Orientation Distributions and Order Parameters for MP Tape

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Objectives

To obtain functions for the distribution of particle orientation directions in metal particle tape

To extract values of the order parameter, S, as a measure of the ordering of the magnetic particles

To use the order parameter to build structurally-based constitutive equations for MP tape — see companion project “Constitutive Relations for Magnetic Tape”
Order Tensor & Parameter

\[ S = \left\langle uu - \frac{1}{3} \delta \right\rangle \quad \rightarrow \quad S = \frac{3}{2} \sqrt{\frac{9}{2} \text{tr}(S \cdot S \cdot S)} \]

- \( S = 1 \) : perfect prolate order
- \( S = -\frac{1}{2} \) : perfect oblate order
Angular Dependence of the Remanence

- Measured on the vibrating sample magnetometer
- $M_p$ is the remanence measured parallel to the applied field
- $M_t$ is the remanence measured transverse to the applied field
Distribution of Particle Orientations

UA-DLT-IV-002

\[ f(\theta) = \frac{(M_p + \frac{\partial M_t}{\partial \theta})}{2} \]

Orientation Distributions in Fuji Ultrium LTO Tape

Angular dependence of parallel remanence ($M_p$) and transverse remanence ($M_t$)

Orientation Distribution
S from Distribution of Particle Orientations

\[ S = \left\langle uu - \frac{1}{3} \delta \right\rangle \]

\[ = \int \int uu f(\theta, \phi) \sin \theta d\theta d\phi - \frac{1}{3} \delta \]

Assume Uniaxial Symmetry

\[ S = S \left( \delta_z \delta_{zz} - \frac{1}{3} \delta \right) \]

\[ S = 1 - \frac{3}{2} \int_0^\pi p(\theta) \sin^3(\theta) d\theta \]

\[ \frac{p(\theta) \sin \theta d\theta}{2} \]
### Summary of Results for DLT IV Tapes

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<th>H&lt;sub&gt;c&lt;/sub&gt; (Oe)</th>
<th>SQ</th>
<th>M&lt;sub&gt;r&lt;/sub&gt;t (memu/cm²)</th>
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</table>
Luo & Bertram suggest:

\[ f(\theta, \phi) \propto e^{-\alpha(1 + \beta \cos^2 \phi) \sin^2 \theta} \]

This suggests using a single out-of-plane remanence measurement to determine \( \beta \) via:

\[
\frac{M_{rx}}{M_{sx}} = \frac{M_{rz}}{M_{sz}} = \frac{\langle u_x \rangle}{\langle u_z \rangle}
\]
Fuji Ultrium LTO Tape

Uniaxial Symmetry

Asymmetric

S=0.786

S=0.678
Conclusions

We can use measurements of the angular dependence of remanence to obtain particle orientation distribution functions.

The distribution functions allow us to calculate the order parameter.

The order parameter for DLT IV MP tape was in the range of 0.56 to 0.67.

Indicates there is plenty of room to improve the degree of orientation of the particles in MP tape.