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MEASUREMENT OF COERCIVE FORCE AND OTHER PARAMETERS OF CYLINDRICAL THIN MAGNETIC FILMS

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The paper describes the method of measuring the coercive force of cylindrical thin magnetic films by means of interrogation pulses. Starting from the definition of the coercive force it is pointed out that with samples having a small demagnetization factor two coercive force values can be measured in dependence on the measuring mode. The set up measuring device is suitable not only for the coercive force measurement but also for that of other important parameters of thin magnetic films as storage elements.

I. INTRODUCTION

The coercive force is tied up very closely with the technology of the ferromagnetic substance preparation and hence its measurement requires an adequate attention within the research pursued into thin magnetic films. The hysteresigraph is one of the oldest measuring devices, a cylindrical one [1] for thin magnetic films (*TMF*) deposited on a wired base. Though handy and lucid, measurements by hysteresigraph also exhibited certain drawbacks. The coercive force H_c could be read only as an average value of the entire sample, small samples were hard to measure owing to the relatively high noise level of the preamplifier. The useful signal to noise ratio could be improved, though, by rising the frequency of the magnetization field, but this brought about also a rise in the width of the hysteresis loop and hence H_c also increased.

Measurement methods have been evolved allowing to measure H_c from small samples or from small *TFM* regions. Bader and Ellis [2] have developed on the nonlinear mixing, in the film, of two high-frequency fields, a relatively complicated measuring device for local measurements on planar *TMF*. Measurements are non-destructive and the angular deviation of magnetization in the small *TMF* regions is done with a high accuracy. Zappe [3] has simplified the measuring method referred to by applying only one high-frequency signal and scanning the phase of the second harmonical which is proportional to the magnetization of the measured sample. The magnetization field in which the second harmonical voltage is zero, corresponds to the coercive force. A typical hysteresis loop may be observed for that case on the oscilloscope.

Paper [4] instigated Chaffin to evolve a new method for measuring H_c especially suitable for plated wire. Certain flaws, however, may be ascribed to his device. An average H_c value is measured from a relatively long section of *TMF* ($\sim$6.5 cm) and the eventual asymmetry of the hysteresis loop may not be determined since the reading-interrogation pulse is generated only during the positive slope of the triangular magnetization field [5].

The method referred to is suitable not only for measuring the coercive force but also other parameters of *TMF* provided that the method is adequately modified or completed. The problems involved and the established measuring device are the subject of the presented paper.

II. METHOD OF COERCIVE FORCE MEASUREMENT WITH AN INTERROGATION PULSE

Similarly as with the hysteresigraph the *TMF* is being magnetized by the magnetization field to a saturated state alternately in both senses. The state of magnetization, depending on the size of the coercive force and on the instantaneous value of the magnetization field H_m is being scanned by the field H_T through an interrogation pulse, the field itself acting in the direction of the hard axis. Hence, when the interrogation pulse changes its position with respect to the instantaneous value of the magnetization field, the sense signal e also undergoes a change owing to the change of magnetization in the course of the leading edge of the interrogation pulse H_T, Fig. 1. At the moment when the field $H_m = H_c$ (*TMF* is in a demagnetized state) the sense signal is

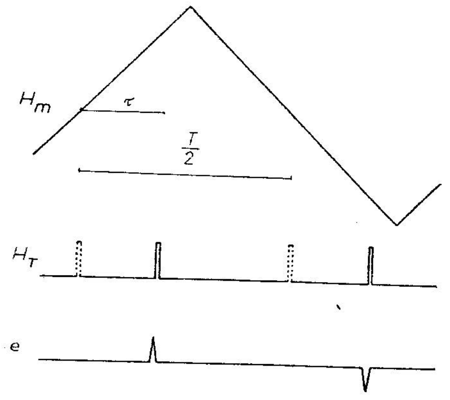

Fig. 1. Shape of the magnetization field H_m, the interrogation field H_T and the sense signal e.

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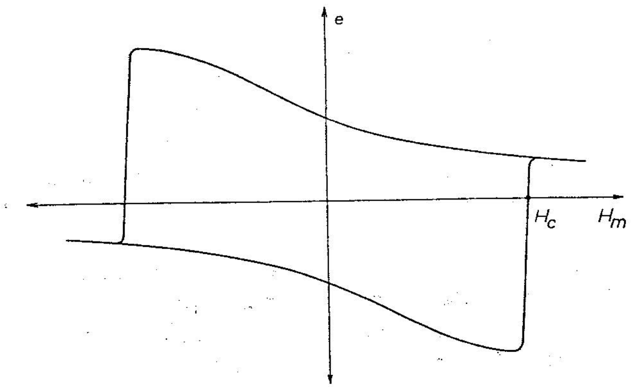

Fig. 2. Hysteresis dependence of the sense signal on the magnetization field.

zero. Thus the coercive force H_c is numerically equal to the magnetization field at a zero sense signal.

By plotting the sense signal in dependence on the magnetization field, we get a hysteresis loop typical for this measurement (Fig. 2) similar to the hysteresis loop obtained in [3], different from the loop obtained by the hysteresigraph [1]. Its typical course is due to the fact that the sense signal is not only the function of the magnetization of the measured sample but also a function of the angle by which the magnetization deviated from the original position owing to the simultaneous action of both the interrogation and the magnetization fields. The larger the interrogation field, the more the thus measured hysteresis loop approaches the loop obtained by the hysteresigraph and both loops will be approximately equal in the case of $H_T \gg H_m$.

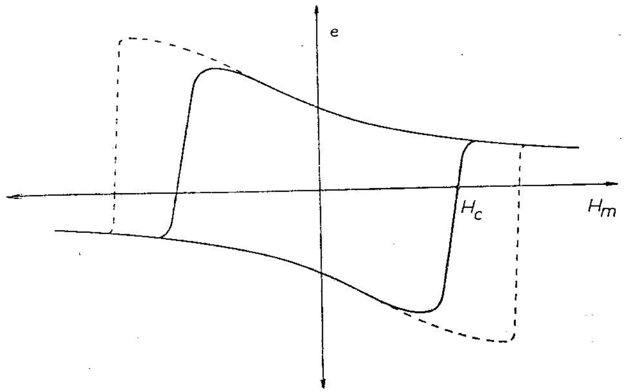

Fig. 3. Hysteresis loop after the establishment of nuclear domains.

III. INFLUENCE OF DEMAGNETIZATION FIELD ON MEASURING H_c

Cylindrical *TMF* with a circumferential easy axis of magnetization exhibit a very small (almost zero) demagnetization factor. Therefore they are easily magnetized into a saturated state and reversely oriented domains start rising only in a relatively strong H_n — nucleation field, which is generally larger than the H_w — domain wall motion threshold. Thus if such a sample previously magnetized up to saturation is magnetized in a reverse sense, the domains with the reversely oriented magnetization are nucleated only at a field $H_m = H_n$ and, since $|H_n| > |H_w|$, the established domains get stretched over the entire volume of the sample by the wall motion. It can be seen that by the method described in the preceding paragraph the coercive force equal to the nucleation field $H_c = H_n$ was measured. This is, as a matter of fact, not only the failure of the presented method because the same value is measured also by hysteresigraph. The fact referred to also accounts for the difference between the coercive force (thus measured) and the digit disturb threshold H_d which produces a discernible change in the readout signal that was essentially smaller (e. g. twice).

If the demagnetization factor were large as, e. g., in planar *TMF*, there would be otherwise oriented domains already with a smaller magnetization field, e. g., at $H_m = H_w$ that would become stretched by the wall motion until the demagnetization of the sample or its magnetization in a reversed sense. The unified orientation of the measured sample domains with a practically closed flow may be infringed, e. g. by a sufficiently strong pulse field acting in a reverse sense or perpendicularly. Domains set up in this way and otherwise oriented start magnifying their volume in the magnetization field $H_m = H_w$ by the wall motion. The measured hysteresis loop is much narrower (Fig. 3) than the loop measured from the same sample without re-entrance (without generating otherwise oriented nuclear domains) [6]. The coercive force thus measured is $H_c = H_w$ and is in good agreement with the distrub digit field H_d.

It is of advantage therefore to modify the method of measuring H_c in this sense. The modification is simple, it suffices to apply a sufficiently strong H_T pulse acting in the direction of the hard axis at a time when the magnetization field is zero, dotted line in Fig. 1.

IV. MEASUREMENT OF OTHER *TMF* PARAMETERS

Such measuring devices are of advantage that produce the possibly largest number of data on the measured sample at one "set up". Thus our device, destined to measure the coercive force, also provides for measuring other *TMF*

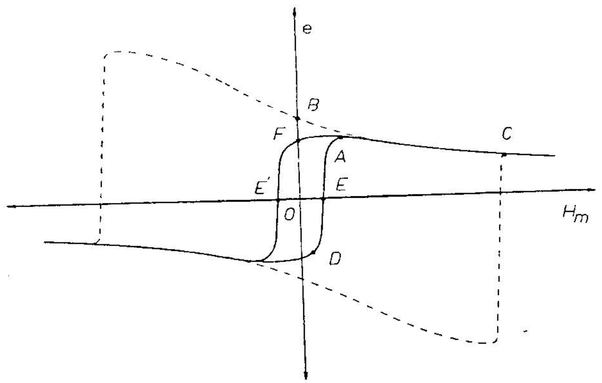

Fig. 4. Hysteresis dependence of "return" sense signal on the magnetization field.

parameters when evaluating the "return" sense signal, i. e., the sense signal from the trailing edge of the interrogation pulse. By plotting the "return" sense signal in dependence on the magnetization field, we get hysteresis loop, Fig. 4, whence some very important *TMF* parameters can be directly read, as far as its storage function is concerned.

Provided that the interrogation pulse has an equal leading and trailing edge, that the interrogation pulse in the storage corresponds to a word pulse and the magnetization field to digit field, then the individual points in Fig. 4 indicate the following parameters:

A indicates the minimal digit field by which a new information may be stored together with the word pulse into the storage element under the hardest conditions, i. e., when the storage element was saturated in a reverse sense.

B indicates the amplitude of the sense signal when reading from a saturated state.

D indicates the digit field in the presence of a nominal word pulse which allows non-destructive reading from the storage element.

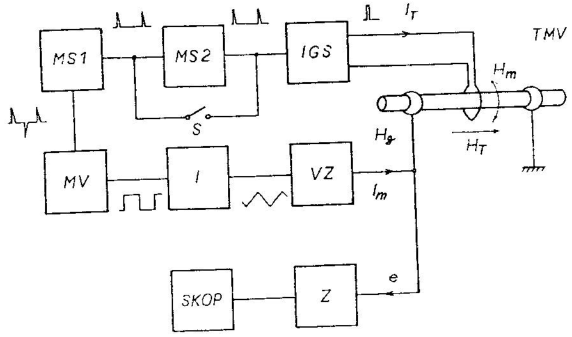

Fig. 5. Block scheme of the measuring device.

E÷*E'* the asymmetry *OE*, *OE'* is due to a skew;.

B—*F* this difference indicates the measure of reading destructiveness; if it is zero, reading is non-destructive. Its size is set up by the amplitude of the interrogation (word) pulse.

In addition to these parameters the field of anisotropy [7] can also be measured in a relatively simple way. It is to be noted, that the parameters *A*, *C*, *D* and *F* are in agreement with those measured by Girard et al. [8] by the modified Belson test.

V. THE MEASURING DEVICE

It could be seen in the preceding paragraphs that important parameters of the storage elements may be obtained by a quasistatic measurement. In designing the measuring device it was our endeavour to set up the individual blocks in a way to achieve conformity with the storage hardware or with the setting in the storage block. In contrast to [5] therefore we have made use of much narrower interrogation pulses of a length and shape equal to the word pulses in storage and the interrogation winding itself has only a few turns.

The block scheme of the measuring device is in Fig. 5. Multivibrator *MV* generates rectangular pulses with a period $T = 3$ ms. These get integrated in *I*, their performance being amplified in *VZ* and they form a magnetic field H_m by a flow through the *TMF* itself, the field being controllable from 0 up to 10 Oe. The triangular shape of the magnetization field was chosen to have its slope:

$$s = \frac{2H_m\,max}{T},$$

constant and to avoid problems in determining its instant value. Derivated pulses proceed into the delay circuit *MS* 1, formed by a monostable multivibrator in which they are delayed so as to have the interrogation pulse generated in block *IGS* with a closed switch *S* just at the moment when the field of magnetization is zero. Othervise, in block *MS* 2, set up by a monostable multivibrator with controllable delay, all pulses are delayed by $\tau \in (0, T\rangle$. The instant value of the magnetization field at the time of the interrogation pulse action is defined according to the following delay:

$$H_m = \begin{cases} s\tau, \text{ if } \tau \in (0, T/2\rangle \\ H_m\,max - (\tau - T/2)s, \text{ if } \tau \in (T/2, T\rangle. \end{cases}$$

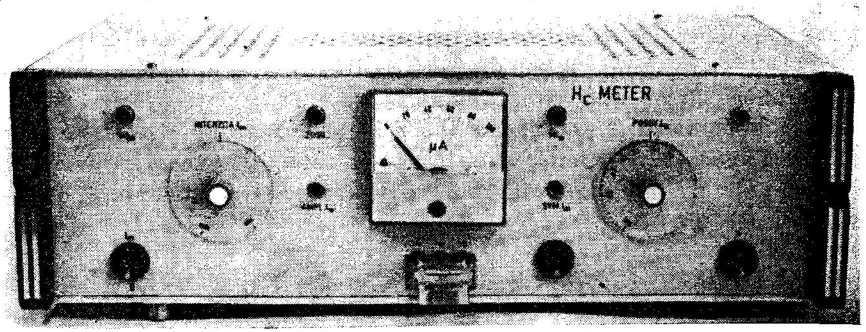

Fig. 6. View of the measuring device.

Sense signals scanned from mercury contacts, in which *TMF* is supplied with the magnetization current I_m, are amplified and observed on the oscilloscope. The delay τ may be changed automatically, too, and according to which of the sense signals is being sampled, as the case may be, the respective hysteresis loop is observed.

It should be noted that it is also the average value H_c that is measured here, but from an essentially shorted section of the *TMF*, only of a few mm in length. The length of the measured section may not be shortened arbitrarily since the effective anisotropy field is considerably increased, thus bringing about a thorough distortion of the rest of the measured parameters.

VI. CONCLUSION

We have described the quaststatic measurement of the coercive force by means of the interrogation pulse. It has been shown that the measuring device built for that purpose is suitable, after a slight modification, not only for measuring H_c but also other very important parameters of the storage elements. We thus obtain a relatively simple but very useful apparatus, rendering the most important *TMF* parameters by a single "set up".

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