RELATION BETWEEN STATIC REMANENCE CURVES: AN EXPERIMENTAL INVESTIGATION OF HARD AND SOFT MATERIALS

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RELATION BETWEEN STATIC REMANENCE CURVES: AN EXPERIMENTAL INVESTIGATION OF HARD AND SOFT MATERIALS

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Abstract. — Plots of the dc demagnetisation remanence vs. the isothermal remanence have been used to investigate many-body effects in soft magnetic materials and recording media. Non-linearities in the plots are ascribed to the demagnetising effects of the many-body interactions in each case.

1. Introduction

The principal remanence curves of a magnetic material are the isothermal remanent magnetisation $I_r$ and the dc demagnetisation remanence $I_d$. $I_r (H)$ is the remanence obtained by the application and removal of a field $H$ and $I_d (H)$ is the remanence resulting from the application of a negative field $H$ to a sample initially at saturation remanence. For a system of non-interacting particles the curves are related by [1]

$$I_d = 1 - 2I_r.$$  

(1)

As has been pointed out by Gaunt et al. [2], equation (1) is also valid for domain wall motion as long as the walls interact with similar pinning site densities during the magnetisation and demagnetisation processes. Equation (1) was used by Henkel [3] in investigations of CuNiFe, using plots of $I_d$ vs. $I_r$ to show any departure from linearity. It was found that the plots were often highly non-linear. Further work has been more recently carried out on hard materials including PtCo [2] and NdFe [4]. Generally these also give non-linear behaviour, with the NdFe materials giving a deviation from linearity in a "positive" sense with the curve concave downwards. Here we extend this investigation to soft FeSi steels and powders of magnetic recording media.

2. Experimental

Measurements were made on compacted powders of CrO$_2$ recording particles using a vibrating sample magnetometer. Because of the unequal field intervals in the $I_r$ and $I_d$ curves the data for the Henkel plots were obtained by a cubic spline interpolation which allowed the field points to be matched for each curve. We have also investigated the behaviour of FeSi ribbons, using a magnetometer based on the use of a dc solenoid and an integrating fluxmeter. Measurements on these materials were made as a function of the applied stress, which has the effect of inducing a uniaxial anisotropy.

3. Results

Henkel plots of $I_d (H)$ vs. $I_r (H)$ were made for two contrasting materials, firstly compacted powders of CrO$_2$ particles. The results for this material are shown in figure 1. It can be seen that the relation between $I_d$ and $I_r$ is non-linear in a "negative" sense in relation to data obtained on NdFe materials. The explanation of the difference is likely to lie in the differences between the microstructures of the materials. In order to explain the behaviour of NdFe materials, Pinkerton [4] proposed the existence of interactions between grains which had a net magnetising effect. The situation in the powders measured here is, however, rather different. It is reasonable to suppose that there exist aggregates of particles whose lowest energies will be achieved by closed loop magnetic configurations. This is likely to make the powders significantly harder
to magnetise, which is consistent with the form of the Henkel plot. Figure 1 shows a small trend towards the Henkel plots becoming more linear with increasing temperature. This small variation is consistent with a decrease in magnetic order with increasing temperature as seems reasonable.

We have also carried out measurements on FeSi soft magnetic materials. Figure 2 shows the Henkel plot for a sample oriental parallel to the rolling direction. It can be seen that there is a deviation in the same sense as the CrO₂ powder, indicating that the many-body effects are having the same (demagnetising) effect. Stressing the samples was also found to have very little effect on either the hysteresis properties or the form of the Henkel plots for these materials. The application of a stress was, however, found to alter the anisotropy of the materials. This was confirmed by measurements of the transverse susceptibility, which will be described in detail separately. Thus the hysteresis properties of the materials are dominated by domain wall motion.

Fig. 2. — Henkel plot for an FeSi ribbon.

The non-linearity of the Henkel plots can be interpreted in terms of the existence of many-body effects. One possible model proposed by Gaunt et al. [2] proposes that the non-linearity arises because the domain wall interacts with different pinning site densities during the magnetisation process. It is also possible that the motion of domain walls is affected by the presence of local fields due to interactions with neighbouring domains which would be expected to be dependent upon the magnetic state and therefore give rise to differences between the magnetic behaviour during magnetisation and demagnetisation, as reflected in the non-linear Henkel plots. There is evidence for the interaction between domains in the measurements of Heiden and Rogalla [5] on small iron whiskers. Repeated sweeps of the hysteresis loops gave statistical variations in the critical field for a given pinning site which could be interpreted in terms of fluctuations in the local field at the site.

The interpretation of the data for the CrO₂ particles can be made directly in terms of many-body effects. Here the Henkel plot shows the interactions to have a demagnetising effect which is consistent with the known effects of interactions on the anhysteretic susceptibility. In this respect it is interesting to note the direct correlation which has been observed [6] between the anhysteretic susceptibility and the inverse of an interaction field estimated as \( H_{\text{int}} = H_r - H_r' \), where \( H_r' \) is an estimate of the remanence coercivity determined using \( I_r \left( \frac{H_r}{H_r'} \right) = 0.5I_r \left( \infty \right) \). \( H_{\text{int}} \) is a measure of the deviation of the Henkel plot from linearity. Thus in the case of recording media particles it is reasonable to suppose that the Henkel plot is characteristic of many-body effects. It is also likely that a similar situation obtains for the soft materials studied here, although further work is required in this area.

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