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A NEW METHOD BASED ON THE SPECTRAL ANALYSIS TO GENERATE THE FREQUENTIAL BEHAVIOR OF MAGNETIC HYSTERESIS

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Abstract—The aim of the paper is to present a simple but well applicable development, to generate the waveform of the magnetic flux density, and so the magnetic hysteresis, for any signal frequency. The proposed approach is based on the knowledge of the signal spectrum for one given frequency. It allows to construct the spectrum for any other frequency. Then, the constructed signal is transformed back to the time domain.

1. INTRODUCTION

Studying in detail the electromagnetic or electromechanical phenomena in electromagnetic devices, like electrical machines, actuators, sensors, often results in solving Maxwell's equations. The performance of electromagnetic devices may be strongly related to the behavior of the magnetic materials of which they are constructed. Therefore, the development of solution techniques of Maxwell's equations in materials with complex constitutive relations, in addition to the experimental identification of the magnetic and magneto-elastic behavior of ferromagnetic materials, become important issues.

The hysteresis is in the heart of the magnetic behavior of materials. All the applications concerning the fields of electrical engineering are strongly related to the particular aspects of magnetic hysteresis. The interest carried to hysteresis is not only due to a technological urgency but also to the need for the comprehension of the physical mechanism responsible of this phenomenon.

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The diversity of the operating conditions of the systems requires a thorough knowledge of the phenomenological aspect of hysteresis because it can guide or modify their magnetic behavior. For example, in an induction heating system, where the materials are subjected to several types of constraints such as those due to the frequency of the excitation and the temperature. In this case, the magnetic hysteresis has an impact on the losses dissipated in the considered material. Indeed, under these constraints the magnetic behavior of materials can be modified considerably and it hysteresis loop evolves according to the frequency and of the temperature.

Modeling of magnetic hysteresis can be approached from a variety of viewpoints. Most models are successful in producing realistic low frequency hysteresis loops, but differ in ability to follow material magnetization dynamically. Model parameters may be chosen to give reasonable results for single frequency sinusoidal excitations. Some models may also be tuned to give reasonable results for excitation by high speed pulses [1].

In preceding work [2], we have proposed a method allowing to identify the modified Lorentz function modeling magnetic hysteresis, from the measured loops. The major handicap of this approach and all others which are based on the parametric identification, is the recourse to the experience each time the frequency varies.

In this paper, we propose a simple method based on the spectral analysis, allowing to describe the frequential behavior of the magnetic hysteresis for an unspecified frequency without making each time the experiment. The measurements and the obtained results are specific to the studied ferromagnetic sample NO FeSi (3 wt%). It can not in no case generalized because each sample has its own frequential behavior.

2. FREQUENCY DEPENDENT HYSTERESIS

Frequency-dependent hysteresis modeling is often developed via generalization of an existing static hysteresis model. For instance, Bertotti [3] generalized the Preisach model by adding dynamic behavior to each elementary loop to synthesize the finite switching rate between magnetization polarities. This model was experimentally verified for soft ferromagnetic materials in [4], and was subsequently applied to computer aided design in [5]. At the macroscopic level, rate-dependent hysteresis is taken into account by adding a second order differential equation [6] or a second-order low-pass filter [7] to the static magnetization. This approach has been generalized in the paper to obtain a dynamic hysteresis model accurate over the practical range of magnetization frequency and amplitude for MnZn power ferrites used in power electronics [8].

The frequency has as effect to inflate the hysteresis loop and consequently to increase the coercitive field. The hysteresis losses are proportional to the surface of the cycle. So, the increase in the frequency results in a greater heating of the magnetic parts. The control of the variation of the hysteresis loop according to the frequency becomes primordial. The following figure show the frequency dependent hysteresis for NO Fe Si (3 wt%) [2, 9].

3. BASIC IDEA AND SIMULATION RESULTS

Let's consider a ferromagnetic material excited by a field H of frequency f. The application of the Fourier discrete transform (FFT) to the magnetic induction allows the passage from the time domain to the frequency domain.

For a signal X of N samples, the Fourier discrete transform (FFT) and its inverse transform (FFTI) are given by the following relations:

$$X(k) = \sum\nolimits_{n=1}^{N} x(n) e^{-j2\pi(k-1)\left(\frac{n-1}{N}\right)} \quad 1 \leq k \leq N \tag{1}$$

$$x(n) = \sum\nolimits_{k=1}^{N} X(k) e^{-j2\pi(k-1)\left(\frac{n-1}{N}\right)} \quad 1 \leq n \leq N \tag{2}$$

The Fig. 2 and Fig. 3 show, respectively, the magnetic induction B and its spectrum for two frequencies $f_1 = 50\,\text{Hz}$ and $f_2 = 200\,\text{Hz}$. According to these figures one can notice:

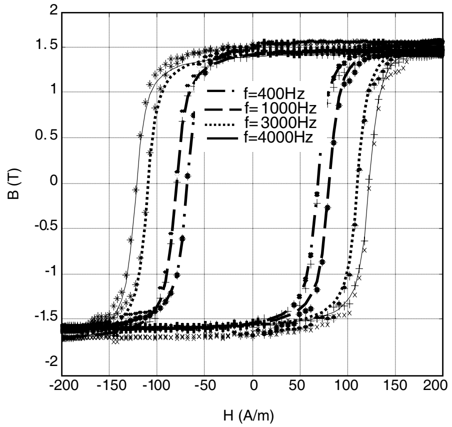
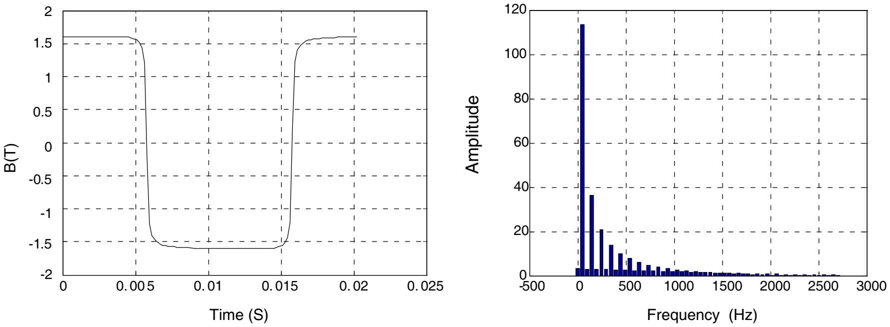
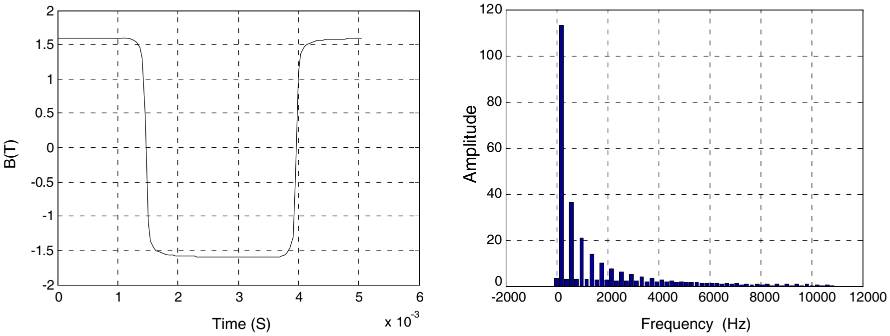


Figure 1. Frequential effect on the magnetic hysteresis for NO Fe Si (3 wt%).



(a) (b)

Figure 2. (a) The magnetic induction for a frequency $f_1 = 50\,\text{Hz}$. (b) The spectrum of the magnetic induction for a frequency $f_1 = 50\,\text{Hz}$.



(a) (b)

Figure 3. (a) The magnetic induction for a frequency $f_2 = 200\,\text{Hz}$. (b) The spectrum of the magnetic induction for a frequency $f_1 = 200\,\text{Hz}$.

- The most significant harmonic is that of the same frequency than the excitation field (the fundamental);
- According to both Figs. 1 and 2, we notice that most significant harmonics are characterized by a multiple of the excitation frequency. For example, harmonic 2 of frequency $2f$ has a magnitude 3.13 for the excitation frequency of 50 Hz and 3.11 for the frequency 200 Hz.

Table 1 gives the amplitudes of the harmonics for two different frequencies of the excitation signal.

This result is very interesting because it enables us to reconstruct the wave form of the magnetic induction for a frequency of excitation

Table 1. The amplitudes of the four first harmonics for two frequencies $f_1 = 50\,\text{Hz}$ and $f_2 = 200\,\text{Hz}$.

Harmonics \ Signal excitation frequency	$f_1 = 50\,\text{Hz}$	$f_2 = 200\,\text{Hz}$
Fundamental	113.38	113.11
$2f$	3.13	3.11
$3f$	36.40	36.19
$4f$	3	2.99

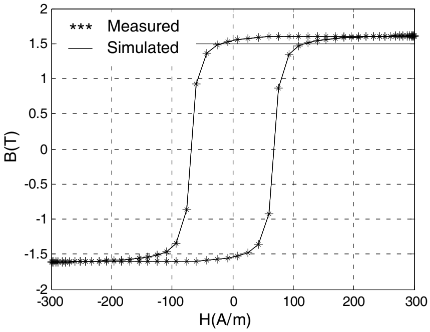


Figure 4. Hysteresis loop for a frequency 400 Hz.

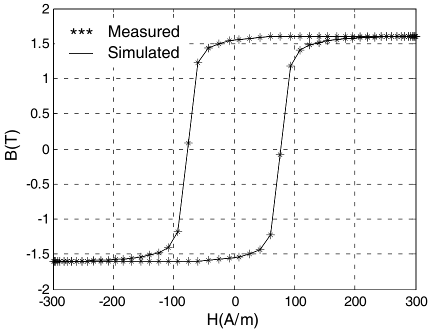


Figure 5. Hysteresis loop for a frequency 800 Hz.

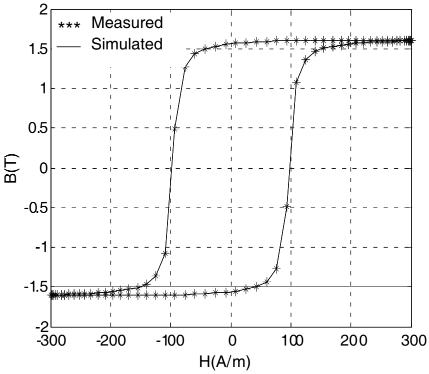


Figure 6. Hysteresis loop for a frequency 2000 Hz.

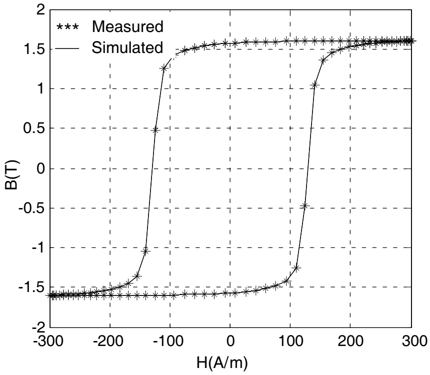


Figure 7. Hysteresis loop for a frequency 4500 Hz.

f_2 starting from the knowledge of its spectrum for a frequency f_1. This will enable us to avoid renewing the experiment and acquiring variable frequencies excitation sources.

Our idea is to make an analysis by the fast Fourier transform (FFT) the magnetic induction B due to a magnetic Field H for a frequency f_1 taken as reference.

Let A_1, $A_2 \ldots A_{N-1}$ be the amplitudes of the harmonics for the frequencies f_1, $2f_1$, $3f_1 \ldots (N-1)f_1$.

If one wants to trace the hysteresis loop for a new frequency f_2, it is enough to construct the wave form of the magnetic induction for this new frequency from the knowledge of its spectrum for the frequency f_1. With this intention, one transforms back, with inverse Fourier transform (FFTI), the spectrum built by the harmonics f_2, $2f_2$, $3F_2 \ldots, (N-1)f_2$, of amplitudes, respectively, A_1, $A_2 \ldots A_{N-1}$.

The Figures 4, 5, 6 and 7 show the reconstructed magnetic induction as well as the corresponding hysteresis loops for different values of the frequency. The reference frequency is 50 Hz.

These results show that there is a good agreement between the measured and the reconstructed cycles.

4. CONCLUSION

The paper presents a new method based on the spectral analysis and allowing to generate the hysteresis loop of a ferromagnetic material for any unspecified frequency without making additional experiments. Starting from the knowledge of the spectrum of the magnetic induction for a frequency f_1 taken as reference, we can construct its wave form for another frequency f_2. Simulation results show the feasibility of our approach.

REFERENCES

1. Carpenter and H. Kenneth, "A comparison of magnetic hysteresis models under high frequency excitation," *American Physical Society, Annual March Meeting*, Mar. 17–21, 1997.
2. Nouicer, A., M. E. H. Latreche, M. Feliach, R. Méhasni, and M. Boubia, "Identification of the parameters of the modified Lorentz function modelling hysteresis cycle," *International Journal of Applied Electromagnetics and Mechanics*, Vol. 25, 165–171, 2007.
3. Bertotti, G., "Dynamic generalization of the scalar Preisach model of hysteresis," *IEEE Trans. Magn.*, Vol. 28, 2599–2601, Sep. 1992.

4. Bertotti, G., F. Fiorillo, and M. Pasquale, "Measurement and prediction of dynamic loop shapes and power losses in soft magnetic materials," *IEEE Trans. Magn.*, Vol. 29, 13–16, Nov. 1993.
5. Fuzi, J. and A. Ivanyi, "Features of two rate-dependent hysteresis models," *Physica B*, Vol. 306, 137–142, 2001.
6. Jiles, D. C., "Frequency dependence of hysteresis curves in non-conducting magnetic materials," *IEEE Trans. Magn.,* Vol. 29, 3490–3492, Nov. 1993.
7. Hsu, J. T. and K. D. T. Ngo, "A Hammerstein-based dynamic model for hysteresis phenomenon," *IEEE Trans. Power Electron.*, Vol. 2, 406–413, May 1997.
8. Nakmahachalasint, P., K. D. T. Ngo, and L. Vu-Quoc, "A behavioral model for frequency-dependent hysteresis in power ferrites," *IEEE Trans. on Magn.*, Vol. 40, No. 4, 1784–1790, Jul. 2004.
9. Nouicer, A. and M. E. H. Latreche, "A neural network model of magnetic hysteresis taking into account the influence of the frequency and the temperature," *1st International Conference on Manufacturing Engineering, ICMEN*, Sani, Halkidiki, Greece, Oct. 2002.