Finite-element micromagnetic modeling of spin-wave propagation with the open-source package TetraX

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Micromagnetic simulations have become one of the standard tools to corroborate experimental results or make theoretical predictions in the research field of magnonics. The freely available finite-difference codes MuMax3 or OOMMF [1,2] have been utilized in countless works on magnetization dynamics or statics. One of the key objectives of micromagnetic simulations, besides looking for equilibrium textures of various geometries, is the determination of the spin-wave dispersion and mode profiles in magnetic samples of various geometries and material parameters. In three-dimensional dynamic simulations, this is often achieved by applying microwave fields in numerical experiments, integrating the Landau-Lifshitz-Gilbert equation of motion forward in time, and later-on performing a Fourier analysis. Although this methodology is very versatile and widely used, it is, in fact, not well-suited to study spin-wave propagation in quasi-infinitely long waveguides or extended layers due to the inability to separate degenerate modes, limited wave-vector resolution and drastically increasing computational effort with increasing sample size [3]. Especially in geometries with surface curvature, which require an accurate modeling of the sample surface, dynamic micromagnetic simulations become computationally exhausting. To address this challenge, we present a finite-element-method (FEM) dynamic-matrix approach to efficiently calculate the dispersion and spatial mode profiles of spin waves propagating in waveguides with arbitrary cross section, where the equilibrium magnetization is invariant along the propagation direction [4]. This is achieved by solving numerically a linearized version of the equation of motion of the magnetization only in a single cross section of the waveguide at hand. To compute the dipolar field, we present an extension of the well-known Fredkin-Koehler method [5] to plane waves. The presented dynamic-matrix approach is implemented within our recently published open-source micromagnetic modeling package TetraX [6] which aims to provide user friendly and versatile FEM workflows for the magnonics community (not only for magnonics community, but FEM simulations in general), covering several classes of sample geometries and also antiferromagnets with fully compensated moments. As a brief introduction, this talk will include a short live-demo of TetraX. Furthermore, as an application of our method, we present results on curvature and symmetry effects on the spin-wave dynamics in magnetic nanotubes of different geometry, from elliptical to polygonal tubes and thick magnetic membranes in general.

References

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