Reversal Modes in Magnetic Nanowires

— Thesis Summary —

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The aim of this thesis is to explain phenomena in the reversal of the magnetisation in magnetic nanowires by analysing the underlying fundamental equations. In numerical simulations two different reversal modes have been found: the *transverse mode* occurring in very thin wires and the *vortex mode* occuring for thicker wires. We study the two modes analytically and investigate the reasons why they occur.

Static domain walls

In the first part of the thesis, we investigate static 180 degree domain walls. Such walls are minimizers of the micromagnetic energy functional

$$E(m) \ := \ \underbrace{\int_{\Sigma} |\nabla m|^2}_{\text{exchange energy}} \ + \ \underbrace{\int_{\mathbb{R}^3} |\nabla u|^2}_{\text{stray field energy}} \ , \qquad \Delta u = \operatorname{div} m \text{ in } \mathbb{R}^3$$

in a set that encorporates the condtion $|m| = 1$ and the boundary conditions $m(\pm\infty) = \pm\vec{e}_x$.

We show the existence of optimal wall profiles, and we discuss the scaling of the energy and the shape of the optimal wall profile.

When the radius tends to zero, transverse walls, i.e., walls that are constant on the cross section, have the optimal scaling of the energy. This scaling is $E \sim R^2$. When the radius tends to infinity, vortex walls, i.e., walls where the magnetisation is always tangential to the closest boundary and with a corotational symmetry, have the optimal scaling of the energy. This scaling is $E \sim R^2\sqrt{\ln(R)}$.

Moreover we show that, when the radius tends to zero the energy minimising problem Γ-converges to a reduced one dimensional problem. The profile of the minimiser m^{red} of the reduced problem resembles a Bloch wall. Thus, for small radii, minimisers of E are almost constant on the cross section and have a similar profile.

The transverse mode

We study the transverse mode via a perturbation argument from the static case. We show that for thin wires and weak external magnetic fields there exist travelling wave solutions of the gradient flow equation with respect to the micromagnetic energy.

The perturbation argument relies crucially on the fact that the wires are thin, since we need strong regularity of the static domain wall. We prove strong regularity in the case of thin wires, and we cannot expect it for thick wires, where the examples of low energy configurations are vortex walls, which have a singularity and are not even continuous. The regularity results are of interest on their own and might be useful for further investigations of magnetic nanowires.

The vortex mode

We model the vortex mode by harmonic map heat flow under an additional external field. This is a simplified model, which captures the highest order terms with respect to the derivatives. Moreover, we assume that the magnetisation in each point is tangential to the closest boundary. This ensures that we have a magnetisation without surface charges.

Using variational methods, we show the existence of corotationally symmetric travelling wave solutions with a moving vortex. We also show that, for weak and strong external fields, the travelling waves connect the original state anti-parallel to the external magnetic field with the fully reversed state in direction of the external field.