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COMBINED THERMAL AND ANHYSTERETIC DEMAGNETIZATION OF REMANENCE IN GAMMA FERRIC OXIDE

D. A. LINDHOLM* and S. K. BANERJEE

Franklin Institute Research Laboratories, Philadelphia, Pennsylvania 19103, U. S. A.

Résumé. — Nous avons utilisé une méthode nouvelle de désaimantation de la rémanence anhystérétique des bandes d'enregistreur en γ Fe₂O₃. La désaimantation « thermo-anhystérétique » consiste à chauffer un échantillon de température initiale T_i jusqu'à $T_f > T_i$ et ensuite à le placer dans un champ alternatif H_{ac} décroissant à zéro. Quand T_i se rétablit, la rémanence est réduite à un niveau plus bas que dans les cas de désaimantation en champ alternatif ($H_{ac} \rightarrow 0$) seul ou de la désaimantation thermique ($T_f \rightarrow T_i$) seule. Le mécanisme du processus « thermo-anhystérétique » s'explique par la dépendance thermique de la valeur modale de la distribution des champs anisotropiques.

Abstract. — A new method for the demagnetization of anhysteretic remanence in γ Fe₂O₃ recording tapes has been devised. In « thermo-anhysteretic » demagnetization, a sample at initial temperature T_i is heated to $T_f > T_i$, followed by the application of an alternating field, H_{ac} , decreasing to zero. When T_i is re-established, the remanence is reduced to a lower level than that resulting from either alternating field ($H_{ac} \rightarrow 0$) or thermal ($T_f \rightarrow T_i$) demagnetization alone. The mechanism of the thermo-anhysteretic process is discussed in terms of the temperature dependence of the modal value of the anisotropy field distribution.

I. Introduction. — A technique has been devised to demagnetize samples of γ Fe₂O₃ instrumentation recording tapes effectively with the combined use of a decaying alternating magnetic field in conjunction with a temperature cycling. As Kneller [1] has pointed out, a demagnetization curve has a profile which is characteristic of the type of initial remanent magnetization. In the present case, the focus is on anhysteretic remanent magnetization (ARM), since this type of remanence is the most representative species for analogue recording [2]. Hence, these demagnetization experiments represent erasure techniques in practical applications.

The use of a decaying alternating magnetic field alone as an erasure technique could be called « anhysteretic demagnetization », since it corresponds to the trivial case of an ARM in zero direct field, $M_{ar}(H_{dc} = 0)$, whose ultimate value is limited by particle interactions. If a temperature cycling is applied, the sample can be thermally demagnetized - - - the ultimate extent occurring when the Curie point, T_c , is reached. Here, these two approaches are combined to give a « thermo-anhysteretic » demagnetization. In this procedure, the temperature of the sample is elevated from an initial value, T_i , to T_f ($T_i < T_f \leq T_c$); a demagnetizing field, H_{ac} , is slowly decreased to zero; and, finally, the initial temperature, T_i , is restored.

Samples composed of seven layers of tape (3.18 mm \times 22.23 mm) of two different manufacturers (A1 and A2) were used in these experiments. The tape parameters are listed in Table I, where M_r refers to dc saturation remanence.

TABLE I

Sample	M_r/M_r	Oxide		M_{ar}^0/M_r (25 °C)	H_{dc} Oe
		H_c Oe	Thickness μ		
A 1	0.74	252	13.18	0.85	70
A 2	0.75	252	6.15	0.17	5

* Present address : Control Data Corporation, Norristown, Pa. 19401, U. S. A.

II. Anhysteretic demagnetization at fixed temperatures. — The effects of temperature on the distribution of anisotropy fields were first studied by making anhysteretic demagnetizations of ARM at elevated temperatures. The spectrum of anisotropy fields, $g(H_k)$, was obtained by taking the field derivative of the demagnetization curve. Such a procedure will yield the coercivity spectrum of the magnetization process which created the initial remanence [3], neglecting magnetostatic interactions [1]. In the experimental situation, the demagnetization curve is obtained discretely at selected values of H_{ac} . In the example of figure 1, the initial level, M_0 , is the ARM

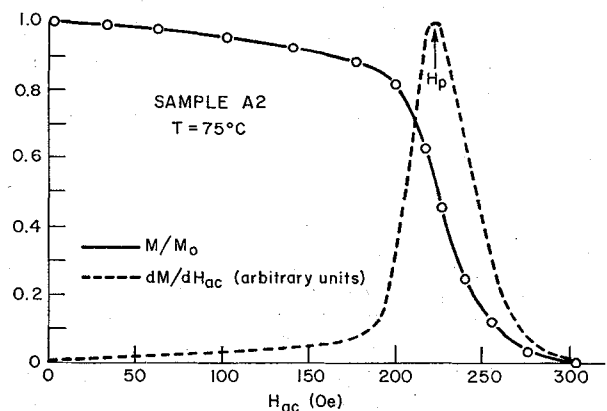


FIG. 1. — Anhysteretic demagnetization of remanence at fixed temperature. The initial remanence, M_0 , is the ARM from $H_{dc} = 5$ Oe at 75 °C.

from $H_{dc} = 5$ Oe at $T = 75$ °C. The next point is obtained by application and removal of H_{ac} at 60 Hz, forming the partially demagnetized remanence, M , at 75 °C. Before progressing to a subsequent value of H_{ac} , M_0 is restored in order to lessen accumulative measurement errors. A smooth curve is computer fitted to these remanences using a Spline interpolation procedure from which the first derivative is numerically determined. A reliable, detailed line shape for

$dM/dH_{ac} \propto g(H_k)$ requires that many real data points be taken. However, the location of the derivative maximum, H_p , can be determined even from limited data.

In this way the $H_p(T)$ dependence for sample A 2 has been determined. Similarly, the shift of H_p with temperature for sample A 1 was deduced, except that the initial remanence, M_0 , was due to the ARM acquired in $H_{dc} = 70$ Oe at each temperature. The results are shown in figure 2a. Since H_p is the modal value of the coercivity spectrum, H_c should have the same temperature dependence as H_p . Indeed, Eagle and Mallinson [4] have measured $H_c(T)$ in the range $-180^\circ\text{C} < T < 300^\circ\text{C}$ for acicular $\gamma\text{Fe}_2\text{O}_3$ fine particles. From their data we have deduced that H_c decreases at the rate of $-0.11\%/^\circ\text{C}$ relative to H_c at 25°C . For our sample A 1, H_p decreases at the rate of $-0.12\%/^\circ\text{C}$. In sample A 2, however, H_p decreases about twice as fast with temperature as A 1.

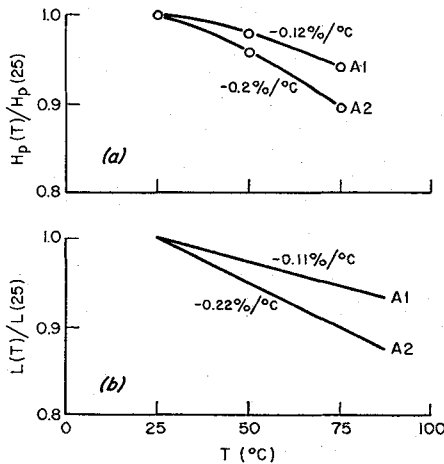


FIG. 2. — Temperature dependence of (a) H_p and (b) high field torque, L , for samples A 1 and A 2. The approximate slope values are indicated. Torque data was recorded continuously.

As a verification that the observed temperature dependence of H_p follows from bulk material properties, high field (5 000 Oe) torque measurements were carried out on single layer disc samples. The maximum torque amplitude, L , for tape A 2 was also found (Fig. 2b) to decay about twice as fast as A 1 in the temperature range of interest. We attribute the sharper decay in both experiments to a greater content of superparamagnetic particles in tape A 2. These have blocking temperatures much lower than the Curie point of the bulk materials and hence, display a steeper decay of anisotropy with temperature.

III. Thermo-anhyseretic demagnetization. — The previous experiments of anhyseretic demagnetization at fixed temperatures have laid the groundwork for the technique of thermo-anhyseretic demagnetization. This procedure has been performed on both samples for a temperature cycle defined by $T_i = 25^\circ\text{C}$ (room temperature) and $T_f = 50^\circ\text{C}$. The thermo-anhyseretic demagnetization of sample A 2 under these conditions is the lower curve (a) of figure 3. The upper curve (b) is the usual anhyseretic demagnetization curve at room temperature ($T_i = T_f = 25^\circ\text{C}$). It is evident

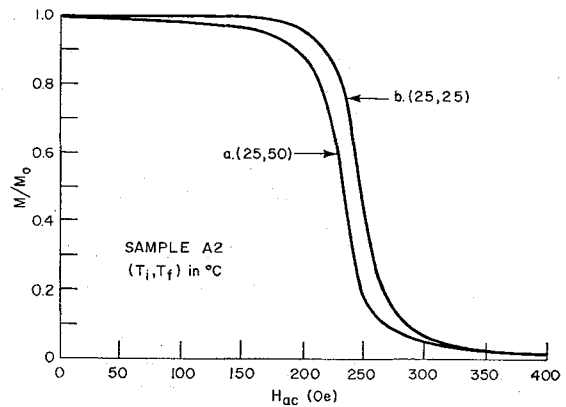


FIG. 3. — Demagnetization of ARM from $M_0 = M_{ar}(H_{dc})$ (cf. Table I) for sample A 2. (a) Thermo-anhyseretic technique, (b) anhyseretic technique. Data points have been omitted for clarity.

that the new technique is considerably more effective than the usual technique, especially in the range $150\text{ Oe} < H_{ac} < 290\text{ Oe}$. The maximum efficiency occurs at $H_{ac} = 240$ Oe (170 Oe rms) where the initial remanence is reduced by 75 % with the combined technique and only 40 % by H_{ac} alone. It was verified that this improvement was not due to the simple addition of anhyseretic demagnetization ($H_{ac} \rightarrow 0$) and thermal demagnetization ($T_f \rightarrow T_i$). Indeed the application of a temperature cycling to 50°C before or after the establishment of the partially demagnetized state from $H_{ac} = 240$ Oe alone only lowers this state by an additional 2 %.

The same experiments on sample A 1, figure 4, reveal

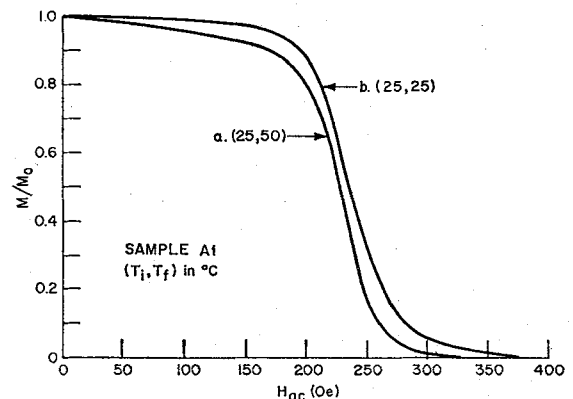


FIG. 4. — Demagnetization of ARM for sample A 1 (cf. Fig. 3).

similar results. However, at intermediate values of H_{ac} , the combined technique is less effective for this sample as compared with sample A 2. This follows from the studies of the temperature dependence of H_p in Sec. II. In sample A 2 the $g(H_k)$ distribution is shifted more toward lower fields than for A 1 at a given elevated temperature T_f . However, it appears within magnetometer sensitivity that in the high field tail region, the combined technique (a) still produces a lower remanence level than field demagnetization (b) alone.

IV. Discussion. — Associated with the anhyseretic demagnetization of an ARM at a fixed temperature T

is a distribution function of anisotropy fields, $g[H_k(T)]$, whose modal value, $H_p(T)$, is related to the coercive force, $H_c(T)$. In thermo-anhyseretic demagnetization, H_{ac} is applied after the temperature is raised from T_i to T_f , consequently it is working on a new distribution function $g[H_k(T_f)] \neq g[H_k(T_i)]$. It will have a different $H_p(T_f) < H_p(T_i)$ and the lineshape (linewidth) of $[gH_k(T_f)]$ may differ also. Due to these modifications of the distribution function, a given H_{ac} can have a far greater effect on demagnetizing an ARM at T_f than at T_i , especially if the linewidth of the distribution is narrow. [Our lineshapes, although derived from limited data, indicate sample A 2 has a smaller linewidth than A 1.] Upon lowering the temperature to T_i after removal of H_{ac} , a net thermo-anhyseretic demagnetization curve results from a

slightly modified version of $g[H_k(T_f)]$. The small changes arise from (1) undesirable acquisition of thermoremanent magnetization ($T_f \rightarrow T_i$) in the presence of stray fields and (2) differences between static and dynamic remanences [1].

Unlike tapes, H_p and lineshapes of $g(H_k)$ in rocks are more strongly temperature-dependent [5] due to variable composition and grainsize of the magnetic materials. Therefore, thermo-anhyseretic demagnetization should find an important application in demagnetization studies in rockmagnetism, also.

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