Normal modes of dipolar-coupled vortex oscillators: A two-magnetic-nanodisk system

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1. Introduction

The magnetic vortex core exhibits nontrivial low-frequency in-plane orbital motion around the equilibrium position in confined magnetic elements: the so-called translational mode [1]. Dipolar-coupled disks have been studied intensively [2-9] for their low-energy-dissipation advantage in information processing applications. Coupled vortex-core gyrations and their eigenfrequency splitting, for instance, have been observed experimentally [6-8]. However, a comprehensive understanding of the fundamentals of dipolar-coupled gyrations remains elusive. In this presentation, we will address normal modes and their dependences on the relative vortex-state configurations in both disks by using micromagnetic numerical as well as analytical calculations.

2. Micromagnetic simulations and analytical calculations

We performed micromagnetic simulations of the magnetization dynamics in two identical Permalloy (Py: $Ni_{81}Fe_{19}$) disks of $2R$ = 303 nm diameter, L = 20 nm thickness, and 15 nm edge-to-edge inter-distance utilizing OOMMF code [10]. In the model, four different relative vortex-state configurations of vortex core orientations and in-plain curling magnetization directions, were examined. In order to excite all of the modes existing in the two dipolar-coupled disks, the vortex core only in the right disk of each pair was intendedly displaced to an initial position, 69 nm in the ^{+}y direction by application of a 300 Oe field in the ^{+}x direction locally, after which both disks were relaxed.

The common features were the beating patterns of the oscillatory x and y components of both vortex-core position vectors along with the crossovers between the local maxima and minima of the modulation envelopes between two disks. The beating frequencies, relative rotation senses and phase differences between two disks, as well as the frequency splitting, were in contrast with the vortex-state configuration in one disk with respect to that in the other disk.

3. Analytical calculations of normal modes

In order to fully understand such complicated coupled gyrations as found in those simulation results, we analytically derived the normal modes of different single eigenfrequencies on the basis of two coupled linearized Thiele's equations [11] accompanying with two normal-mode coordinates [9] derived from considering the symmetry of the two identical disks of a given relative rotational sense of gyrotropic motions. From the superposition of two normal modes in each disk, we obtained the net coupled vortex gyrations in both disks, which were in excellent agreements with those obtained from the simulation results.

4. Conclusions

We found from analytical derivations and micromagnetic numerical simulations that there exist two distinct normal modes in apparently complex vortex gyrotropic motions in two dipolar-coupled magnetic nanodisks. This work provides a simple but complete means of understanding complex vortex gyrations in dipolar-coupled vortex oscillators in terms of the superposition of the two normal modes

This work was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education, Science and Technology (No. 20110000441)..

5. References

[1] K. Y. Guslienko et al., J. Appl. Phys. **91**, 8037 (2002).

[2] J. Shibata, K. Shigeto, and Y. Otani, Phys. Rev. B **67**, 224404 (2003).

[3] A. Vogel, A. Drews, T. Kamionka, M. Bolte, and G. Meier, Phys. Rev. Lett. **105**, 037201 (2010).

[4] S. Sugimoto et al., Phys. Rev. Lett. **106**, 197203 (2011).

[5] A. Barman, S. Barman, T. Kimura, Y. Fukuma, and Y. Otani, J. Phys. D. **43**, 422001 (2010).

[6] H. Jung, Y.-S. Yu, K.-S. Lee, M.-Y. Im, P. Fischer, L. Bocklage, A. Vogel, M. Bolte, G. Meier, and S.-K. Kim, Appl. Phys. Lett. **97**, 222502 (2010).

[7] H. Jung, K.-S. Lee, D.-E. Jeong, Y.-S. Choi, Y.-S. Yu, D.-S. Han, A. Vogel, L. Bocklage, G. Meier, M.-Y. Im, P. Fischer, S.-K. Kim, arXiv:1011.6399 (2010).

[8] A. Vogel et al., Phys. Rev. Lett. **106**, 137201 (2011).

[9] K.-S. Lee, H. Jung, D.-S. Han, and S.-K. Kim, arXiv: 1102.0519 (2011).

[10] See http://math.nist.gov/oommf.

[11] A. A. Thiele, Phys. Rev. Lett. **30**, 230 (1973); D. L. Huber, Phys. Rev. B **26**, 3758 (1982).