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THE INFLUENCE OF THE FREQUENCY AND WAVEFORM ON THE HYSTERESIS LOOP OF SOME NiZnCu FERRITES

M. Fecioru-Morariu*, A. Paduraru, O. Caltun

„Al. I. Cuza“ University, Faculty of Physics, 11 Bd. Carol I, 700506, Iasi, Romania

The magnetic properties and consequently, the hysteresis loops of the ferrites are influenced by the microstructure of the samples and by the frequency and waveform of the magnetization field. In this paper the hysteresis loop of the NiZnCu ferrite samples was experimentally measured in different conditions as frequency and waveform, using an original hysteresisgraph realized by us. Sinus and triangular waveform of the magnetic field were applied in the frequency range 1 – 50 kHz. The hysteresis loop softly changes in shape in this domain of the frequency. The Jiles – Atherton model was used to calculate the hysteresis loops obtained at different frequency and different waveform. A good agreement between the experimental and calculated hysteresis loop was observed. Also, we have discussed the dependence of the parameters of the Jiles – Atherton model on frequency and on the magnetic field waveforms.

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1. Introduction

The magnetization curves, and hysteresis loops of ferromagnetic materials change as a function of the frequency of the applied magnetic field and of the waveform of the applied magnetic field. Many measurements of the magnetic hysteresis were performed under dc, or quasi dc, conditions, but in most applications the magnetic materials are subjected to an ac field and is very important to see how the magnetic properties are changing under these conditions. The differences between the dc and ac magnetic hysteresis curves depend on a number of factors including the electrical conductivity and permeability of the material, the rate at which the magnetic moments can rotate into the field, the frequency of the applied magnetic field strength and its waveform, whether sinusoidal, or triangular wave [1]. In an earlier paper we have studied the structure and magnetic properties of Ni-Zn-Cu ferrites sintered at various temperatures [2].

In this paper we study the dependence of the experimental magnetic hysteresis loops on the frequency and the waveform of the applied magnetic field. Also, we use the Jiles-Atherton model to simulate the magnetic hysteresis loop at different frequency of the applied magnetic field in order to see how the parameters of the model are changing.

2. Experimental device and measurement

In order to measure the dependences of magnetic hysteresis loops and magnetic properties of some ferrites under the ac conditions, we have realized a measurement system (hysteresisgraph), which contain the probe, toroidal in shape, the wave generator with sinusoidal and triangular waveform, a power amplifier, an oscilloscope. The entire system is connected to a PC [2,3], (see Fig. 1). The measuring system can plot the hysteresis curves and calculate the initial permeability, the

* Corresponding author: mfecioru@stoner.phys.uaic.ro

saturation and remanence magnetization, the coercive field strength, the hysteresis losses and power losses of soft magnetic materials.

The magnetic quantities can be determined either directly via sensor (Hall probe for field strength meters, measuring coils for flux meter) or indirectly by current and voltage measurements. The magnetic flux is excited by a frequency-variable voltage applied to the primary winding part of a RL circuit [4]. The induced voltage is measured on the secondary winding, and the magnetic flux density can be determined. Sinus and triangular waveform of the magnetic field were applied in the frequency range 1 – 50 kHz.

The measured hysteresis curve serves as a basis for the determination of the parameters of the Jiles - Atherton model.

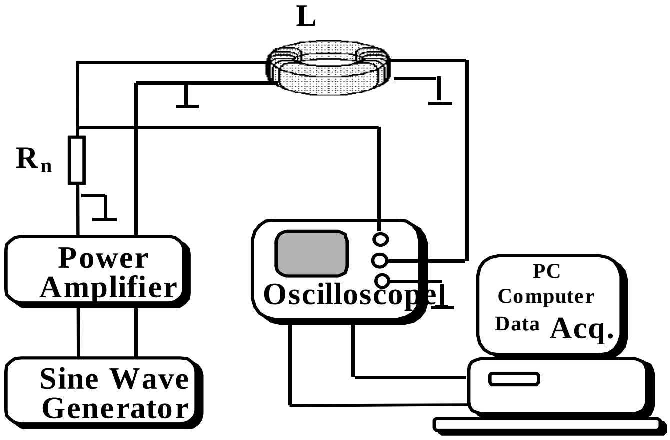


Fig.1. Measurement system for magnetic characterization of soft magnetic materials.

Using the previous presented measurement system, we have measured the magnetic hysteresis loops of NiZnCu ferrite for different values of frequency of applied magnetic field.

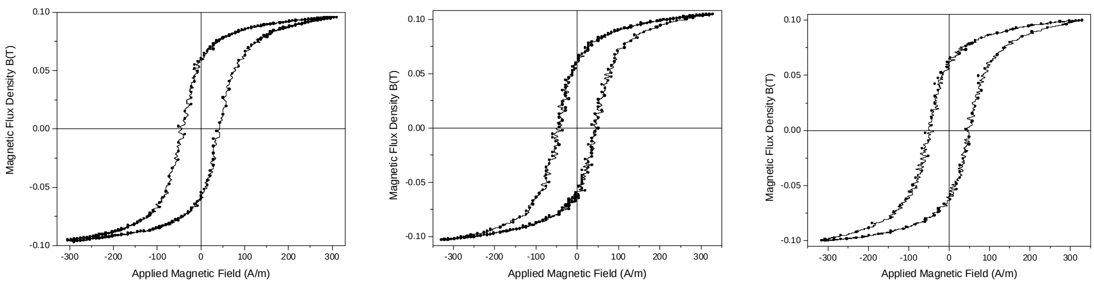
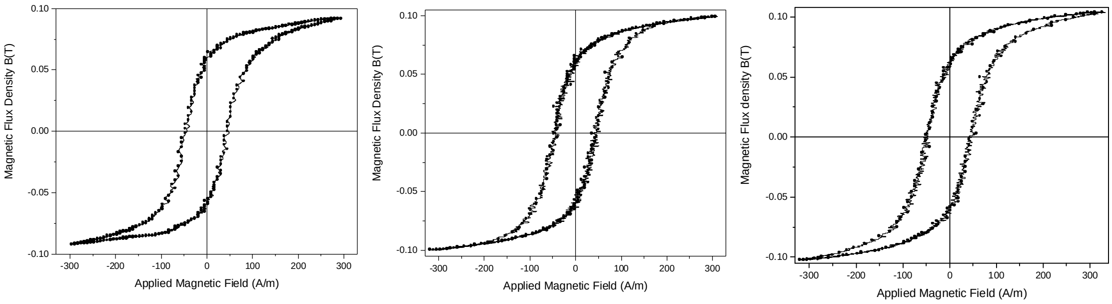


Fig. 2. Magnetic hysteresis loops for three different values of frequency of applied sinusoidal magnetic field: (a)-500 Hz, (b)-10 kHz (c)-30 kHz.

In Fig. 2 we can observe that, when frequency of the applied magnetic field increase, the form of the hysteresis loop softly change and also the magnetic coercivity field, the remanence magnetic flux density and the hysteresis loss softly increases.

The magnetization curves and the magnetic properties of soft magnetic materials change, also, as a function of the waveform of the applied magnetic field. We have studied the dependence of the frequency of the applied magnetic field when we have used the triangular waveform for applied magnetic field (see Fig. 3).



a b c

Fig. 3. Magnetic hysteresis loops for three different values of frequency of applied triangular magnetic field: (a)-500 Hz, (b)-10 kHz (c)-30 kHz.

In Fig. 3, we can also see that, when the frequency of the applied magnetic field increases, the shape of the hysteresis loop softly changes and also the magnetic coercivity field, the remanence magnetic flux density and the hysteresis loss softly increase.

From Fig. 2 and Fig. 3, which showed the hysteresis loops at the same frequencies but under sinusoidal and triangular waveform of the applied magnetic field we could study the dependence of the magnetic properties on the waveform. Therefore, we can see that the shape of the hysteresis loops doesn't change significantly with the waveform, but the coercivity field and remanence magnetic flux density are slowly increasing for triangular waveform comparative to sinusoidal waveform. We present, in Table 1, the change of the magnetic properties with frequency and with waveform of the magnetic applied field.

Table 1. Dependences of the magnetic properties with frequency and with waveform of the applied magnetic field.

	Sinusoidal Waveform		Triangular Waveform	
Frequency (kHz)	Hc (A/m)	Br (mT)	Hc (A/m)	Br (mT)
0.5	44	58.5	46	59.2
10	46.3	59.7	48	60.3
30	48.5	61.2	50.2	61.6

The rate of the change of the applied magnetic field under triangle waveform is greater comparison with the rate of the change under sinusoidal waveform. Therefore, the rate of response of the magnetization in external field under triangular waveform is greater comparison with the rate of response of the magnetization in external field under sinusoidal waveform. This can be an explication for greater values of coercivity field and remanence under triangular waveform comparison with sinusoidal waveform.

3. Jiles-Atherton model for non-conducting media

In non-conducting media, we assume that the effects of the eddy currents can be ignored. In this work, the time dependence of the magnetization is treated as a second order linear differential equation, in which the equilibrium position of the magnetization at a field strength H, is simply the dc hysteresis curve.

The differential equation of the Jiles-Atherton model for non-conducting magnetic materials, which describe the dependence of the magnetization by the time [1], is:

$$\frac{d^2}{dt^2}M(t)+2\lambda\frac{d}{dt}M(t)+\omega_n^2 M(t)=\omega_n^2 M_\infty(H) \tag{1}$$

where ω_n is the natural frequency, which can be calculated from ferromagnetic resonance, λ is a decay constant and $M_\infty(H)$ is uniquely defined by the magnetic field history of the specimen and is obtained by calculating the value of the bulk magnetization that would be achieved when all transients in the magnetization process have been completed. This means that $M_\infty(H)$ is represented by the value of bulk magnetization on the quasi-dc hysteresis loop [4][5]. The natural frequency ω_n represents the frequency at which the magnetic moments inside the material can oscillate in the absence of any external damping forces. The damping coefficient λ in this equation is also equivalent to that defined in Landau-Lifschitz equation of motion. The relation between the resonant frequency ω_r of domain wall motion and the initial permeability of the hysteresis curves is given by the Eq. (2):

$$\omega_r = \gamma\frac{M_s}{\mu_i - 1}\left(\frac{8\pi(\mu_i - 1)}{d}\delta\right)^{1/2} \tag{2}$$

where γ is the gyromagnetic ratio (0.22×10^6 rad×m×s^{-1}×A^{-1}), μ_i is the relative initial permeability, which is dimensionless ($\mu_i - 1 = \chi_i$ the initial susceptibility), M_s is the saturation magnetization, δ is the wall thickness and *d* denotes the average domain size.

The resonance frequency ω_r and the natural frequency ω_n are related by the Eq. (3)[6]:

$$\omega_r = \omega_n\sqrt{1-\left(\frac{\lambda}{\lambda_{cr}}\right)^2} \tag{3}$$

where λ_{cr} is the critical value of λ, which is the value of λ separating conditions under which wall resonance, rather than wall relaxation, occur. This enables the natural frequency of the material to be determined from the initial susceptibility and the damping coefficient λ in the differential equation (1). The damping parameter λ determines the rate of response of the magnetization to an external field, and from the equation this can be expressed in terms of an equivalent relaxation time $\tau = 1/\lambda$.

4. Results

We have simulated the hysteresis loops, for some NiZnCu ferrites with Jiles-Atherton model, for non-conducting media, at different values of frequency of the applied magnetic field and under sinusoidal and triangular waveform. We present, in Fig. 4, a comparison between the experimental hysteresis loops measured under sinusoidal and triangular waveform and simulated hysteresis loops with Jiles-Atherton model, at two different values of frequency of magnetic applied field: 1 kHz and 20 kHz.

From Fig. 4 we can see that there is a good agreement between the experimental and calculated hysteresis loop for sinusoidal and triangular waveform at both frequencies of the applied magnetic field. Also, we can observe that the model predict the increase of coercivity field and remanence magnetic flux density at higher frequency and under triangular waveform comparative with sinusoidal waveform.

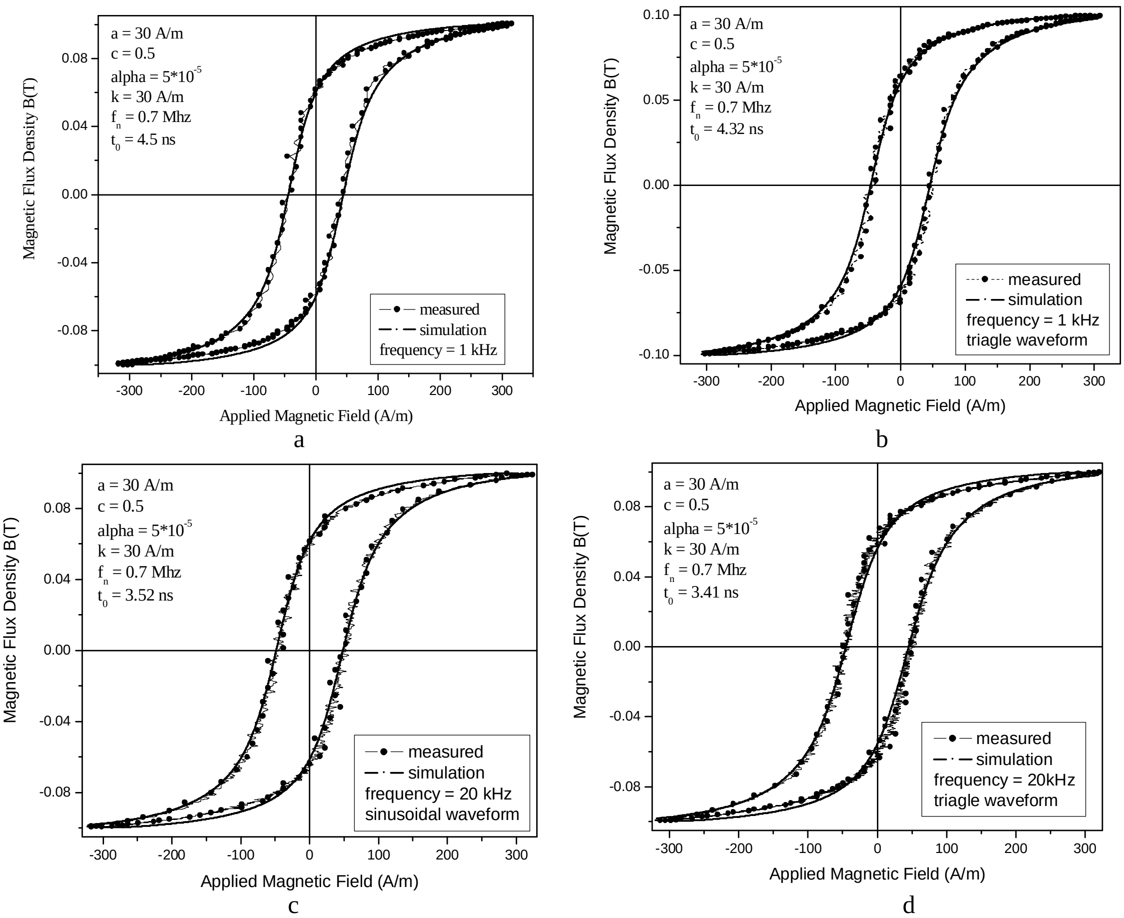


Fig. 4. Magnetic hysteresis loops measured and simulated with Jiles-Atherton model under sinusoidal (a, c) and triangular waveform (b, d) at 1 kHz (a, b) and 20 kHz (c, d).

The Jiles-Atherton model parameters which was used in simulations from Fig. 4 are shown, and we can observe that the a, c, α, k and ω_n model parameters has a constant values for the same probe at different values of frequency of applied magnetic field under sinusoidal and triangular waveform. The damping parameter λ, which determines the rate of response of the magnetization to an external field and which is equivalent to an relaxation time, depend on the frequency of the applied magnetic field and the waveform. The values of the λ parameter increase at higher frequency of applied magnetic field and also the values of the λ parameter increase when we have used the triangular waveform comparative with the sinusoidal waveform.

5. Conclusions

In this work we have studied the experimental and simulated dependences of the magnetic hysteresis loops by the frequency of the applied magnetic field and the waveform. We have measured the magnetic hysteresis loops at different frequency and it can be seen that there is an increase in coercivity, remanence magnetic flux density and hysteresis loss with increasing frequency. The influence of waveform on the magnetic hysteresis loops is an increase in coercivity, remanence and hysteresis loss under triangular waveform comparative with sinusoidal waveform.

The Jiles-Atherton model was used to calculate the hysteresis loops at different frequency, under triangular waveform and sinusoidal waveform. A good agreement between the experimental and calculated hysteresis loop was observed.

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