APPLICATION OF PREISACH MODEL FOR MODELLING FERRITE-BASED CORES OF SENSORS

Piotr Frydrych* - Roman Szewczyk*

Paper presents adaptation of Preisach type model to modelling symmetrical hysteresis minor loops of ferrites. Proposed extended Preisach model takes into account three types of magnetisation mechanism represented by three normal distributions. Model parameters depend on magnetizing field amplitude. Model was verified for different types of ferrites. Results of modelling are confirmed by very good agreement with experimental data. R^2 coefficient calculated for model exceeds 99%.

Keywords: Preisach model, soft ferrites

1 INTRODUCTION

Common use of high permeability ferrites in electrical devices [1] demands an accurate and fast modelling, appropriate for technical application. Recently developed models [2], such as Jiles-Atherton-Sablik model [3, 4], create possibility of modelling magnetic characteristics depending on temperature, mechanical stresses as well as both amplitude and frequency of magnetizing field. The main disadvantage of Jilies-Atherton-Sablik model is requirement of complicated and time-consumming calculations.

For this reason modelling methodology based on extended Preisach model was developed. It is faster and gives sufficient accuracy for technical applications. Moreover presented model is connected with physical principles, especially with magnetisation mechanism such as wall bending, wall movement and domain rotation.

2 METODOLOY OF MEASUREMENT OF MAGNETIC CHARACTERISTICS OF SOFT FERRITES

Analyses of extended Preisach model were made on the base of experimental measurements of magnetic hysteresis loop of three types of ferrites:

- $Mn_{0.51}Zn_{0.44}Fe_{2.05}O_4$ (Mn-Zn high permeability ferrite),
- $Mn_{0.70}Zn_{0.24}Fe_{2.06}O_4$ (Mn-Zn power ferrite),
- $NiFe_2O_4$ (Ni ferrite).

Primary curves and symmetric hysteresis *B(H)* loops (up to saturation) were measured using computer controlled hysteresisgraph. Measurements were carried out in quasi-static conditions for frame-shaped ferrite cores [5]. For Ni ferrite only minor loops were recorded due to limitations of measuring range of the system.

3 PROPOSED EXTENSION OF THE PREISACH MODEL

In classical Preisach model, material is considered as a set of particles. For each particle magnetization process is described by rectangular hysteresis operator, which can assume only values –1 and +1 for characteristic switching values H_- and H_+. Distribution of switching values of particles among material is similar to normal. Under increasing field particles are switching up according to they characteristic switching values. Magnetization of sample is sum of particles magnetic moments, what leads to hysteresis curve [2]. This simplified approach doesn't take into account internal interactions or influence of temperature and stress. Preisach model also does not include any information about magnetization mechanism [6].

Presented model is developed for assumption, that different types of magnetization mechanism can be represented by normal distributions. For every type of magnetization mechanism different particles and switching values can be considered. Particles are connected to physical magnetic domains, but they cannot be identified with them. Magnetisation of sample is calculated as integrate of switching value distribution along magnetizing field**.** Actual value of flux density B is sum of previous state of material and integral of three distributions in limits from previous field value to actual field value as it is presented in equation (1).

$$B_i = \sum_{i=1} B_{i-1} + \int_{H_{i-1}}^{H_i} N\left(H_i; H_{Amp}\right) \mathrm{d}H \qquad (1)$$

Those distributions represent three types of magnetization mechanism: domain wall bending α, domain wall movement β and domain rotation γ, what is presented in equation (2).

$$N = \left(A_\alpha \mu_\alpha + A_\beta \mu_\beta + A_\gamma \mu_\gamma\right)\mu_0 + \mu_0 \qquad (2)$$

Each distribution is described by parameters m andσ, as well as A which depends on amplitude of magnetising field. Mean switching value m for each distribution is symmetrical for decreasing and increasing field. Other

* Institute of Metrology and Biomedical Engineering, Warsaw Univ. of Technology św. A. Boboli 8, 02-525 Warsaw, Poland; piotrfrydrych@gmail.com

ISSN 1335-3632 © 2010 FEI STU

parameters do not change in field direction what leads to equation (3).

$$\mu_\alpha = \frac{1}{\sigma_\alpha \sqrt{2\pi}} \exp\left(-\frac{(H_i - m_\alpha)^2}{2\sigma_\alpha^2} \right) \qquad (3)$$

4 MODELLING RESULTS

Derivative of magnetisation by magnetizing field is a distribution function. During experiment flux density B was measured, thus derivative dB/dH has constant component, which was corrected. Primary curve distribution was calculated in for such derivative. Distribution was fitted with sum of three different distributions, using μ+λ [7] optimisation strategy and gradient optimisation. Primary curve can be described by nine parameters, independent from field value. Fitted line consists of three distributions as it is presented in Fig. 1. Good agreement leads to conclusion, that magnetisation mechanism can be represented by normal distribution. Therefore magnetic moment produced by each particle in the set has the same value.

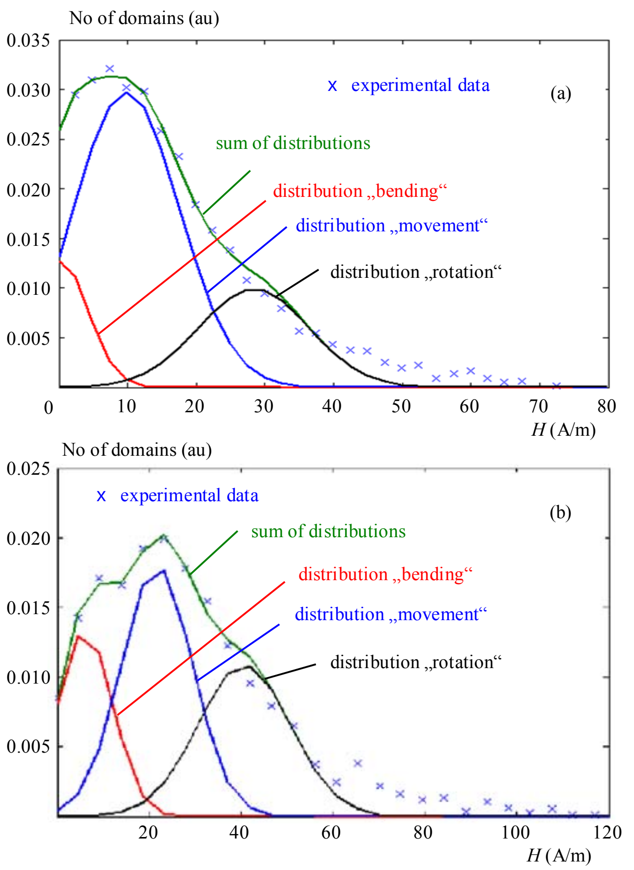

Fig.1. Distribution calculated for primary curve spit into three normal distributions connected with magnetization mechanism: (a) - for Mn-Zn high permeability ferrite, (b) - for Mn-Zn power ferrite

Model was optimised for symmetrical hysteresis loops of three kinds of ferrites for wide amplitude range. Range of model parameters values is limited by maximum magnetizing field amplitude (for m and σ) and saturation flux density (for A). Limitation of parameters shortens optimisation time and ensures that model follows physical principles.

Due to noise in input data, for three distributions many solutions are possible, and have the same conformity with experimental data. Therefore function of distribution parameters has high noise component, and there is no correlation for neighbouring points. Moreover for each field amplitude one distribution can represent one of three magnetisation mechanisms. To overcome that, optimisation was started for major loop, because of its best signal to noise ratio. Therefore evolution optimisation was carried out for wide range of parameters, large population (480 individuals) and 240 steps to find the best solution. For next loops parameters range is limited to small neighbourhood around solutions found for previous loop. Therefore resultant parameters from previous loop are input for modelling the next loop. As result there is connection between solutions for each field amplitude value. There is no problem with recognition, if the distribution describes the same magnetisation mechanism. For every amplitude value after evolution strategy, gradient optimisation was used to improve results.

Hysteresis fitting indicates that only two distributions are needed to describe reversal magnetisation process, Fig. 3, to Fig. 5. It seems that there are only two magnetisation mechanisms: domain wall movement and domain wall rotation. This conclusion was confirmed by Kerr effect observations of amorphous Ni-Fe by Zhenghong Qian [8], who called that nucleation-rotation mechanism.

Participation of magnetic harder distribution (higher absolute m value) increases with magnetizing field amplitude, what indicates that it can represent rotation mechanism. For soft ferrite and power ferrite, one distribution is close to zero or even positive. What means that for negative magnetic field magnetisation can be positive. That would have no sense for primary curve, but for hysteresis loop it is possible. Parameter σ, represents standard deviation. They increase with field amplitude, because more particles take part in magnetisation process. Only for lower amplitude, increase of σ parameter can be observed. This can be effect of small participation parameter A value. Thus multiplied other parameters have small influence on result (2). For the same reason very high values of m parameter for power ferrite for distribution 2 is observed, Fig. 4(b).

Calculated model exhibits high conformity with experimental data. Pearson coefficient exceeds for most amplitude values 99% (Tab. 1.). The modelled hysteresis curves are shown in Fig. 3 to Fig. 5.

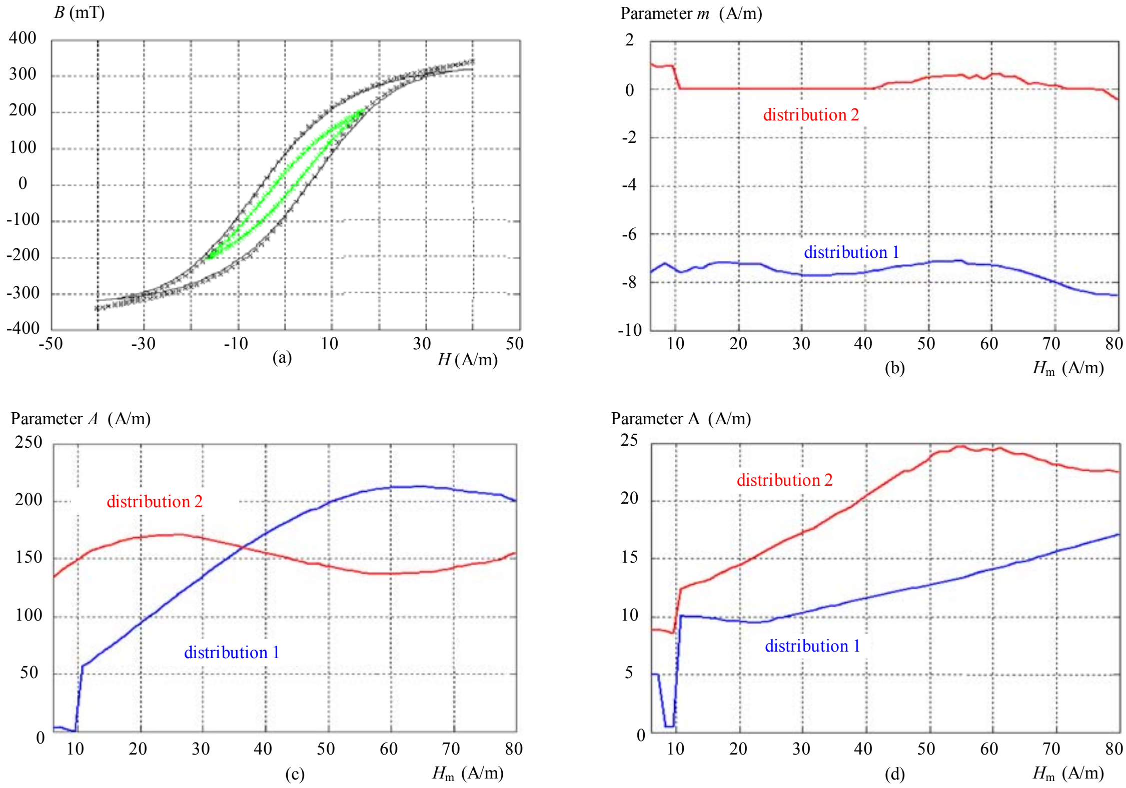

Fig. 2. Results of the modelling of characteristics of Mn-Zn high permeability ferrite: (a) - Magnetic *B(H)* hysteresis loop modelling and experimental results (x), and changes of parameters: (b) – *m*, (c) - *A* , (d) - *σ* , as functions of amplitude of magnetizing field H_m

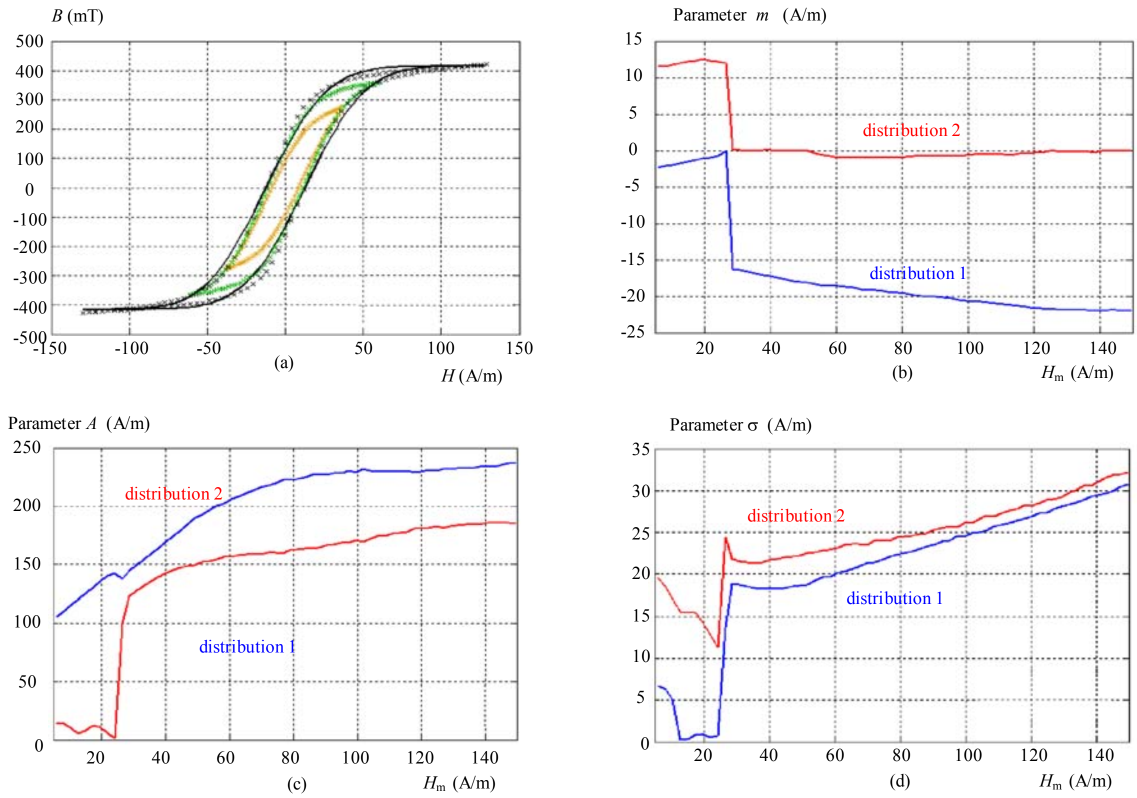

Fig. 3. Results of the modelling of characteristics of Mn-Zn high power ferrite: (a) - Magnetic *B*(*H*) hysteresis loop modelling and experimental results (x), and changes of parameters: (b) – *m*, (c) - *A* , (d) - *σ* , as functions of amplitude of magnetizing field H_m

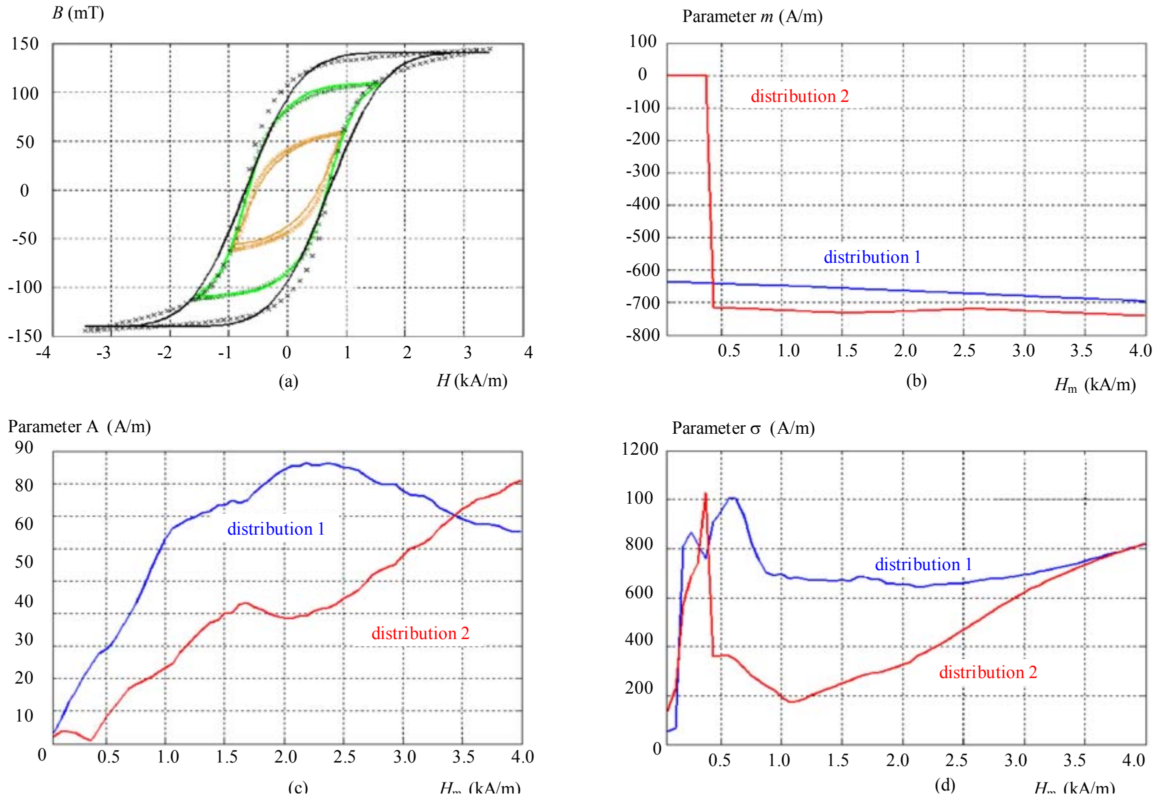

Fig. 4. Results of the modelling of characteristics of Ni ferrite: (a) - Magnetic *B*(*H*) hysteresis loop modelling and experimental results (x), and changes of parameters: (b) – *m*, (c) - *A* , (d) - *σ* , as functions of amplitude of magnetizing field H_m

Tab.1. Pearson coefficient for different types of ferrites

Mn-Zn high permeability ferrite		Mn-Zn power ferrite		Nickel ferite	
amplitude (A/m)	R^2 %	amplitude (A/m)	R^2 %	amplitude (A/m)	R^2 %
20.07	99.30	28.82	99.94	188.64	99.67
25.94	99.46	40.23	99.97	500.76	99.82
31.79	99.63	51.70	99.99	813.13	99.53
37.67	99.91	63.13	99.99	1123.23	99.87
43.52	99.95	74.50	99.99	1436.36	99.95
49.38	99.91	85.93	99.99	1748.48	99.96
55.26	99.96	97.36	99.99	2060.61	99.95
61.14	99.96	108.69	99.99	2371.72	99.96
66.97	99.96	120.11	99.99	2682.83	99.96
72.89	99.97	131.45	99.99	2997.98	99.96
78.68	99.95	143.06	99.99	3307.10	99.97

5 CONCLUSION

Assumptions considered in model are clearly related to physical principles of magnetisation process. Three distributions represent three types of magnetisation mechanism: domain wall bending, domain wall moving and domain rotation. This novelty gives new possibilities of development of extended Preisach model. Modelling results exhibit good conformity with experimental data for wide range of magnetising field amplitude and for different types of ferrites.

REFERENCES

[1] LEBOURGEOIS, R. – COILLOT, C.: Mn–Zn ferrites for magnetic sensor in space applications, J. Appl. Phys. **103** (2008) 07E510.

[2] LIORZOU F. – PHELPS, B. - ATHERTON D. L.: Macroscopic models of magnetization, IEEE Trans. Magn. 36 (2000) 418.

[3] SZEWCZYK, R. – BIEŃKOWSKI - A. - SALACH J.: Extended Jiles-Atherton model for modelling the magnetic characteristics of isotropic materials, J. Magn. Magn. Mater. 320 (2008) e1049.

[4] JILES D. C.: Introduction to Magnetic Materials. Champman&Hall, London (1998)

[5] BIEŃKOWSKI, A.: Magnetoelastic Villari effect in Mn–Zn ferrites" J. Magn. Magn. Mater. 215-216 (2000) 231.

[6] MAYERGOYZ, I.: Mathematical models of hysteresis and their applications, Elsevier (2003).

[7] SCHWEFEL H.P.: Evolution and optimum seeking, Wiley (1995)

[8] QIAN, Z. – KIEF, M. T. – GEORGE, P. K. – SIVERTSEN, J. M. – JUDY, J. H.: Kerr effect observations of magnetization reversal process in antiferromagnetically pinned permalloy thin films, J. Appl. Phys. 85 (1999) 5525-5527

Received 30 September 2010