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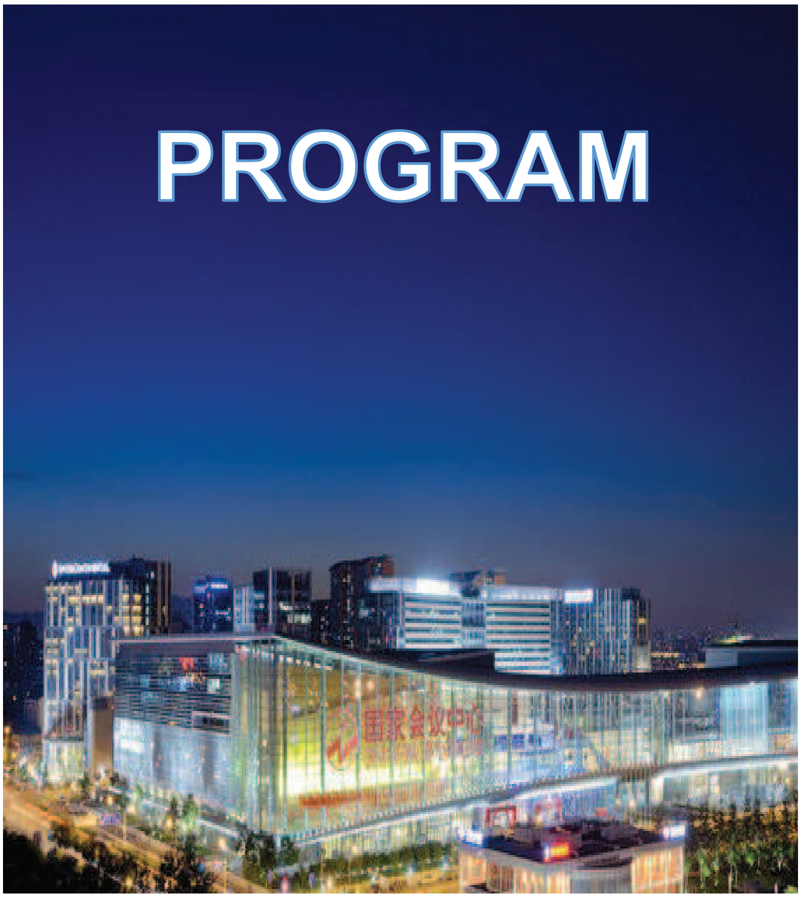

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Analysis of Different Hysteresis Models When Considering Magnetization Dynamics in Non-oriented Soft Magnetic Steel Sheet.

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Introduction

Non-oriented (NO) soft magnetic steel sheets (SMSSs) exhibit specific properties such as saturation due to material properties and dynamic hysteresis due to induced eddy currents. Modeling of magnetization dynamics, transients and iron losses in laminated structures is a complex problem, still open nowadays and of critical importance in different areas of applied research.

The quantitative description of the magnetization process in thin and long sheets neglecting edge effects can be reduced to the integration of 1-D penetration equation [1, 2]. In this paper, however, this problem is solved using the parametric magneto-dynamic (PMD) model [3, 4]. This model offers the flexibility to implement various inverse hysteresis models to analyze their ability to handle the intricate problem. The applied hysteresis model to represent the constitutive relation of the SMSS plays a central role for the resulting eddy current and flux distributions due to different magnetization trajectories in different layers of the sheet.

The aim of this work is to present a comparative analysis of most of well-known hysteresis models in combination with the PMD model for prediction of magnetization dynamics and power loss calculation under arbitrary excitation waveforms.

Parametric Magneto-Dynamic Model

The PMD model is based on the discretization of the observed SMSS into N_s equally thick slices. Based on average values and Faraday's law, induced eddy currents i_{es} inside all the slices can be calculated, which directly affect the excitation of magnetic field inside individual slices. Considering this by expressing the equilibriums of magneto-motive forces (mmfs) in all the slices of the SMSS using Ampere's law, the PMD model is expressed in form of a simple matrix differential equation (1) [3, 4]

$$\mathbf{\Theta}=Ni_p=\mathbf{H}(\mathbf{\Phi})l_m+\mathbf{L}_m[d\mathbf{\Phi}/dt]=\mathbf{R}_m\mathbf{\Phi}+\mathbf{L}_m[d\mathbf{\Phi}/dt]. \quad (1)$$

In (1) $\mathbf{\Theta}$ represents a vector of the mmfs generated by the applied current i_p in the excitation winding, $\mathbf{H}(\mathbf{\Phi})$ is a vector of average magnetic field strengths as hysteretic functions of the average magnetic fluxes in the slices and l_m is the magnetic path length. $\mathbf{N}$ is a vector with number of turns N of the excitation winding, $\mathbf{R}_m$ is a vector of nonlinear reluctances and $\mathbf{L}_m$ is the magnetic inductance matrix of the SMSS [3, 4].

The presented PMD can be both current- [using (1)] and voltage-driven, where (1) can be coupled with an external excitation circuit calculating induced voltage u_i in the excitation winding by (2)

$$u_i=\mathbf{N}^T[d\mathbf{\Phi}/dt]. \quad (2)$$

Hysteresis models

The development of hysteresis models is influenced by generally conflicting demands regarding accuracy, simplicity, and physical behavior. The major driving forces are the ability to describe the shape of the hysteresis loops and determine iron losses. Initially magnetic hysteresis loops were modeled using mathematical models, e.g. the Preisach model or the Stop-and-Play models [5]. Later on, physical based models such as the Jiles-Atherton [6] or the GRUCAD model [7] were proposed.

One of the most known and used model is the Jiles-Atherton (J-A) model [6]. This model has been largely employed due to some advantages such as relatively small number of parameters and good computational performance. Nevertheless the J-A model's popularity, there are still some issues with the identification of model's parameter and its stability [8]. Especially when modeling distorted and irregular hysteresis loops, the deviation between the modeled and measured loops is often not adequate. In the present paper, we focus in addition on an alternative description, which relies in contrast to the J-A model on the decomposition of total field strength into reversible and irreversible terms [7]. This model could be easily extended to include other energy contributions.

As an alternative transplantation type hysteresis models directly based on measured major loops or first-order reversal curves are suited for certain applications. The simplest of such models is the Tellinen (TLN) model [9], where more advanced models represent the Zirka-Moroz (Z-M) hysteresis models, which can be history-independent or history-dependent [2].

Application of individual models depends on the complexity, accuracy and other model's properties. In this paper several of the most used and well known hysteresis models are evaluated and analyzed. The inverse $[H(B)]$ formulations are used due to the straightforward implementation in the PMD model of SMSSs.

Results

Different hysteresis models were evaluated by comparing the calculated and measured major and minor dynamic hysteresis loops for NO steels under sinusoidal and distorted excitation waveforms. In this digest the results for M400-50A SMSS samples are presented, where only the TLN and the GRUCAD models are compared. In Fig. 1 the measured and calculated dynamic hysteresis for frequency f=1000 Hz and B_{max}=1.5 T are presented. In Fig. 2 the comparison of the TLN and the GRUCAD models for distorted voltage excitation is shown. The calculated results show differences when different hysteresis models are applied to the PMD model.

Conclusion

In the full paper several of widely used hysteresis models implemented in the PMD model are analyzed and discussed in detail. These models are compared in terms of identification procedure facilities, accuracy, numerical implementation and computational effort.

[1] S.E. Zirka, Y.I. Moroz, P. Marketos, A.J. Moses, D.C. Jiles, and T. Matsuo, "Generalization of the Classical Method for Calculating Dynamic Hysteresis Loops in Grain-Oriented Electrical Steels," *IEEE Trans. Magn.*, vol.44, no.9, pp.2113-2126, Sept. 2008

[2] S.E. Zirka, Y.I. Moroz, P. Marketos, and A.J. Moses, "Viscosity-based magnetodynamic model of soft magnetic materials," *IEEE Trans. Magn.*, vol.42, no.9, pp.2121-2132, Sept. 2006

[3] M. Petrun, V. Podlogar, S. Steentjes, K. Hameyer, and D. Dolinar, "A Parametric Magneto-dynamic Model of Soft Magnetic Steel Sheets," *IEEE Trans. Magn.*, to be published, Apr. 2014

[4] M. Petrun, V. Podlogar, S. Steentjes, K. Hameyer, and D. Dolinar, "Power loss calculation using the Parametric Magneto-Dynamic Model of Soft Magnetic Steel Sheets," *IEEE Trans. Magn.*, vol.50, no.11, November 2014

[5] T. Matsuo and M. Shimasaki, "Two types of isotropic vector play models and their rotational hysteresis losses," *IEEE Trans. Magn.*, vol. 44, no. 6, pp. 898–901, 2008.

[6] D. C. Jiles, D. L. Atherton, "Theory of ferromagnetic hysteresis," J. Magn. Magn. Mater., vol. 61, pp. 41-60, 1986.

[7] P. Koltermann, L. A. Righi, J. P. A. Bastos, R. Carlson, N. Sadowski, H. J. Batistela, "A modified Jiles method for hysteresis computation including minor loops", Physica B, vol. 275, pp. 233-237, 2000.

[8] Zirka, S.E.; Moroz, Yuriy I.; Harrison, Robert G.; Chwastek, Krzysztof, "On physical aspects of the Jiles-Atherton hysteresis models,"*Journal of Applied Physics*, vol.112, no.4, pp.043916,043916-7, Aug 2012

[9] J. Tellinen, "A Simple Scalar Model for Magnetic Hysteris," *IEEE Trans. Magn.*, vol.34, no.4, pp.2200-2206, Jul. 1998

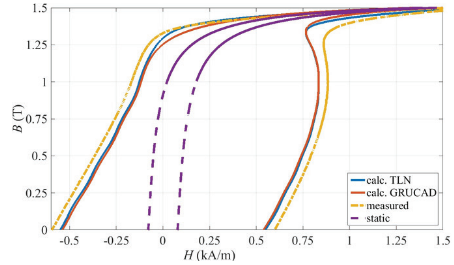

Fig.1. Calculated dynamic hysteresis due to eddy currents for sinusoidal excitation

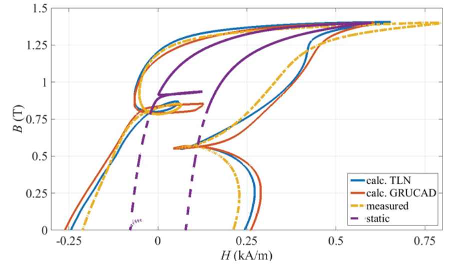

Fig. 2. Calculated dynamic hysteresis due to eddy currents for sinusoidal excitation with added 5th harmonic with a phase shift of 45°