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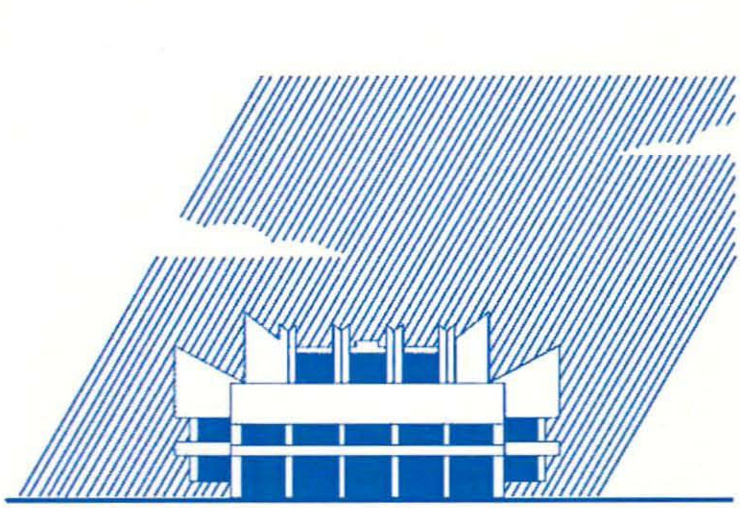

AXIAL-SYMMETRIC VORTEX POLARITY SWITCHING IN FERROMAGNETIC PARTICLES

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Process of switching of vortex polarity in magnetic nanodots under the action of transversal magnetic dc field is studied numerically and theoretically. Three different models of ferromagnet are considered: (i) Heisenberg ferromagnet with volume easy-plane single-ion anisotropy, (ii) Heisenberg magnet with additional surface anisotropy, (iii) Heisenberg magnet with anisotropic exchange. We show that depending on the type of interactions, the vortex polarity switching is accompanying by the Bloch point mechanism or not. The switching process in all cases is described analytically with a good agreement with numerical study.

Recent technical development makes possible creation and investigation of submicron-size magnetic particles with closed magnetic flux. In many cases such structures demonstrate a variety of ground states with closed magnetic flux depended on their geometry. The simplest examples of the closed magnetic flux structures are single vortices, formed in disk-shaped particles with characteristic size about 50 nm (for such typical soft ferromagnet as Permalloy, $Ni_{20}Fe_{80}$). The magnetization in the sample center is always perpendicular to the sample; its direction is called polarity (positive or negative). The controlled switching of the vortex polarity by external fields or spin currents makes them a perspective candidate for a high speed magnetic random access memory and high density magnetic storage devices, where one bit of information is associated to the polarity direction.

There are few ways to change polarity by external field. In this work we consider the axial-symmetric or, so-called punch-through switching process, which takes place under the action of dc [1, 2] or ac [3] magnetic fields. According to micromagnetic simulations, the switching in thick samples is mediated by the Bloch point [1], while another mechanism accompanied by the temporal creation of a planar vortex was suggested in [2]. These results are referred to micromagnetic simulations, where the modeling of singularity is mesh–dependent, because within the continuum description the switching is forbidden. To avoid such problems, we study the polarity switching phenomena, including the Bloch point problem, in thin disks via in-house developed spin-lattice simulator SLaSi [4, 5], which works on discretized version of Landau-Lifshitz-Gilbert equation. The next models of ferromagnet are considered: (i) Heisenberg magnet with volume easy-plane single-ion anisotropy; (ii) the same as previous in addition with surface single-ion anisotropy; (iii) Heisenberg magnet with easy-plane anisotropic exchange.

(i) Homogeneity of anisotropy parameters in case of single-ion anisotropy leads to equivalency between 3D and 2D model, because magnetic moments with different coordinate along nanodisk axis move simultaneously. The ground state corresponds to one of equivalent states with opposite vortex polarities. By applying an external field we break the symmetry between these states. Initially the vortex polarity is directed opposite to the external field. Under the action of the field the vortex losses its stability, which finally leads to the switching of its polarity above some threshold value. The first stage of this process consists in reorientation of the magnetization far from the vortex core due to the field influence (the vortex in a cone state); the magnetization inside core does not change sufficiently. During the next stage, the magnetization inside the core rapidly decays and changes its direction via the state with a zero core magnetization. It can be interpreted as appearance of a spatio-temporal Bloch point, see Fig.1, which resembles a singularity during the switching process in antiferromagnets [6]. Our numerical study is well confirmed by developed collective variable dynamical theory of the switching phenomena.

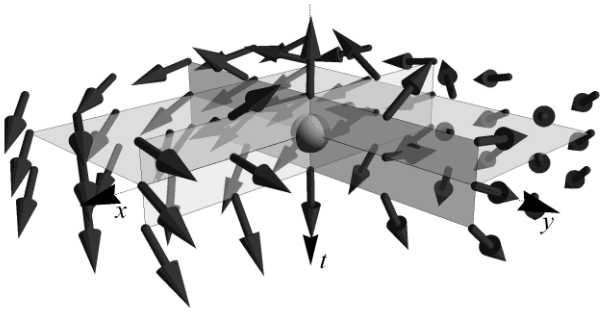

Fig. 1. Point singularity in space-time representation. Sphere corresponds to spatio-temporal Bloch point.

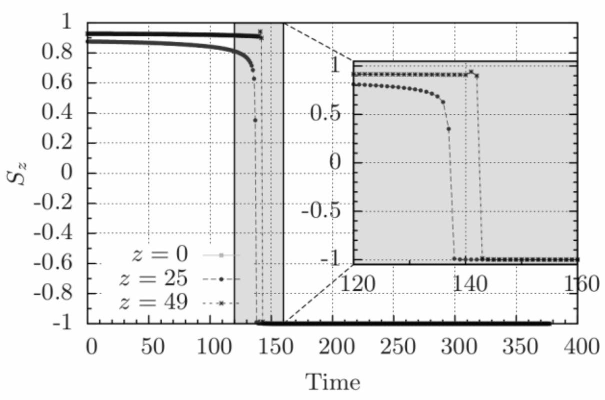

Fig 2. Bloch point mediated switching in the sample with sharp surface single-ion anisotropy. Z projections for spin vectors at the face surfaces and center of the sample are shown.

(ii, iii) Appearance of additional surface single-ion anisotropy breaks the symmetry between different layers in spin lattice along nanodot axis. The same is observed in the case of anisotropic exchange due to the different number of neighbors on edges of the sample. The ground state of such a magnet is a vortex one with a spatially deformed core along the thickness; its width is depended on a sign and absolute value of the surface anisotropy. For easy-plane surface anisotropy the width of the vortex core reaches maximum at the center of the vortex line. We describe the shape of the vortex core analytically taking into consideration the influence of a surface energy, which leads to the mixed boundary conditions for magnetization. For the case of the strong surface anisotropy the Bloch points appear simultaneously from the center of the axis under the influence of external field. The vortex line breaks into three parts with different polarity directions; the singularities move in direction to the face surfaces. In contrast, easy-axis and low easy-plane surface anisotropies give an opposite picture for core shape and Bloch point dynamics. Singularities appear near the face surfaces and move to the center of the sample.

All numerical data are confirmed by developed theoretical description.

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