The Mechanism of Spin-wave Switching

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Motivation

We want to understand switching in magnetic media (e.g., hard disk).

Basic problem: switch

Known mechanisms of switching:

- Curling
- Buckling
- Nucleation at end
Or, spin-wave switching (Safonov & Bertram 1999):

- Magnetization vs time for a $4 \times 4 \times 4$ system (finite temperature initial condition):

Does not go to -1 because spin wave energy cannot be dissipated (no damping)
Basic equation for precession

\[
\frac{d\mathbf{M}}{dt} = -\gamma \mathbf{M} \times \mathbf{H}
\]

\[
\mathbf{H} = \mathbf{H}_{\text{ext}} + \mathbf{H}_K + \mathbf{H}_{\text{exch}}
\]

- \(\mathbf{H}_{\text{ext}}\) - external magnetic field;
- \(\mathbf{H}_K = \frac{2K}{M_S^2} M_Z \hat{z}\) - effective anisotropy field due to intrinsic crystalline anisotropy or to sample shape
- \(\mathbf{H}_{\text{exch}} = \sum_{\text{nbrs}} J M'\) - effective exchange field;

Landau-Lifshitz equation without:
- damping (not important in early stages of fast switching)
- thermal (Langevin) noise (small, \(k_B T << \text{Zeeman energy}\))
Visualizing spin waves

Fourier-transform to get spin wave amplitudes:

\[ M(k) = \frac{1}{N^3} \sum_r M(r)e^{-i k \cdot r} \]

Each \( M(r) \) can be written as the sum of its Fourier components:

\[ M(r) = \sum_k M_k(r) \]

where the Fourier component is

\[ M_k(r) \equiv \text{Re}(M(k)e^{i k \cdot r}) \]

Rather than display the complex vector \( M(k) \) at each point in \( k \)-space, we display all the individual components \( M_k(r) \) for all cells \( r \) (\( N \) different values, 4 here) – they lie on an ellipse.

In \( k \)-space we show red polygon (approx. to ellipse)
Visualizing One Spin Wave

Two spaces:

- k-space shows spin waves present in the system. In this picture there is one spin wave with $(0,0,k_z)$ wave vector represented in k-space by the red polygon. The red line at point $(0,0,0)$ represents $k=0$ component (average magnetization).

- real-space shows the corresponding positions of magnetization vectors in the system.
Back to switching

We found:

• a uniform system with an almost-downward $H_{\text{ext}}$ would get close to the equator, but not switch (the upper picture);

• if we add exchange interactions we have switching. Lower picture is the last frame ($t = 0.3$ ns) of a movie (http://bama.ua.edu/~visscher/mumag/) which shows amplitude of spin waves - ‘k- space’ and magnetization - ‘real space’.

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Growth of spin-wave amplitudes

\[(n_x, n_y, n_z) = \text{wave vector in integer form:}\]

\[k = 2\pi \left( \frac{n_x}{L_x}, \frac{n_y}{L_y}, \frac{n_z}{L_z} \right)\]
Summary

We have identified the instability responsible for spin wave switching. Future plans include:

• Consider samples with boundaries (above results are for periodic b.c.’s)

• Add magnetostatic interactions (Fast Multipole Method)

• Determine which wavelengths are most unstable

• Model subsequent dissipation of spin-wave energy