Influence of Material Dynamic Hysteresis Modelling in Losses Computation

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***Abstract* — In electromagnetic applications, hysteresis phenomena in magnetic materials are responsible of considerable causes of losses especially in transformer modelling cases. In specific case, such as current sensor, the output signal can be modified because of this loss. The paper presents the implementation proceeding used for some hysteresis material models and how they are applied in a sensor study case. A priori loss computation, simultaneously carried out with the simulation is one of the main advantages of this implementation. A transformer application is performed with the dynamic hysteresis characteristic taken into account and compared with experimental measurements.**

I. Introduction

Nowadays, electrical engineering is concerned with energy efficiency. In addition, in the case of electromagnetic devices, such as current sensors, the energy losses change the output signals; so, to approach an ideal sensor, losses have to be minimized. Thus, to improve electrical device design, loss computation has to be carried out with a maximal accuracy. Many works allow a posteriori loss estimation [1], however,"Real time" approach, meaning a priori computation is furthermore interesting as it allows more accuracy in simulation.

Generally, in such devices, the total losses come from different sources as resistances and magnetic cores. The first one, copper losses are practically calculable by resistance and current measurements. However, the last one, magnetic losses or iron losses is more complicate to identify. In soft magnetic materials, experimental results show that they can be evaluated in two terms: hysteresis static losses, and dynamic losses. By adding these two terms, we obtain the so called iron losses. The static part corresponds to the B(H) loop area in quasi-static mode, i.e. at low frequency. The dynamic one depends on the variation speed of the excitation source which is more important at high frequency.

II. Material Model with Hysteresis

A. Hysteresis model

Studies have shown that the mechanism that causes magnetization phenomena depend on many factors [2]: the material, the excitation field, the external environment, etc.

From an experimental point of view, two operating conditions can be distinguished: the quasi-static and the dynamic one. In quasi-static condition, the B(H) loop representing the material behavior does not depend on the excitation frequency.. Following the predefined criteria such as induction response and losses computation, some compatible models are identified. Among them, the chemical model [3] provides a good accuracy for soft magnetic materials by a description of two main microscopic mechanisms of the static magnetization: Bloch wall displacement and domain rotation. Furthermore, based on the balance of chemical equation analogies, this model has the advantage of a fast implementation and a quick computation. Another model, with a different approach, is called Derivative Static Hysteresis Model (DSHM). It focuses in the knowledge of memorization effect in the material during the magnetization. DSHM uses a matrix representation. Its accuracy depends only on the matrix size.

In dynamic operating conditions, the loop *B(H)* expands according to the increasing frequencies (Fig.1).

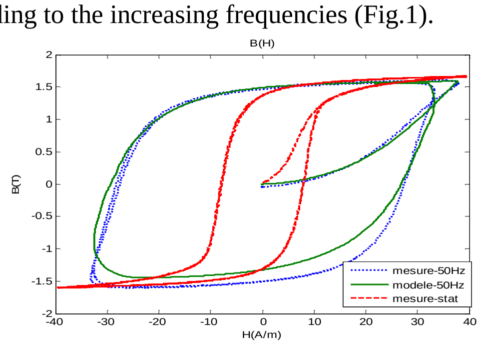

Fig. 1. B(H) loop in static mode measurement (narrow cycle) and dynamic mode by measurements (large cycle in continuous line) and by simulation (large cycle in dotted line)

The area of this loop represents the energy of the material losses during a period. This energy loss is higher in dynamic state (the area is bigger). The flux tube model using a single dynamic parameter has been studied [4] to represent the additional dynamic losses:

$$H_{exc} = \mathrm{H}_{\mathrm{stat}}(B) + \gamma \frac{dB}{dt} \quad (1)$$

with *Hexc* the excitation field, *Hstat* virtual static excitation field for a given flux density and γ a coefficient depending of the electrical and magnetic properties (resistivity, permeability, etc.) of the material.

B. Model identification on soft magnetic material

A test bench able to automate material characterization proceedings was carried out in Ampère laboratory (Lyon). The output is given in the form of *B(H)* loops.

For each sample/material, a numerous of measurements corresponding to a variation of excitation field and of frequency are realized. Optimization algorithms allow an automatic identification of models parameters.

III. ELECTROMAGNETIC DEVICE SIMULATION

Once the magnetic material model parameters have been identified, the relation between the excitation current and the flux in the magnetic circuit is established. Magnetic equation system is so obtained. By a coupling with electrical equation system, all the system is completely described.

For the coupling equation solving, some numerical techniques as Newton-Raphson are applied at each time step. A numerical ODE solver is used to give the system behavior in transient mode.

All these algorithms are implemented inside a new tool called ReluctTool [5], dedicated for the modelling of low voltage electromagnetic devices.

IV. APPLICATION AND RESULTS

A. Simulation of a current sensor

To illustrate that hysteresis causes considerable losses in electromagnetic devices, a simple current sensor is simulated. The primary coil is supplied by a pseudo-sinusoidal current source, 50Hz with a variable primary current *Ip*; the secondary coil is connected to a load, flowed by a current *Is*. The magnetic core is made of a grain oriented silicon iron (SiFe) used in industrial production that provides a good characteristic in saturation induction and magnetic losses. In the ideal case, without loss, the *Is/Ip* ratio is equivalent to *Np/Ns*, the ratio of the number of wire turns respectively in the primary and secondary. Here the ideal ratio *Is/Ip* is 0.1.

B. Result

Simulations with a chemical model have been carried out. The comparison with experimental results is taken via the secondary currents and the core losses found out, in two cases, according to the introduced primary current value (fig.2). A very good match between our model and the measures is observed. The non-ideal characteristic of the transformer that is represented by the variation of the quotient *Is/Ip* is correctly modeled. The iron losses in the magnetic core, obtained by modelling, are very close to the experimental value.

These losses contribute to the system total losses so the energy balance that is established during the simulation process, not a posteriori.

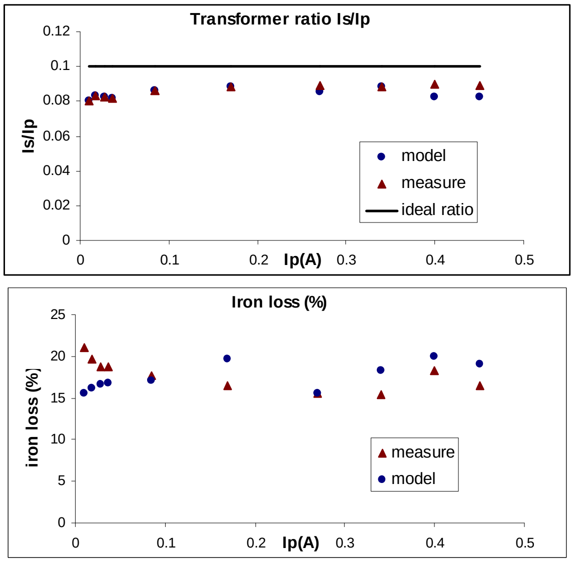

Fig. 2. Comparison of simulation and measurements results. On the top: losses make the ratio Is/Ip lower than the ideal one. On the bottom: iron losses in percentage of input coil energy.

V. CONCLUSIONS AND INCOMING WORK

Simulations with variable frequency have been carried out. They allow confirming the model performance in dynamic mode.

From these results, the same proceedings can be applied to other hysteresis models. A comparison between different models can be thus performed to aid in the choice of an adapted model according to the application needs. The authors are carrying out a material model library of soft magnetic materials, useful for designers. Additional results will be presented in the full paper.

For sensor applications, further interesting studies can be developed such as amplitude and frequency range limits research thanks to the simulation with dynamic hysteresis models. In the future, a complete electronic component library will allow simulating more complex systems.

VI. REFERENCES

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