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## Implementation of a temperature dependent magnetic model in Simplorer using VHDL-AMS language

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**Abstract** — This paper presents a study based on the work done to create a temperature dependent magnetic model able to represent the dynamic behavior of magnetic materials. This model is developed using system simulation software (Simplorer) and hardware description language (VHDL-AMS). Simulation results are then compared to measurements done on nanocrystalline materials which are being increasingly used in modern power electronic systems.

### I. INTRODUCTION

Magnetic materials are becoming more important in the development of power electronic converters, since they constitute a major part in filters and energy storage components [1]. Hence magnetic material modeling is essential in order to predict their behavior under variable operating conditions.

The aim of this work is to develop a magnetic model, using VHDL-AMS modeling language, in which material properties, static and dynamic hysteresis laws and other variables are defined. This model is implemented in circuit simulation software (SIMPLORER) where both dynamic operating conditions and temperature can be varied to study their influence, especially since a temperature increase can lead to major changes in the component behavior [2] which is not taken into account in pre-defined software models. Thus our model can be associated with other active component models to serve a more accurate virtual prototyping of power electronic converters. Then it is validated by comparing the simulation results of a nanophy nanocrystalline material [3] to the measured ones.

### II. MAGNETIC COMPONENT MODEL

Due to the multi-domain modeling feature of VHDL-AMS [4], our model combines electrical, thermal and magnetic domains, which are related in terms of characteristic equations (simultaneous and concurrent statements) in the coded program.

For a better description, a schematic of the model is represented in Fig. 1;

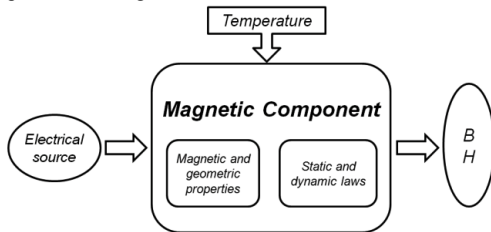


Fig. 1. Magnetic component model description.

The model is connected to an electrical and a temperature source; both static and dynamic laws are defined in addition to magnetic and geometric component properties in order to obtain the magnetic field H and flux density B as outputs.

There are different static and dynamic models that can be used to describe the hysteresis behavior of magnetic materials [2]. In this paper we use static and dynamic laws in which their choice is justified below.

#### A. Static magnetic model

Nanocrystalline materials usually have a very thin static hysteresis (coercive field about 0.5A/m). Hence the B-H curve is almost piecewise linear as shown in Fig. 2 (blue).

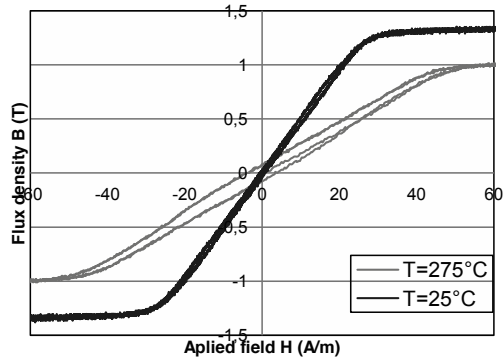


Fig. 2. Flux density as function of applied field at f=1Hz.

Based on these characteristics a piecewise polynomial of order  $n$  can be used as a static law defined by different temperature-dependent parameters. The number of these parameters, accuracy and computation time, all are directly related to  $n$ . This type of model is a purely mathematical and its application is limited to materials with low coercive field. The trace in red shows the effect of high temperature on the material's static hysteresis, where the coercive field remains relatively low even with a temperature increase till 275°C.

#### B. Dynamic Static Feedback model (DSF)

This model, developed by AMPERE laboratory [5], represents the different dynamic effects developed in the magnetic material using the first order differential equation (1), where  $H_{tot}$  is the magnetic field related to the current by Ampere's law, B is the average flux density and  $H_{stat}(B)$  is the material's static law.

$$H_{tot}(t) = H_{stat}(B(t)) + \gamma \cdot \frac{dB(t)}{dt} \quad (1)$$

This model requires only one parameter  $\gamma$  lumping eddy currents and wall motion effects, and the static magnetic model previously presented. Advantages of *DSF* are assembled in its low number of parameters, short calculation time, reversibility and ability of being time-domain simulated. The model is quite accurate in a condition that no diffusion effects are considered.

### III. RESULTS AND MODEL VALIDATION

Flux density is measured in terms of an applied sinusoidal magnetic field to observe the hysteresis loop under different temperatures (between 25°C and 275°C) for frequencies up to 10 kHz (negligible skin effects) as shown in figures Fig. 2 and Fig. 3.

Based on these measurements static and dynamic parameters had been identified [6] and implemented in the model. Evolution of these parameters as function of temperature will be discussed in the full paper.

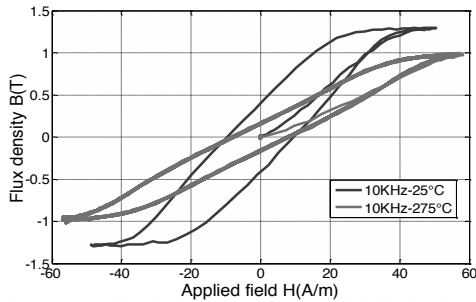


Fig. 3. Measured flux density as function of applied field at  $f=10$  kHz.

In order to validate the developed model, comparison between measured and simulated B-H curves is proposed for different temperatures and frequencies. First results are shown in Fig. 4 and Fig. 5.

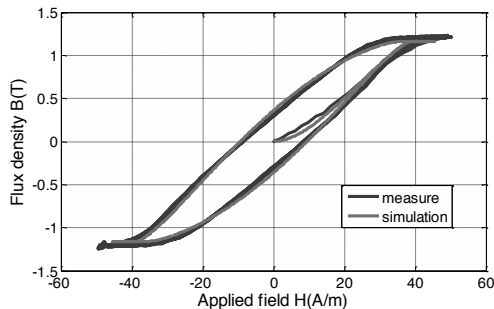


Fig. 4. Measured and simulated B-H curves at  $T=75^\circ\text{C}$  -  $f=10$  kHz.

First comparison is between measured hysteresis major loop in blue and simulated one in red at 75°C and 10 kHz (Fig. 4), while the second comparison is between minor loops at 25°C and 10 kHz using a low applied field (Fig. 5).

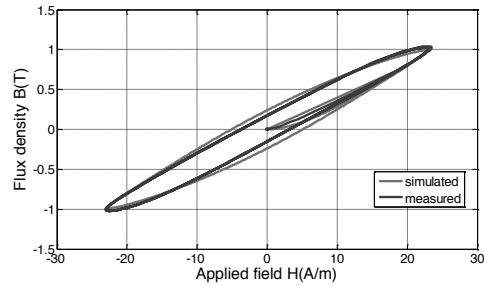


Fig. 5. Measured and simulated minor loops at  $T=25^\circ\text{C}$  -  $f=10$  kHz.

In order to monitor the effect of the temperature on the simulated model, two simulations at 25°C and 200°C are executed at the same applied field, result is shown in Fig. 6.

We can notice that for having a flux density of 0.5 T, we need an applied field of 15 A/m at 25°C, while that of 21 A/m at 200°C which means a 25% higher current that may have negative effects on the circuit.

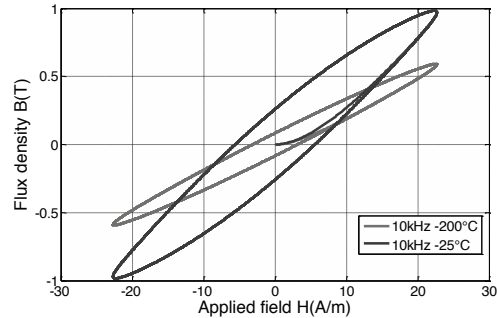


Fig. 6. Simulated minor loops at 25°C and 200°C.

### PERSPECTIVES

The results are in a good agreement under these operating conditions, more tests and analysis of the model are yet to be done with more precision.

Other complex static and dynamic laws could be added to the model to test its function for different magnetic materials and higher frequencies. Simulation of real circuit including our model will be presented in the full paper.

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