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TITLE: Proposal for a Standard Problem for Micromagnetic Simulations Including Spin-Transfer Torque

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Digest Body: The spin-transfer torque between itinerant electrons and the magnetization in a ferromagnet is of fundamental interest for the applied physics community. There exist theoretical descriptions of the spin-transfer torque for the case of a current traversing an interface between a ferromagnet and a non-magnetic metal and for the case of a current passing through a continuously varying magnetization. For the second case a description has been developed by Berger [1] and was later refined by Zhang and Li [2] as well as by Thiaville et al. [3]. For a comparison of different simulation tools it is important to develop standard problems that can be simulated by different tools and allow to verify the correctness of the implementation. Previous standard problems do not include the spin-transfer torque. We propose a standard problem, including the spin-transfer torque in the case of a continuously varying magnetization. For the proposed problem, we define criteria necessary to ensure that the problem is suitable for the validation and falsification of micromagnetic simulation tools. These criteria are then applied to the underlying extended micromagnetic model. The resulting standard problem geometry is a permalloy cuboid of 100 nm edge length and 10 nm thickness, which contains a Landau pattern with a vortex in the center of the structure. A spin-polarized dc current density of 10^{12} A/m^2 flows laterally through the cuboid and moves the vortex core to a new steady-state position as shown in Fig 1. To proof the suitability of the proposed problem as a standard problem, we investigate the influence of typical errors, such as erroneous variations of the spin-transfer torque extension by a constant factor or an improper spatial discretization. Finally numerical results from the extended OOMMF by Krüger et al. [4], the extended OOMMF by Vanhaverbeke et al. [5,6], M^{3}S [7], and NMag [8] as well as the analytically calculated values according to Krüger et al. [4] are compared. This comparison substantiates the good falsification and validation properties and shows that the problem discriminates errors larger than 5.41 kA/m (1.9 %) and 4.80 kA/m (3.0 %) for $\langle M_x \rangle$ and $\langle M_y \rangle$, respectively.

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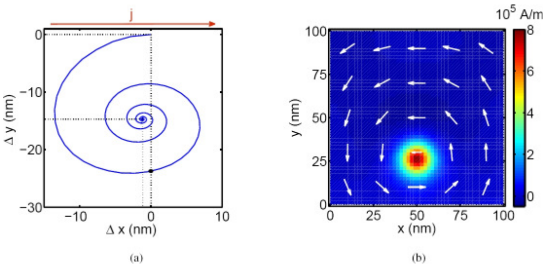
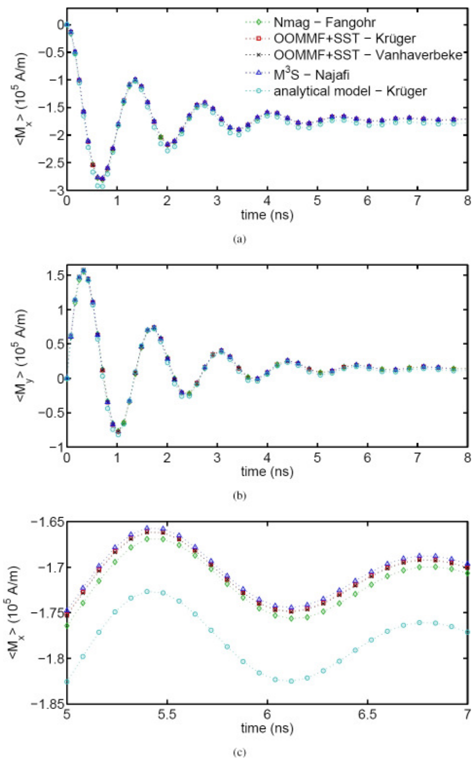


(a) Two-dimensional representation of the position of the vortex core as a function of time. The dot indicates the vortex-core position at the time t = 0.73 ns. (b) Snapshot of the magnetization of the permalloy cuboid at t = 0.73 ns when the vortex-core position crosses the line Δx = 0 for the first time. The magnetization is excited by a homogeneous spin-polarized current density of 10^{12} A/m^2 in the x-direction, i.e., the electrons flow from right to left. The magnetization is averaged along the z-direction. The color scale shows the z-component of the magnetization. Simulations are computed with M^3S.



Solution of the proposed standard problem for a 100x100x10 nm^3 permalloy cuboid calculated with four different simulation tools and the analytical model. A spatially and temporally homogeneous current density of 10^{12} A/m^2 is applied instantaneously in x-direction. (a) The x-component of spatially averaged magnetization $\langle M_x \rangle$ (b) $\langle M_y \rangle$. (c) Close-up of the x-component for the time interval 5 ns $\leq$ t $\leq$ 7 ns.
