Comparison of FORC Analysis Methods for Ni Nanorods in a Hydrogel

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The First Order Reversal Curve (FORC) analysis method has been shown to be a good qualitative tool for detecting interactions and their distributions between magnetic spins in ferromagnetic materials. As a consequence it is becoming a common technique in the examination of collections of nanoparticles and of both hard and soft ferromagnets. However, since the technique relies upon determining the distribution function:

$$\rho(H_R, H) = -\frac{1}{2}\partial^2 M(H)/\partial H_R \partial H$$

where M is the magnetization, H is the applied field, and H_R is the reversal field, proper calculation of the numerical derivative when there is no analytic function expressing the M versus H relationship is necessary if the technique is to be made quantitative.

For illustration, in this study we have measured the magnetization as a function of applied magnetic field for a large number of reversal fields on a system of 200 nm long Ni nanorods (20 nm diameter) randomly dispersed and embedded in a hydrogel. We then performed FORC analyses on this data set using several of the different methods (running average, local regression, etc.) presently being used in the community, as well as a new method using cubic splines developed at NIST, to calculate the distribution function ρ. Here, we develop metrics to assess the quality of each of these methods for FORC analysis. These metrics include the residuals in the magnetic moment and the standard error in the moment calculated from the predicted behaviour relative to the measured behaviour, as determined by each analysis method. By presenting these metrics as a function of field for different reversal fields, we also highlight regions where each method becomes problematic.

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