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## BLOCH POINT DYNAMICS IN VORTEX POLARITY SWITCHING PROCESS

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*Bloch point (BP) is a micromagnetic singularity, which plays a key role in dynamical switching process of the vortex state magnetic nanoparticle. The Bloch point dynamics is studied theoretically using spin-lattice simulations for two ultrafast processes: (i) the magnetization reversal under the action of DC magnetic field; (ii) the vortex core switching mediated by the creation and annihilation of the vortex-antivortex pair. The range of the nanodot sizes where the mechanism of the vortex switching, mediated by the Bloch point formation, takes place is computed. The structure of the static singularity is studied analytically.*

A strikingly rapid development of the elementary base of systems of information storage and processing causes the changeover to magnetic particles and their superstructures with typical scales less than a micron. Investigations of magnetic nanostructures include studies of magnetic nanodots, i. e. submicron disk-shaped particles which have a single vortex in the ground state due to the competition between exchange and magnetic dipole-dipole interaction. A vortex state is obtained in nanodots that are larger than a single domain whose size is a few nanometers: e. g. for the Permalloy (Py, $Ni_{20}Fe_{80}$) nanodot the exchange length is about 6 nm. Magnetic nanodots with their vortex ground state show a considerable promise as candidates for high density magnetic storage and high speed vortex random access memory. The state representing a bit is usually associated with the polarity, which corresponds to the upward or downward magnetization of the vortex core.

There exist different ways to cause the process of the vortex polarity switching. Investigations were started with the switching under the action of a DC magnetic field. Under the action of magnetic field, directed opposite to the vortex polarity, the vortex loses its stability, which finally causes polarity switching. This type of the switching was observed experimentally in Py disks [1]. The micromagnetic modeling of the switching effect for relatively thick disks [2] indicates that the possible switching mechanism is the formation of a Bloch point (BP) in the centre of the vortex. The typical size of Bloch points is about 20 nm according to Ref. [2]. However, in thinner nanodisks this mechanism of vortex polarity switching is questionable. Another mechanism [3] describes the vortex switching process through the temporary formation of pure planar vortex, i.e. without the BP formation. However all mentioned above switching processes are forbidden in the continuum theory, thus the switching process should be revised.

The purpose of the current work is to study the switching process in details, especially, the role of the micromagnetic singularity, i. e. the BP in the vortex polarity switching. We studied, first of all, the structure of the BP. The BP is known to appear as a simplest 3D “hedgehog” singularity in the distribution of the magnetization vector $\mathbf{M} = M_0\mathbf{r}/r$, where $M_0$ is the saturation magnetization and $\mathbf{r}$ is the radius vector. The shape of the BP in the media has typically more complicated form, $\mathbf{M} = M_0\left(\sin\vartheta\cos\left(\chi-\gamma\right),\sin\vartheta\sin\left(\chi-\gamma\right),\cos\vartheta\right)$ with $\vartheta,\chi$ being the spherical coordinates of the radius vector $\mathbf{r}$. The angle $\gamma$ of the BP orientation is caused by the dipole-dipole interaction [4]. The dipolar energy of BP is found to be equal to $W_{dip}\left(\gamma\right) = \dfrac{8\pi^2 M_0^3 R^3}{135}\left(5\left(1+2\cos\gamma\right)^2 + 4\sin^4\dfrac{\gamma}{2}\right)$, where $R$ is the BP radius. This stray field energy is minimized by the BP orientation angle $\gamma = \pi - \arccos\left(3/7\right) \approx 115°$.

In order to investigate the ultrafast process of the vortex switching, mediated by the BP creation, we performed 3D SLASI simulator, an in-house-developed spin-lattice code [5], extending ideas on quasi-2D simulator [6]. Since the simplest model which supports the vortex appearance is the

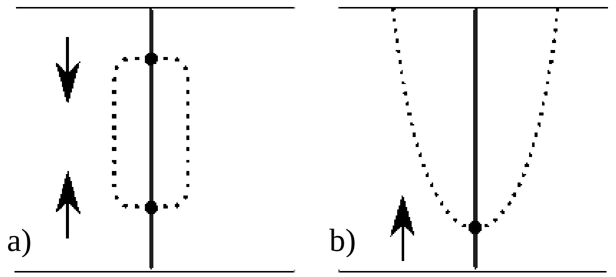


*Fig. 1. Schematic of the BP dynamics during the switching under the action of DC field. ): (a) for exchange anisotropy simulations; (b) for dipolar ones. Solid curves indicate vortex lines, dotted curves correspond to the isosurface $S_z = 0$, circles indicate BP position, and arrows indicate BP motion direction.*

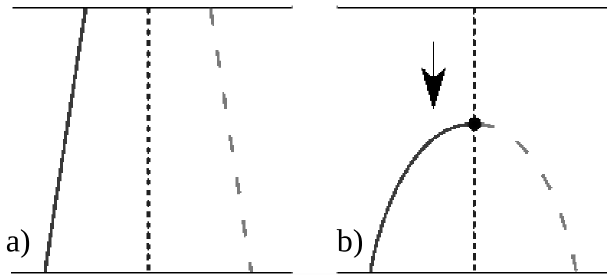


*Fig. 2. Schematic of the vortex-antivortex annihilation process:(a) before annihilation and (b) during the process. The dashed curves indicate the antivortex lines. Other notations are the same as in Fig. 1.*

Heisenberg magnet with the easy-plane anisotropy, we studied the vortex switching in the anisotropic system without dipolar interaction.

Numerically, we studied the switching process for the vortex state disk-shape system. In the case of the single-ion anisotropy, the switching process is homogeneous along $z$ and one has a linear singularity, the Bloch line instead of the BP. In the case of the exchange anisotropy, there appear simultaneously two BPs at face surfaces of the disk, see Fig. 1(a). They move in opposite directions and annihilate at disk centre. The main part of interest was to study the switching process in the magnet with account of the dipolar interaction, with parameters similar to soft nanomagnets like Py. Numerical simulations confirm that the switching process of the vortex polarity is mediated by the BP for both thick and thin nanodisks. The BP appears on one of the face surfaces and moves along the vortex line during the switching process, see Fig. 1(b).

We also study the BP dynamics in different kind of numerical experiment. It is known [7] that the ultrafast vortex polarity switching can be caused by AC fields. In this case the switching occurs through the process of creation of the vortex-antivortex pair, which has a polarity opposite to the original vortex, and annihilation of original vortex with a new antivortex. While the general scheme of the process seems to be studied [8], the detailed study of the pair annihilation is not clear. It was found in [9] that the BP can appear during the process of the vortex-antivortex annihilation. Numerically we studied this process in a wide range of the particle thickness $h$ and found the critical behaviour: the BP mediated switching occurs for thin enough particles, when $h < h_{cr}$, see Fig. 2. In case of thicker particles the new born vortex-antivortex pair annihilates by itself.

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