Hodographs of the magnetization vector obtained during 90-degree pulsed magnetization of iron borate single crystals

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Hodographs of the magnetization vector during transient processes in iron borate single crystals were investigated. Analysis of the hodographs showed that the process of 90–degree pulsed magnetization proceeds via quasiuniform rotation of the magnetization and the break in the pulsed magnetization curve is due not to a change in the nature of the magnetization mechanism but rather to a decrease of the energy expended on the excitation of shock magnetoelastic oscillations. © *1995 American Institute of Physics.*

A very important problem in the physics of transient processes in magnetic materials is how to take into account the energy losses correctly.[1,2] This problem is ordinarily solved phenomenologically[1–8] by introducing the Landau–Lifshitz damping constant λ (Refs. 3, 5, and 6) or Gilbert's damping constant α (Refs. 4–6), since the actual mechanism of energy transfer out of the spin system of the crystal lattice is not clear. The experimental methods for estimating λ and α are based on comparing the computed and real pulsed characteristics of a magnetic material. Two very simple magnetization mechanisms are invoked: domain wall motion (see, for example, Refs. 9–11) and coherent rotation of the magnetization (Refs. 1 and 12–15). In the first case the question of how well the model employed for the domain walls (as a rule, one-dimensional Bloch walls) corresponds to the real structure of the walls is still the bottleneck. The possibility of employing the second method is limited by the small choice of magnetic materials which are reliably known to be magnetizable in relatively weak fields (<10 Oe) by uniform rotation of the magnetization. Until now, uniform rotation of the magnetization has been observed only in permalloy films and only in a few studies: Stein's work[14,15] on 180-degree magnetization reversal and the work performed at the Moscow Power Engineering Institute on 90-degree pulsed magnetization reversal.[16] Other attempts to observe this mechanism have not been successful.[17,18] It should also be noted that permalloy films possess a polycrystalline structure, which gives rise to additional difficulties in the theoretical interpretation of the results obtained in the investigations of the quantities λ and α.

There is therefore a pressing need to search for magnetic materials which can be magnetized by a uniform rotation of the magnetization. Here we investigate hodographs of the magnetization vector during transient processes in single crystals of iron borate ($FeBO_3$). Compared with other materials, this magnetic material has a number of advantages which are important from the standpoint of the possibility of investigating energy losses: samples with a high degree of perfection of the crystal lattice can be obtained,[19] the amplitudes of the pulses of the magnetic field which is necessary for exciting transient processes are low,[20] and the interaction of the magnon and phonon systems is strong (Refs. 21–23). The latter property is manifested in the fact that the transient processes are accompanied by easily observable shock magnetoelastic oscillations.[24–26] Their intensity evidently characterizes the degree of magnetoelastic interaction. In the present work we studied the simplest transient process — 90-degree pulsed magnetization.

As in the case of permalloy films,[14–18] in constructing the hodograph of the magnetization vector **M** of $FeBO_3$ single crystals the analysis can be confined to the two components of the magnetization which lie in the plane of the sample, since in the case of the transient processes considered here **M** virtually remains in this plane. In contrast to permalloy films, this circumstance is due not so much to the effect of the demagnetizing field as to the large value of the effective field of easy-plane anisotropy.[22]

The investigations were performed using the standard induction apparatus which is ordinarily employed for studying permalloy films.[27] The temporal resolution of the setup was close to 1 ns. The components M_x and M_y, parallel and perpendicular, respectively, to the pulsed field H_s which gives rise to the transient process under study, were analyzed. These components were registered with the aid of longitudinal and transverse sensing coils.[27] Integrating the signals, we found the reduced values of the components $m_x(t)=M_x(t)/M_s$ and $m_y(t)=M_y(t)/M_s$. Here M_s is the saturation magnetization. The initial state of the saturation of the sample was produced with the aid of the reset field H_0 oriented perpendicular to the field H_S. Since there is virtually no anisotropy in the plane of the $FeBO_3$ single crystals,[22] the angle θ_l by which the magnetization vector must turn after the transient process is given by the relation

$$\theta_l=\cos^{-1}\frac{H_0}{\sqrt{H_s^2+H_0^2}}. \tag{1}$$

The results obtained are illustrated for the example of a sample with the following parameters: thickness — 24 μm; field required for technical saturation in the plane of a single crystal — 1.3 Oe; and average period of the shock magnetoelastic oscillations — 13 ns. Just as in other samples which have been investigated,[20] the pulse magnetization curve, which gives the reciprocal τ^{-1} of the transient time of the process as a function of the amplitude of the field H_s, consists of two sections separated by a breakpoint at field H_{br} ($\approx$3.4 Oe), after which the magnetization rate increases rapidly. It is known[25–27] that transient processes in iron borates characteristically consist of two stages: the main stage and a stage associated with the damping of the magnetoelastic oscillations. The duration of the main stage was assumed to be equal to the interval between the times t_i and t_f, for which the voltage of the longitudinal signal is equal to 0.1 times the signal amplitude A_m.

The hodographs obtained with $H_s=2.5$ Oe ($<H_{br}$) and $H_s=8$ Oe ($>H_{br}$), respectively, are shown in Figs. 1a and 1b. Magnetization was accomplished in a reset field $H_0=1.5$ Oe. A corresponding time (in ns) is indicated near each experimental point showing the instantaneous position of the tip of the normalized magnetization vector **m** $=$ **M**$/M_s$. The points corresponding to the times t_i and t_f are indicated. The limiting

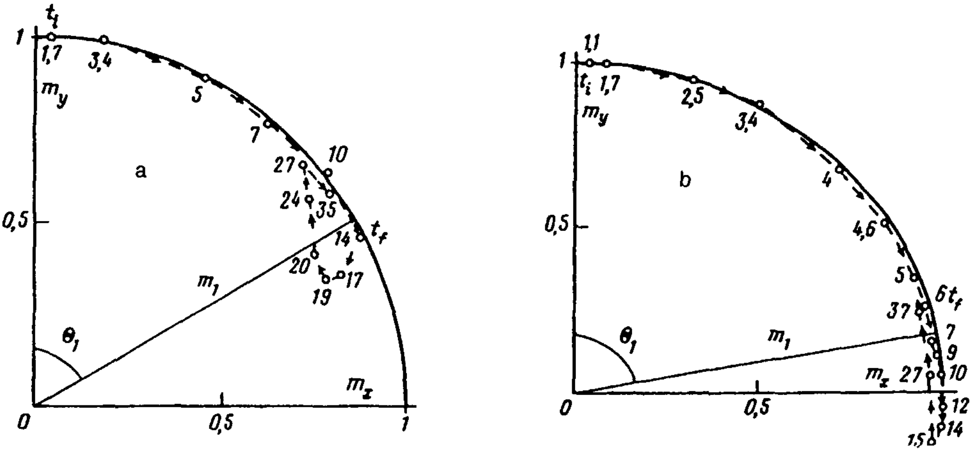

FIG. 1. Hodograph of the magnetization vector obtained with magnetizing pulse amplitudes $H_s = 2.5$ Oe (a) and $H_s = 8$ Oe (b).

position which the magnetization vector $\mathbf{m}_l$ should reach according to the relation (1) is indicated. We see that, irrespective of the magnitude of the field H_s, in the time interval $t_i < t < t_f$ the experimental points lie near the arc of a unit circle. This means that at the main stage of the transient process the 90-degree magnetization of the iron borate single crystals is accomplished by a coherent rotation of the magnetization for both $H_s < H_{br}$ and $H_s > H_{br}$. Additional studies showed that for $H_s > H_{br}$, similarly to the case of 180-degree magnetization reversal,[26,27] the intensity of the magnetoelastic oscillation decreases appreciably.

Figure 1 shows several points which reflect the stage of the magnetoelastic oscillations. We see that, in general, at this stage the position of the vector **m** and its modulus change.

In summary, our results show that at the main stage of the 90-degree pulsed magnetization of single crystals of iron borate the change in magnetization is accomplished via a coherent rotation of the magnetization. We clearly see the case in which the breakpoint in the curve $\tau^{-1}(H_s)$ is associated not with the change in the nature of the mechanism of magnetization but is due to the decrease in the energy expended on the excitation of magnetoelastic oscillations.

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