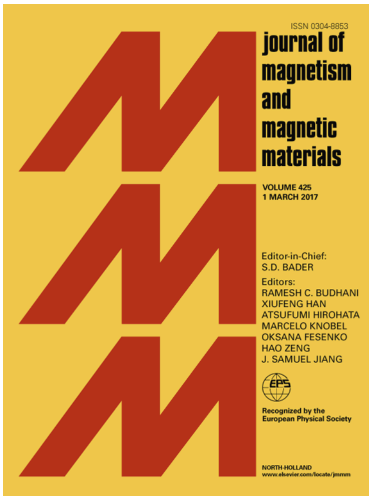

Interaction plots obtained from in-field magnetization instead of remanence measurements

J. Geshev

PII: S0304-8853(18)31649-4
DOI: https://doi.org/10.1016/j.jmmm.2018.07.009
Reference: MAGMA 64115

To appear in: *Journal of Magnetism and Magnetic Materials*

Please cite this article as: J. Geshev, Interaction plots obtained from in-field magnetization instead of remanence measurements, *Journal of Magnetism and Magnetic Materials* (2018), doi: https://doi.org/10.1016/j.jmmm.2018.07.009

Interaction plots obtained from in-field magnetization instead of remanence measurements

J. Geshev
Instituto de Física, URFGS, Porto Alegre, 91501-970 Rio Grande do Sul, Brazil

The great majority of experimental studies on magnetic interactions employ a technique based on the Wohlfarth's relation and require an initially demagnetized state. In the present work a relation analogous to that of Wohlfarth though between in-field magnetization curves instead of remanence curves is derived. This allowed to introduce interaction plots obtained via measurements of the major hysteresis loop and a recoil curve only. The method is effectively tested on three real magnetic systems which evidence different interaction effects. Although the plots introduced here seem to provide information about interactions alike the classical remanence plots, they present important advantages. These plots are acquired in an easier and faster manner and do not demand demagnetization, which significantly simplifies the measurement procedure and allows assessment of interaction effects in virtually impossible to demagnetize systems with rectangular major loops. Furthermore, this method can easily be adapted for estimation of effects leading to deviations from theoretical behavior of other hysteretic quantities.

I. INTRODUCTION

For more that 50 years, the presence and intensity of dipolar and/or exchange interactions in systems presenting magnetic hysteresis have been determined by employing remanence plots.[1–3] This technique is based on a comparison of isothermal remanent magnetization (IRM) and DC demagnetization curves (DCD). The former, $M_{\rm r}(H)$, is obtained by measuring the remnant magnetization, $M_{\rm r}$, of a sample initially exhibiting zero magnetization (M) by applying and subsequently switching off a positive magnetic field, H. Increasing fields are successively applied and the procedure repeated until saturation in positive fields is reached. The DCD curve, $M_{\rm d}(H)$, is obtained after previous negative saturation using the same procedure where the respective remanence $M_{\rm d}$ is recorded. The variations in $M_{\rm r}(H)$ and $M_{\rm d}(H)$ are associated with irreversible magnetization processes only. The Wohlfarth relation[4]

$$M_{\rm d}(H) = 2M_{\rm r}(H) - M_{\rm r}(\infty) \qquad (1)$$

should be valid for non-interacting uniaxial-anisotropy particles. Deviations from the δM function[1]

$$\delta M(H) = 2M_{\rm r}(H) - M_{\rm d}(H) - M_{\rm r}(\infty) \qquad (2)$$

are ascribed to magnetic interactions. Positive δM values are normally attributed to exchange interactions and negative values are believed to indicate interactions (usually dipolar) stabilizing the demagnetized state. The so-called Henkel plot,[5] i.e., $M_{\rm d}(H)$ versus $M_{\rm r}(H)$, is a straight line with a slope of -2 in case of no interactions. Systems with Henkel plots that lie above (below) the straight line are considered as easier (harder) to magnetize than to demagnetize.

The $M_{\rm r}(H)$ curve depends on the method by which the (thermally, DC or AC) demagnetized state is attained. A connection between $M_{\rm d}(H)$ and the IRM curve traced starting from dc demagnetization state, $M_{\rm r}^{\rm dc}(H)$, has been derived.[2] The latter is produced by applying H equal to the remanence coercivity $H_{\rm r}$ [i.e., $M_{\rm d}(H_{\rm r})=0$] after a previous positive saturation, and then reducing H to zero. For $H<H_{\rm r}$, the $\delta M^{\rm dc}$ plot[6] equals

$$\delta M^{\rm dc}(H) = M_{\rm r}^{\rm dc}(H) - M_{\rm d}(H) - M_{\rm r}(\infty), \qquad (3)$$

and it reduces to $\delta M^{\rm dc}(H) = M_{\rm r}^{\rm dc}(H) - M_{\rm r}(\infty)$ for $H \geq H_{\rm r}$. The respective Henkel plot in the absence of interactions is a straight line with a slope of -1.

For non-interacting cubic-anisotropy systems, δM plots are intrinsically positive and, when different anisotropies coexist, their shape may vary significantly.[7] In ferromagnet/antiferromagnet layered structures, demagnetizing interaction effects could be achieve without the presence of dipolar interactions and remanence plots can be used to obtain information on the exchange coupling in each layer.[8,9] Surface spin disorder of isolated nanoparticles may lead to effects on δM similar to those produced by dipolar interactions.[10] The remanence plots technique has been adapted for studies of exchange-bias systems[11] which present asymmetric and shifted loops. The method can also be used for characterizing non-magnetic, e.g., ferroelectric, systems.[12]

Another interaction plot proposed by Masheva et al.[13] employs the initial magnetization curve, $M_{\rm ini}(H)$, and the major hysteresis loop, $M_{\rm hys}(H)$, transformed into periodic functions in the interval $(0,\,2\pi)$. Namely, $M_{\rm ini}(x) = M_{\max}\sum_n a_n^{\rm ini}\cos(nx)$ and $M_{\rm hys}(x) = M_{\max}\big[\sum_n a_n^{\rm hys}\cos(nx) + \sum_n b_n^{\rm hys}\cos(nx)\big]$ for odd n and with $x = \frac{1}{2}\pi(1 - H/H_{\max})$ for H changing between the positive and negative maximum values of H ($+H_{\max}$ and $-H_{\max}$), and $x = \frac{3}{2}\pi(1 + H/H_{\max})$ for H changing between $-H_{\max}$ and $+H_{\max}$ [here $M_{\max} = M(H_{\max})$]. For a non-interacting system, $a_n^{\rm ini}$ and $a_n^{\rm hys}$ are equal[13] and a function $\delta M_{\rm a}$ is defined as

$$\delta M_{\rm a}(x) = M_{\max}\sum_n (a_n^{\rm hys} - a_n^{\rm ini})\cos(nx). \qquad (4)$$

The characteristics of experimental $\delta M_{\rm a}$ and δM, plots yield on thermally or AC demagnetized samples, are very similar,[13] being $\delta M_{\rm a} \approx \frac{1}{2}\delta M$. Thamm and Hesse[14] proposed a plot, $\delta\hat{M}$, equal to $M_{\rm ini} - \overline{M}_{\rm hys}$, where $\overline{M}_{\rm hys} =$