

Improvement and Application of the Viscous-Type Frequency-Dependent Preisach Model

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Abstract—Dynamic hysteresis modeling and its application in numerical field analysis are challenging tasks. This paper presents a measurement system to realize and to measure frequency-dependent behavior of ferromagnetic hysteresis. The well-known static Preisach model of hysteresis has been extended to simulate the dynamic behavior. The full paper will present the model in detail as well as its application in the numerical field analysis of the measurement setup.

Index Terms—Magnetic hysteresis, Magnetic losses, Numerical analysis.

I. INTRODUCTION

From electrical engineering point of view, the aim of measuring hysteresis characteristics of ferromagnetic materials is to perform appropriate input data for numerical implementation and identification of hysteresis models. The realized models can be inserted into electromagnetic field simulation procedures. The electrical devices have various shapes which can be modeled efficiently by Finite Element (FEM) mesh, but the constitutive relation between the magnetic field intensity H and the magnetization M or the magnetic flux density B must be described accurately by hysteresis models. The connection between FEM procedures and hysteresis models can be realized by iterative techniques, one of them is the so-called fixed-point scheme [1], [2], [6].

The rate-independent hysteresis models, such as the original scalar Preisach model, can simulate the B - H relationship at very low frequency. It is known from experiments that the enclosed area of the hysteresis loop, which is the energy loss per cycle, is increasing rapidly by the increase of the frequency of supplied field. The energy loss is a very important technical parameter of soft magnetic materials, and it must be analyzed while developing or designing an electrical device. Rate-independent models in FEM cannot predict losses accurately at higher frequencies, however Maxwell's equations contain the term of eddy currents and their appropriate losses. These losses are smaller than the measured ones. This is the reason why frequency dependency must be taken into account in hysteresis models used in computer aided design applications [3], [4], [5].

The absent losses can be taken into consideration according to the loss separation theory [1], [3]. An extra magnetic field intensity term can be added to the one simulated by the rate-independent model. The loop area, i.e. the loss can be increased in this way. According to experiments, this extra magnetic field intensity is depending on the magnetic flux density B and its variation dB/dt . There are known techniques to describe this complicated term, $\Delta H(B, dB/dt)$ [3].

The paper presents a measurement system, containing a toroidal shape core, which can be used to measure static and dynamic scalar hysteresis loops, and a scalar Preisach model to predict these curves as well as the losses. The developed model has been inserted into a two dimensional FEM procedure to analyze the measurement system with axial symmetry. Different kind of motors will also be analyzed.

II. THE MEASUREMENT SYSTEM

The block diagram of the measurement set up can be seen in Fig. 1. The magnetic field intensity inside the analyzed toroidal shape core has been generated by the current $i(t)$ of the primary coil of the core. The primary coil has N_p turns. The arbitrary waveform of current has been built up by applying LabVIEW functions. The time variation of the magnetic field intensity results in a time varying magnetic flux $\Phi = \Phi(t)$ inside the specimen, finally the effect of this flux can be measured by the secondary coil wound on the core. The secondary coil has N_s turns which output is the induced voltage $u(t)$. The waveform of magnetic flux density can be prescribed by a simple proportional controller [2].

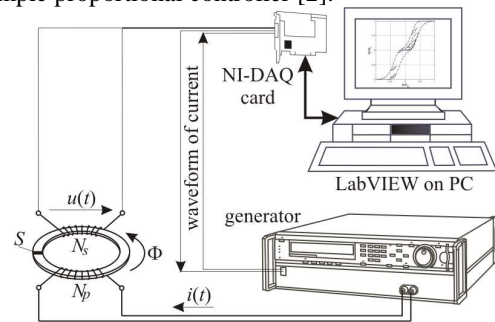


Fig. 1. The measurement system

The measured static hysteresis curves (concentric minor loops) can be seen in Fig. 2, as well as the Everett surface according to an inverse Preisach model. Different dynamic curves can be seen in Fig. 3 measured by the presented system.

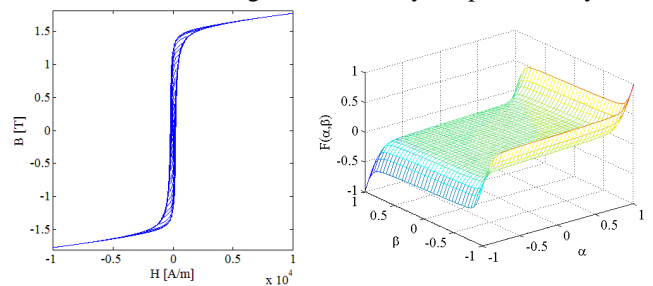


Fig. 2. Static hysteresis loops and the Everett function

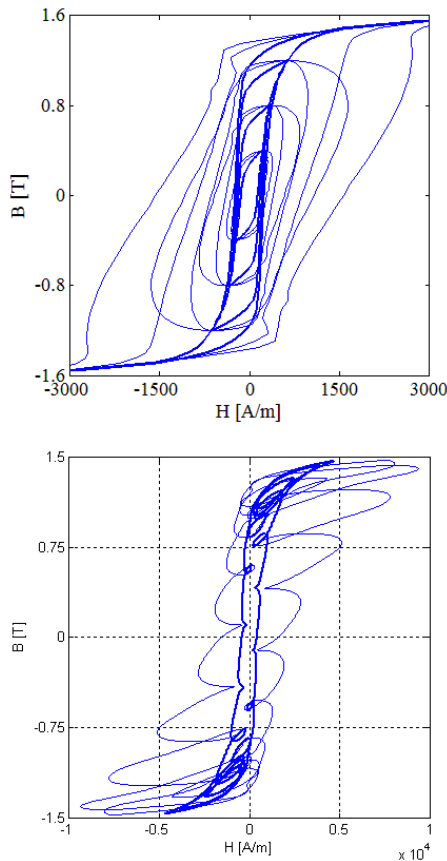


Fig. 3. Dynamic hysteresis loops

III. DYNAMIC MODEL OF HYSTERESIS

The investigated frequency-dependent scalar Preisach model is based on the theory that the total loss under sinusoidal magnetization can be decomposed into three terms, i.e.

$$W_{\text{tot}} = W_{\text{hysteresis}} + W_{\text{classical}} + W_{\text{excess}}, \quad (1)$$

where $W_{\text{hysteresis}}$, $W_{\text{classical}}$, and W_{excess} are the hysteresis loss, the classical eddy current loss, and the excess loss [1], [2], [3]. The hysteresis loss is the area of the hysteresis loop at very low frequency and it is independent of the frequency, the classical eddy current loss is generated by the eddy currents simulated by Maxwell's equations assuming perfectly homogeneous conducting material. This term is proportional to the frequency. According to the experiments, the total loss is usually larger than the sum of these two loss terms. This is why an excess loss term must be added to the sum of hysteresis loss and classical eddy current loss. The last term is proportional to the square of the frequency, and it is depending on microstructural features of the material. The measured total loss, the simulated hysteresis loss and the simulated eddy current loss, for comparison, can be seen in Fig. 4. Here, only the frequency-independent Preisach model has been used in the simulation, and the pure results can be seen on the left of Fig. 5, too. The difference between measured and simulated

data can be decreased by the use of frequency-dependent Preisach model, as it can be seen on the right of Fig. 5.

The full paper will present the developed viscous-type dynamic Preisach model in detail.

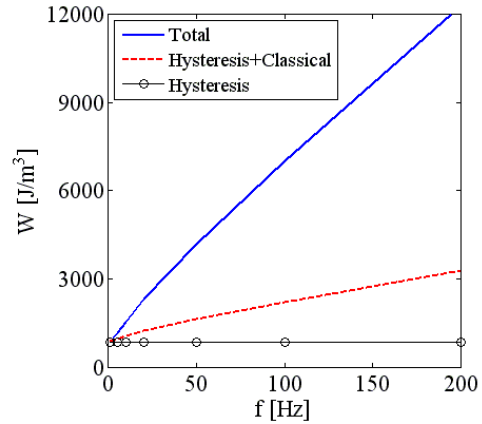


Fig. 4. Measured total losses and the simulated components

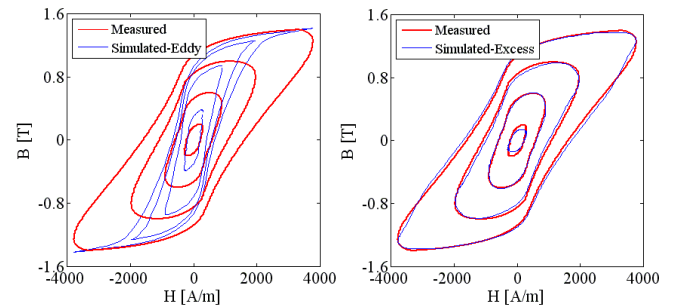


Fig. 5. Comparison of the measured concentric minor loops and the curves simulated by the static model and eddy current field component (left), and the curves simulated by the static model with the eddy current field component and the excess field component (right)

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