A "BURST" SYSTEM FOR THE STUDY OF ISOTHERMAL MAGNETIC HYSTERESIS LOOPS OF SOFT FERRIMAGNETIC MATERIALS

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ABSTRACT

A simple apparatus for the study of magnetic hysteresis loops of soft ferrimagnetic materials is presented. This apparatus can be operated in a "burst" mode that allows heat dissipation by applying the exciting signal only during a fraction of the total period. Some typical experimental results as obtained by means of this apparatus are compared with those obtained by the normal mode, on Ni-Zn ferrites.

RESUMEN

Presentamos un dispositivo simple para el estudio de ciclos de histéresis magnética en materiales ferrimagnéticos suaves. Este dispositivo puede operarse en modo de "ráfagas", lo que permite la disipación de calor mediante la aplicación de la señal de excitación durante una fracción del período total. Se comparan algunos resultados típicos con el modo normal, obtenidos con ferritas Ni-Zn.

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INTRODUCTION

The magnetic hysteresis loop is one of the most fundamental expressions of magnetic ordering. In the case of soft magnetic materials, hysteresis loops can easily be obtained on an oscilloscope by means of a simple electronic circuit. The magnetic sample, in a toroidal shape is used as a core transformer. The external field is applied by an ac current in the primary coil, see Fig. 1. The applied field leads to flux variations within the sample that are detected as an ac voltage in the secondary coil, as a result of the electromagnetic induction law. This signal can then be integrated and received in the Y-axis of an oscilloscope. A series resistor in the primary coil is used in order to obtain a signal that is proportional to the current and hence to the applied field. This voltage is applied to the X-axis of the oscilloscope and the B vs. H relationship can then be observed at the oscilloscope screen. The modules are a signal generator and a power amplifier to generate the applied field; as the secondary voltage is generally low, it is convenient a voltage amplifier before the integrating circuit. The general arrangement we have just described can also be used[1] to measure the initial magnetic permeability as a function of temperature. This property has shown[2] to be very useful for the determination of the Curie temperature. In order to measure initial permeability, the applied field (and hence the primary current) must be very small to remain within the reversible range of the magnetization (i.e., no hysteresis). The secondary voltage is then[1] proportional to the magnetic permeability. In the present case, a high primary current is needed to attain the irreversible magnetization range, and the secondary voltage must be integrated to obtain the magnetic induction of the sample.

A simple calculation leads to the expressions that allow a direct measurement of the loop. For the X-axis, we have

$$H = \frac{n_p i_p}{2r_m} \quad , \tag{1}$$

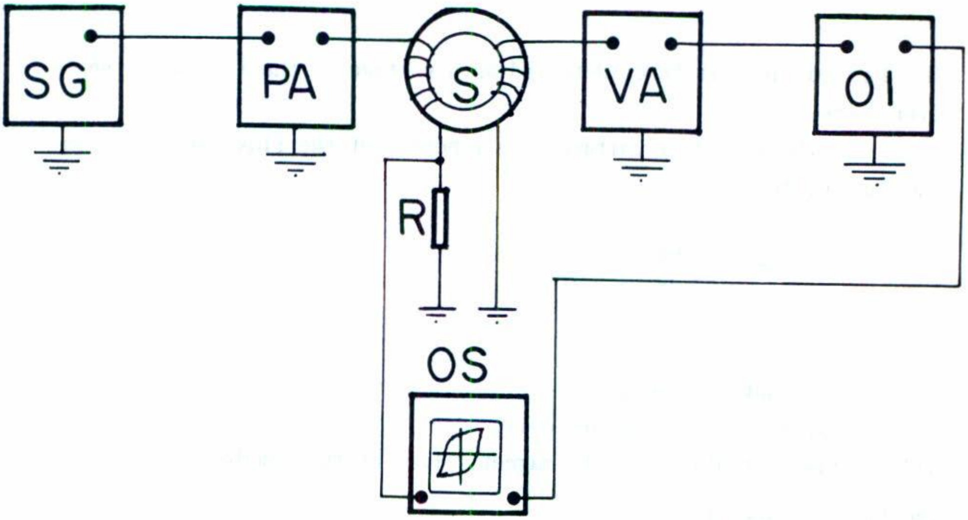

Fig. 1 Layout of the modules for the measurement of magnetic hysteresis loops. SG-signal generator, PA-power amplifier, S-sample, Va-voltage amplifier, OI-operational integrator, OS-oscilloscope, R-series resistor.

where:

H - applied field,

n_p - turns in the primary coil,

i_p - electric current in the primary coil,

r_m - mean radius of the toroidal sample.

As

$$i_p = V_p / R_p \quad , \tag{2}$$

with:

V_p - voltage drop across the series resistor,

R_p - series resistor,

and by using the inner and outer diameters of the sample, we obtain

$$H = \frac{n_p}{R_p(D+d)} V_p \quad . \tag{3}$$

The applied field is hence detected as a voltage in the X-axis of the oscilloscope.

The secondary voltage is a function of the flux variations in the sample, this is

$$V_s = -n_s \frac{d\phi}{dt} \quad , \tag{4}$$

where:

V_s - secondary voltage,

n_s - turns in the secondary coil,

$d\phi/dt$ - time variations of the magnetic flux of the sample.

The flux is given by

$$d\phi = BdA \quad , \tag{5}$$

with:

B - magnetic induction,

dA - differential area.

As dA = ydr (see Fig. 2), then

$$d\phi = bydr \quad , \tag{6}$$

with:

y - sample thickness.

We can hence write

$$V_s dt = -n_s Bydr \quad . \tag{7}$$

This equation can be integrated by assuming that B is uniform within the sample, which is a good approximation[3]:

$$B = -\frac{V_s dt}{n_s y(R_o - r_o)} \quad . \tag{8}$$

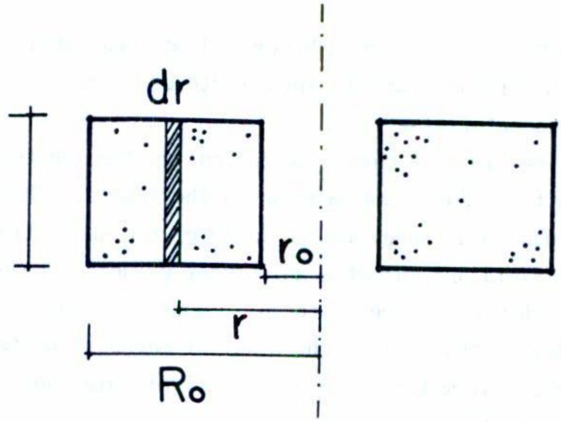

Fig. 2 Toroidal sample. r_o inner radius, R_o outer radius, y thickness, dr differential radius.

The integrating circuit gives

$$V_i = \frac{1}{RC} V_s dt \quad , \tag{9}$$

with:

V_i - integrated voltage,

R,C - components (resistor and capacitor values) in the operational amplifier.

Finally, the magnetic induction is given in terms of the integrated voltage:

$$B = \frac{RC}{n_s y(R_o - r_o)} V_i \quad . \tag{10}$$

In the case of ferrimagnets, the working frequency can be set as high as 1 kHz, as far as the electric resistivity of these materials is high enough[(4)] to prevent conductivity losses. This frequency is also well below from the resonance or relaxation phenomena[(5)] of magnetic domain walls. A normal power amplifier is capable of producing a ∿4A peak current, which on a sample of "normal" dimensions (∿2 cm OD, ∿0.5 cm

ID), with n_p ∿20 turns gives a ∿1000A.m (∿12Oe) peak applied field. This field is enough for the study of minor hysteresis loops of a full range of soft magnetic materials.

However, in some cases the current applied on the primary coil is high enough to produce some heating on the sample. The temperature increase can lead to a change in the value of the saturation magnetization, coercive field and magnetic anisotropy values. These changes may introduce some changes in the hysteresis loops. In this paper, we present a simple device that allows the study of magnetic hysteresis loops of soft ferrimagnetic materials under relatively high applied fields in an isothermal condition.

THE "BURST" SYSTEM

A simple idea was proposed[6] in order to limit the heating of the samples. The exciting signal is formed by waves packs separated by rest periods (Fig. 3) that allow heat dissipation. This can easily be done by using a signal generator that is triggered by a control circuit. The waves period can be as low as 15% of the total period (waves + rest) allowing the observation (and photographing) of the hysteresis loop in the oscilloscope screen (Fig. 4).

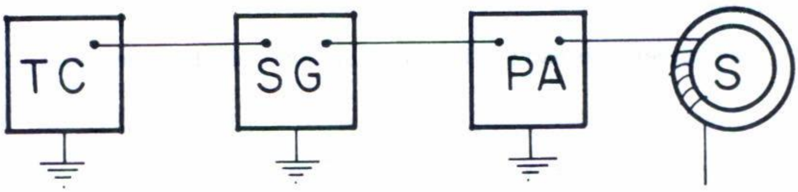

Fig. 3 Modification of the excitation signal in the burst system. TC-triggering circuit, SG-signal generator, PA-power amplifier, S-sample.

The system is made with the following modules: HP 3310A and HP 3310B function generators for the burst signal; a Philips LBB52-10 power amplifier; a Tektronix Am-501 op amp (with R = 180kΩ and C = 0.012μF) was used as integrating circuit; and a Philips PM 5170 voltage amplifier served for the secondary voltage amplification.

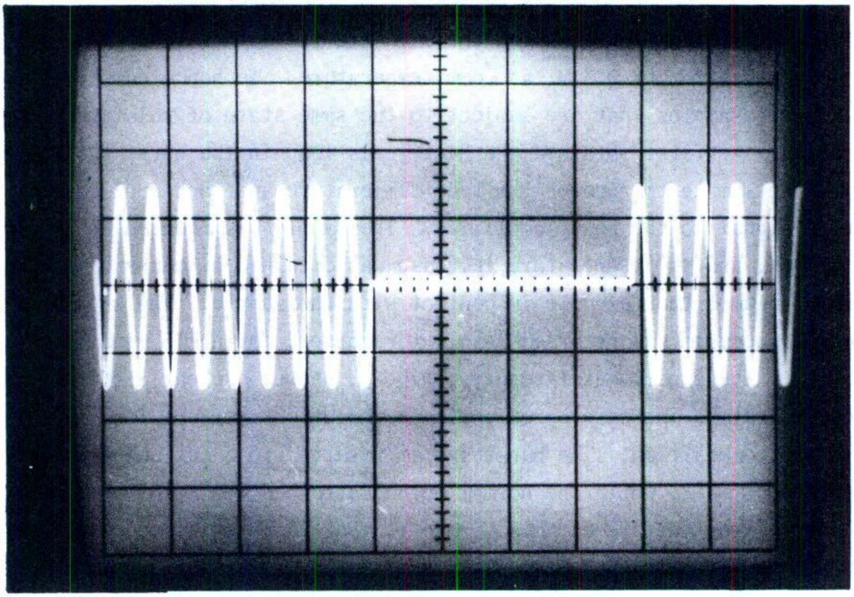

Fig. 4 The burst signal.

TYPICAL RESULTS

Ferrite samples in the Zn-Ni system were used to test the system. The general formula is

$$Zn_xNi_{(1-x)}Fe_2O_4 \quad ,$$

and the samples with composition x = 0.22, 0.40, 0.53 and 0.70 were prepared by a special[7] ceramic method that allows a very low impurity content. The stoichiometric quantities of the NiO, ZnO and Fe_2O_3 oxides are mixed and milled by a special milling technique[8] in an alcoholic medium. After drying, the powder is pressed under the shape of a toroid. Typical sintering conditions vary between 1150 and 1200°C, from 6 to 64 hours, in an oxidant atmosphere. Obtained densities are normally greater than 85% of the theoretical density for each composition. The chemical homogeneity of the samples was verified by a sensitive method[2] based on the continuous measurement of the initial magnetic permeability[1].

In order to compare the effect of the burst system, we obtained the hysteresis loop by applying the magnetic field that leads to a maximum magnetization of 0.3 M_s at room temperature. We hence compare the heating of samples that are subject to the same state of relative magnetization. We first obtained the hysteresis loop in the burst system, allowed the sample to recover the room temperature and then applied the normal signal to the power amplifier. The sample was mounted in an isolated box, and the temperature increase was obtained by means of a chromel-alumel thermocouple in contact with the sample. The signal of the thermocouple was recorded in a x-t recorder, during 15 minutes.

The experimental results, Fig. 5, showed a clear difference in the temperature increase by comparing both methods, except for the $x = 0.70$ composition. The burst system resulted in a maximum temperature increase of $\sim 3°K$, while the normal method attained $\sim 25°K$ for $x = 0.22$. An interesting feature of this figure is that there exists a relationship between composition and temperature increase. As the zinc content increases, the heating of the sample decreases. For $x = 0.7$, there is not significant difference between both methods. An interpretation of these results can be proposed on the basis of the thermal variations of the coercive force for the Ni-Zn ferrite system[9]. The coercive force is very high for low temperatures and decreases as temperature approaches T_c. For $x = 0.92$, the Curie temperature[10] is $\sim 736°K$ while for $x = 0.70$, $T_c \sim 353°K$. As the experiments were performed at room temperature, the coercive force is very high for $x = 0.22$ ($T/T_c \sim 0.41$) while it is not so for $x = 0.70$ ($T/T_c \sim 0.85$). The external field needed to attain 0.3 M_s is hence much higher for $x = 0.22$ than for $x = 0.70$, and this leads to the excitation of all the loss mechanisms in the sample. A more systematic study of this phenomenon seems, however, necessary.

Fig. 5 illustrates the advantages of the burst system for the study of samples that have a relatively high coercive field.

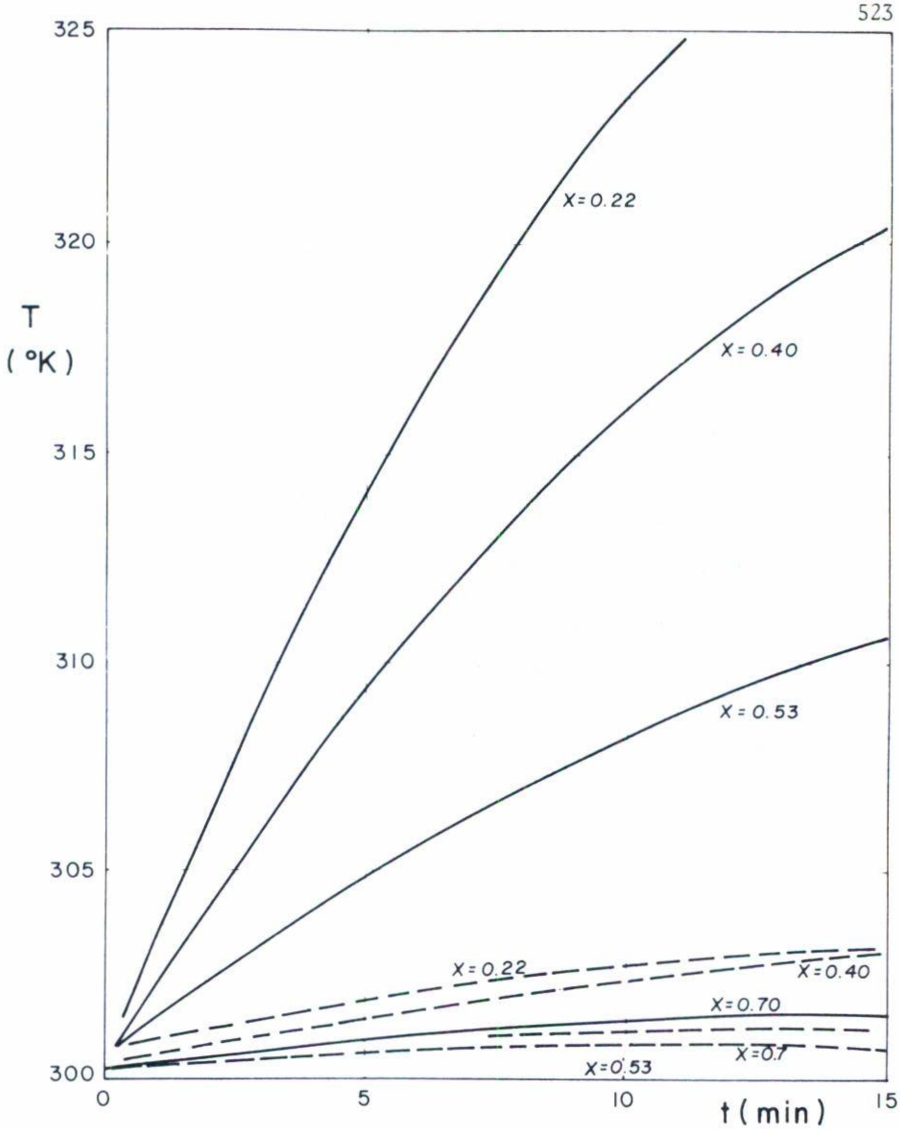

Fig. 5 Thermal behaviour of the samples in the Ni-Zn system. Continuous line, normal mode; broken line, burst mode.

CONCLUSIONS

We have presented a "burst" system for the study of magnetic hysteresis loops of soft ferrimagnetic compounds which allows relatively high applied fields while producing a very small temperature increase on the sample. For the whole range of Ni-Zn ferrites we measured, the temperature increase was lower than $\sim 3°K$.

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