Magnetical behaviour representation taking into account the temperature of a magnetic nanocrystalline material

T. Chailloux, M.A. Raulet, C. Martin, C. Joubert, F. Sixdenier, L. Morel
Université de Lyon, Université Lyon 1, F69622, France
CNRS UMR5005 AMPERE, 43, Bd du 11 Novembre 1918, Villeurbanne, F69622
thibaut.chailloux@univ-lyon1.fr

Abstract — The aim of this study consists in modelling the magnetic behaviour of a nanocrystalline material taking into account temperature variation. Indeed the development of power electronic embedded systems leads to increase the operating temperature range. Besides nanocrystalline material is more and more used in such systems, so temperature influence is a key point in the inductance design.

I. INTRODUCTION AND PROBLEMATIC

The increasing performance of static converters leads to more severe operating conditions. Because of self-heating due to losses or the proximity of heat sources, magnetic components are exposed to high temperatures which can decrease the performance of the magnetic material.

The aim of this work is to model the magnetic behaviour of a nanocrystalline core used in a passive common mode filter with increasing temperature and frequency. Nanocrystalline materials have been chosen for common mode filtering because of their rather high saturation induction (≈1.25T), high permeabilities, low losses and a Curie temperature much higher than the operating temperature.

II. MAGNETIC MODELS

A. *Dynamic Static Feedback model ("DSF")*

Since their marketing, more than 20 years ago, nanocrystalline materials are a great success and have given rise to many investigations into their manufacturing [1] and the relation between their structural and magnetic properties [2].

However, there are very few works about their macroscopic dynamic behaviour representation [3].

In the case of a power electrical application where skin effect in the material is insignificant, a macroscopic dynamical model (1) based on homogenised diffusion equations is used [4]. This model requires a $H_{stat}(B)$ static behaviour law and only one parameter named γ lumping eddy currents and the wall motion effects.

$$\frac{dB_m(t)}{dt} = \frac{1}{\gamma}\left[H_{dyn}(t) - H_{stat}\left(B(t)\right)\right] \qquad (1)$$

B. *Static magnetic model*

A static measure at 25°C has led to the B-H curve shown in Fig. 1.

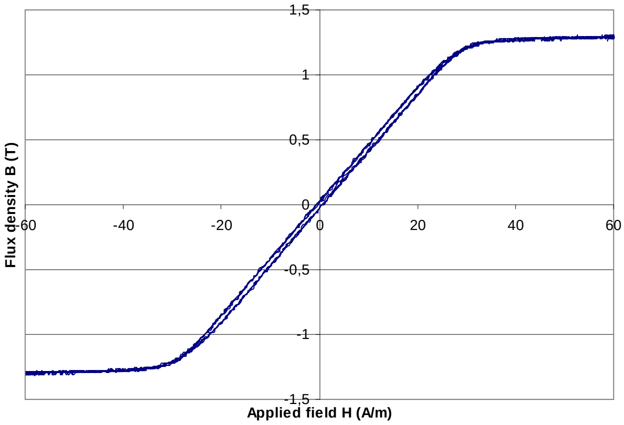

Fig. 1. Flux density as a function of applied field – T=25°C – f=1Hz

We can notice that the B-H curve is almost piecewise linear. The coercitive field is very low (approximately 0.5A/m). Given this thin static hysteresis, a simple and reversible mathematical function can be used as a static law for a first approach. This static law is defined by two parameters (named Js and Hb in this paper). In the full paper, more complex static models will be discussed. Accuracy and time computation will be two criteria to compare these models.

III. MEASUREMENTS

B-H curves have been measured for various temperatures between 25°C and 275°C and frequencies up to 10 kHz (Fig. 2, 3 and 4). For these frequencies, the skin effect is negligible. All measurements have been performed with sine excitation field.

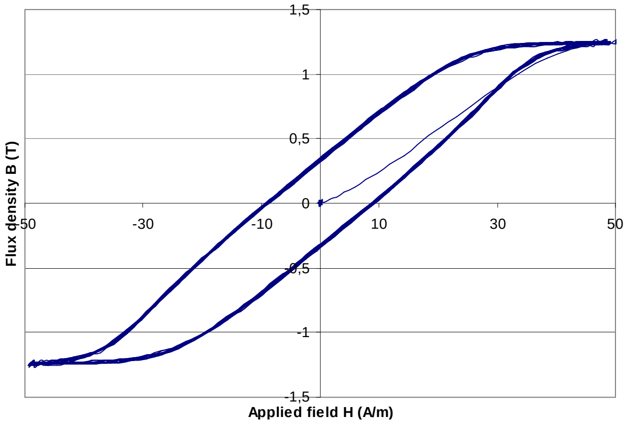

Fig. 2. Flux density as a function of applied field – T=75°C – f=10kHz

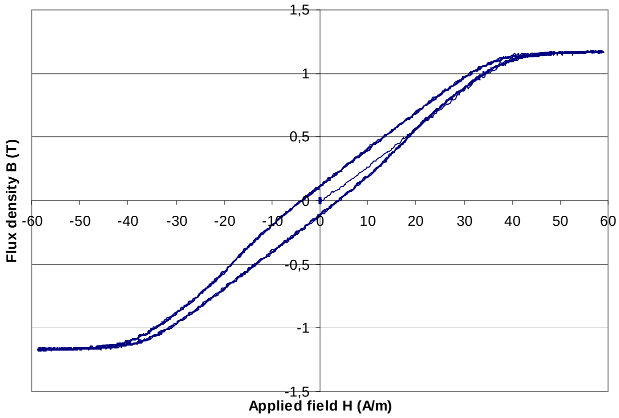

Fig. 3. Flux density as a function of applied field – T=151°C – f=1kHz

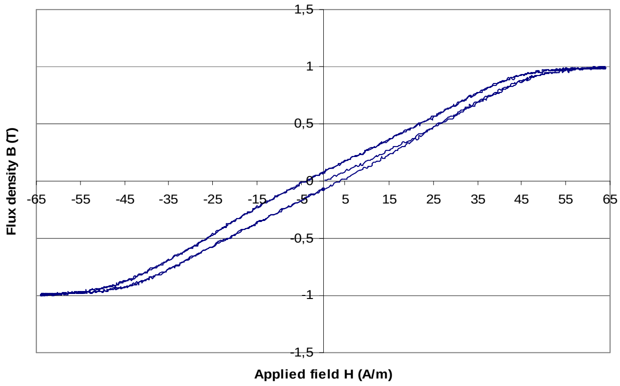

Fig. 4. Flux density as a function of applied field – T=275°C – f=1Hz

For each temperature, the parameters used for static and dynamic models have been identified (Tab. 1).

TABLE I

T (°C)	Js (T)	Hb (A/m)	γ
25	1,303	30,821	7,848E-05
49	1,294	32,436	8,073E-05
75	1,260	33,624	8,300E-05
101	1,233	35,244	8,690E-05
125	1,207	36,838	8,830E-05
150	1,179	39,296	9,120E-05
176	1,150	40,980	9,470E-05
201	1,113	44,117	9,650E-05
207	1,109	44,964	9,635E-05
215	1,096	45,132	9,750E-05
219	1,094	45,901	9,725E-05
234	1,070	46,838	1,000E-04
241	1,065	47,737	1,000E-04
253	1,038	47,929	1,022E-04
260	1,032	49,048	1,029E-04
275	1,006	49,467	1,057E-04

Thanks to these measures, the trend of evolution of the parameters has been determined, and the coefficients of the polynomial interpolation minimizing the sum-of-squares have been calculated.

IV. FIRST RESULTS AND VALIDATION OF THE MODELISATION

A. *Intermediate temperatures*

In order to check the reliability of the model and particularly the evolution of the parameters, measures at intermediate temperatures have been compared with simulation. At 135°C the measured major loop (red full line) fits rather well with the simulated one (blue dotted line) (Fig. 5).

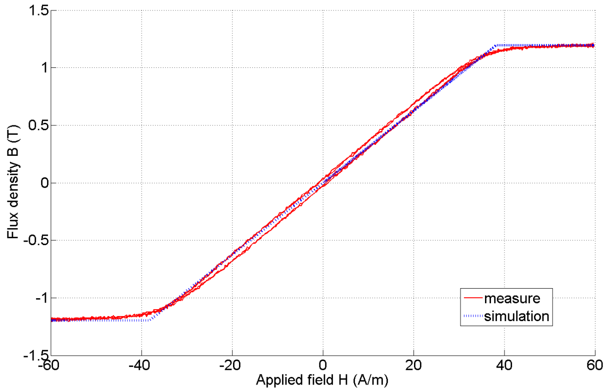

Fig. 5. Measured and simulated B-H curves – T=135°C – f=1Hz

B. *Minor loops*

Some tests with minor loops have been performed. In spite of the simple static law used, simulated curves give a realistic magnetic behaviour of the material (Fig. 6).

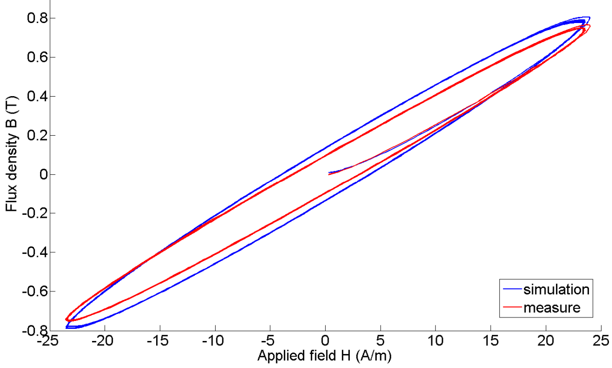

Fig. 6. Measured and simulated minor loops – T=100°C – f=10kHz

V. FUTURE PROSPECTS

In the full paper, we will show the results with more complex static models and analyze more precisely the trend of evolution of the parameters. The manuscript will also show the results for a wider temperature range and different waveforms of applied field.

VI. REFERENCES

[1] Yoshizawa Y., New Fe-based soft magnetic alloys composed of ultrafine grain structure, Journal of applied Physics, vol 64, pp 6044, 1988

[2] Herzer G., Grain size dependence of coercivity and permeability in nanocrystalline ferromagnets, IEEE Transactions on Magnetics, vol 26, 1990.

[3] Revol B., Chazal H., Roudet J., Common mode choke caracterisation method and modeling for EMI filter in Power Electronic, EPE, 2003.

[4] Raulet M., Sixdenier F., Guinand B., Morel L., Goyet R., Limits and rules of use of a dynamic flux tube model, COMPEL vol. 27, pp 256-265, 2008.