, since some non-negligible magnetic momentum (and magnetization) remains.

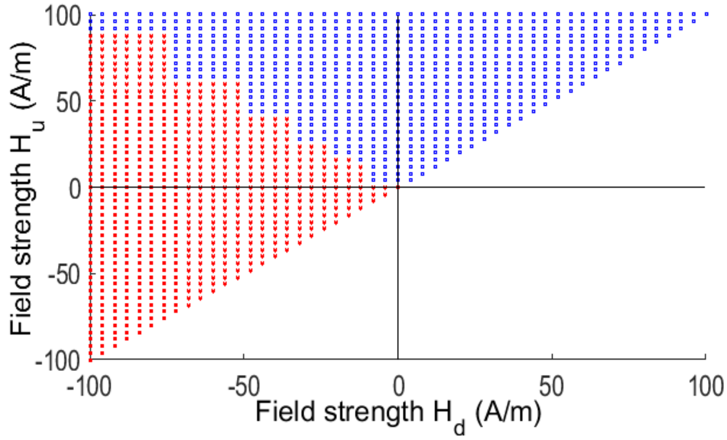


Figure 3. Demagnetrization by decerased shithing current.

3 Weighting Function

Since switching field strengths of hysteron in Fig. 1a are given by their position in Preisach triangle in Fig. 1b, the only variable parameter is hysteron momentum. The distribution of momentums in Preisach triangle is given by weighting function. Therefore the weighting function determines the magnetic properties of material. The most general approach of the weighting function determination is possible from experimental method resulting in FORC (first order reversal curve) [3, 4, 5, 6]. Simpler approximate approach is to use the analytical presentation and search its optimum parameters.

For the investigated grain oriented magnetic materials the weighting function exhibits sharp maximum and its position is on the secondary diagonal in Fig. 1b near to the main diagonal. As the prototype of the weighting function the probability density is used. Typical simple example of such a weighting function is in Fig. 4. Sharp maximum is well visible. Furthermore, its values far from the maximum are small. However, it is not visible well in Fig. 4.

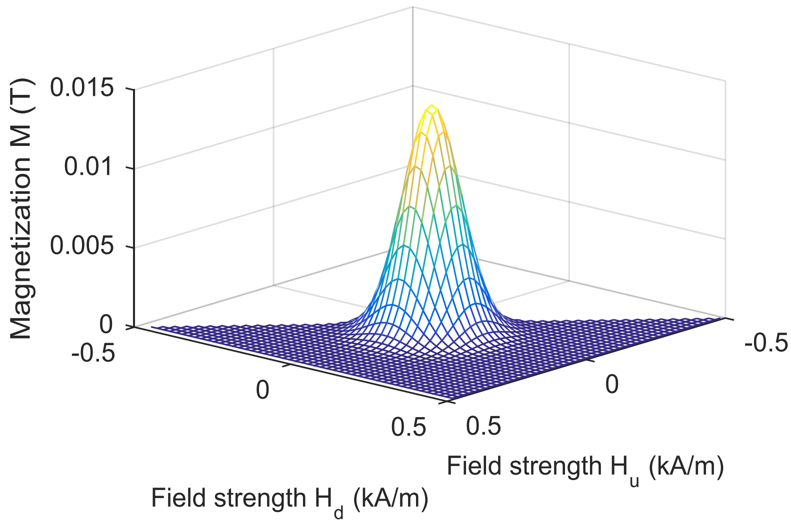


Figure 4. Example of weighting function in 3D presentation.

In order to get a better insight, horizontal cut of approximating weighting function going through its maximum is in Fig. 5, where both the linear and logarithmic scales are used on the vertical axis. The standard deviation is 16. The logarithmic graph reveals that the weighting function changes by several orders, therefore only the effect of hysterons near its maximum is dominant. The contribution from hysterons far from maximum is negligible.

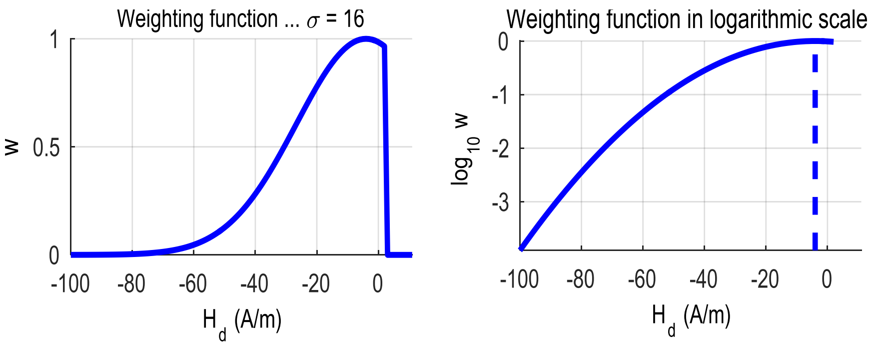
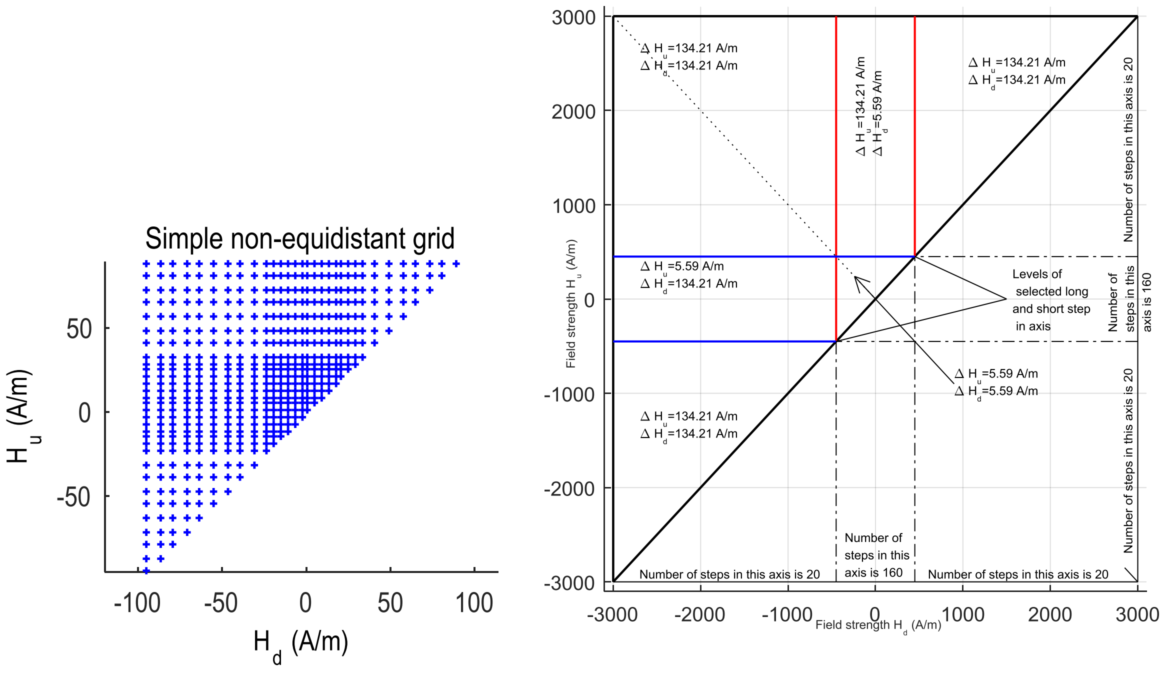


Figure 5. Horizontal cuts of the weighting function going through its maximum. Both linear and logarithmic graphs are used.

4 Irregular Grid

Since the contribution of hysterons far from maximum position is low in the regular grid, the coarser grid is satisfactory for this area. To verify this assumption, the simplest irregular grid, shown in Fig. 6a, is considered. The grid consists of two regular grids with different grid constants[2]. In our case the grid constants differ by a factor of two.

The cell area must be different in the irregular grid. All the possibilities are shown in Fig. 6b. The cell areas differ by a factor of 1, 2 or 4. This condition must be included into the calculations.



a) b)

Figure 6. Simple irregular grid. a) Position of nodes. b) Area for hysteron

5 Speed of Calculation

The key algorithm should switch up or down the hysterons in Preisach triangle according to the level of external excitation magnetic field strength. It is explained in Fig. 2. Using the excellent MATLAB matrix processing the algorithm is very simple and it is shown in Fig. 7. Algorithm has several rows.

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[2] We use basic terms of elementary crystallography. We consider regular square grid. Grid constant is the distance between neighbouring nodes. Since we consider the same distance in both the directions, there is only one grid constant. Cell is the area belonging to one node and is the same for all the nodes

```
function [ M ] = PM_mag_mom(M, H, level, Mom, increase)
 % Setting up of hysterons momentums of Preisach model.
% Procedure parameters:
% M is N x N matrix of dipole momentums, only upper half is used. Index i is for vertical and j horizontal direction.
% Level is the value of exciting field.
% Logical variable increase defines the sign of Level change.
% The vector H of length N are magnetic field strengths at edges of M matrix lattice.
%Mom is momentum of hysteron.
if increase == 1;
 M(H<level,:)=Mom;
else
 M(:,H>level)=-Mom;
end;
end
```

Figure 7. MATLAB function for hysterons switching.

However there is another problem in calculations. The excitation field is time varying and the increment of time is constant for simplicity. Therefore the step between neighboring excitation levels varies. For the case of harmonic excitation the values of excitation field in Preisach triangle are shown in Fig. 8. The function *PM_mag_mom* from Fig. 7 is applied for the each excitation value. For levels between hysteron rows the calculation are unnecessary, since nothing was changed. If the calculation were not made, the speed increases two times in this area for the selected time increment. For the case of decreasing excitation after the maximum in Fig. 8b, there are a lot of unnecessary calculations. If they are not performed, the calculation speed increases several times in this area.

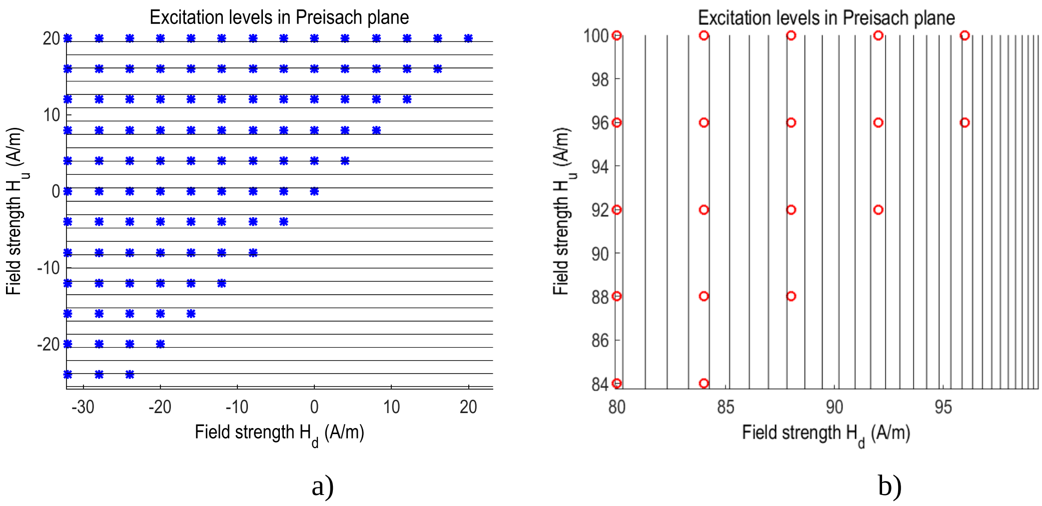

Figure 8. Levels of external excitation magnetic field strength in Preisach triangle. a) Field increases near zero crossing. b) Field decreases after reaching its maximum.

From the practical point of view it is important to select the time increment to produce the excitation levels close to rows or columns in Preisach triangle in the area of maximum excitation change. In the case of harmonic excitation this area is around zero (see Fig. 8a). For slower change, the unnecessary calculations are made (see Fig. 8b for harmonic excitation).

The discrete Preisach model results in stair-wise response. The steps cannot be reduced by decreasing the time increment. Finer grid must be used for the reduction of steps in the response.

The best way is to modify the algorithm to apply the *PM_mag_mom* function only in the case, when row or column in Preisach triangle is crossed by the external excitation field. Then the gird reduction is connected with rapid computation speed increases. On the other hand the algorithm is complicated, not robust and errors can be hidden in it.

6 Preliminary Results

The main task was to verify, if the irregular grid can be used. The comparison of time response between regular (equidistant) and irregular (non-equidistant) grid is in Fig. 9. The fragment of time response close to the maximum is selected, since the difference is highest in this area. The only change between results is the existence of steps for irregular grid. They are well visible for used magnification, nevertheless almost immeasurable practically. The explanation is simple, the distance between neighbouring hysteron increases two times. It corresponds to the time increment increase also two times for regular grid.

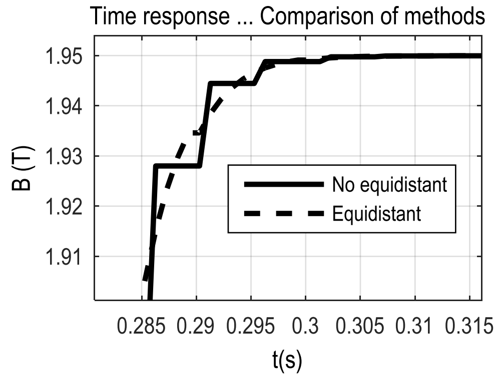

Figure 9. Comparison of time domain response from regular and irregular grid.

7 Discusion

Non-equidistant model exhibits many advantages: fast computation speed and short measuring time of the weighing function with maintaining of good resolution. The margin, when the hysteron pitch changes, is derived from the hysteresis loop width and shape. The determination of the margin level is given by the user selected model and his experience.

Although the simplest two level non-equidistant grids were used, the results are quite satisfactory. The differences with respect the fine grid are negligible. On the other hand the differences for strongly reduced equidistant grid are high.

8 Conclusion

We successfully tested modified Preisach model with non-equidistant steps in the field strength axis. This approach significantly saves computation time with maintaining small changes in the modeled flux density at steep part of the hysteresis loop. The computation algorithm of the model was not changed. The only change consists of re-computation of the weighing function with regards to the hysteron area. The computation time speeds up circa four times. The FORC measuring and data preprocessing time in the process of the weighting function obtaining was lowered circa three times.

9 Acknowledgment

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Jakub Eichler, PhD student, Technical University of Liberec, Studentska 2, 46117 Liberec 1, Czech Republic
Miroslav Novak, Assistant Professor, Technical University of Liberec, Studentska 2, 46117 Liberec 1, Czech Republic
Miloslav Kosek, Emeritus Professor, Technical University of Liberec, Studentska 2, 46117 Liberec 1, Czech Republic