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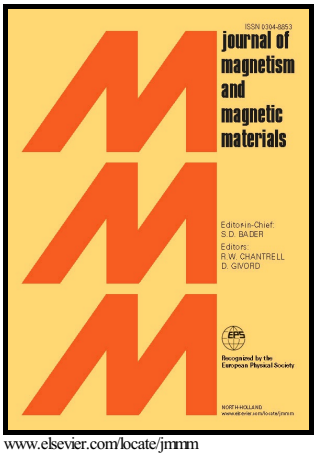

www.elsevier.com/locate/jmmm

PII: S0304-8853(16)31209-4
DOI: http://dx.doi.org/10.1016/j.jmmm.2016.06.066
Reference: MAGMA61587

To appear in: *Journal of Magnetism and Magnetic Materials*

Received date: 15 April 2016
Revised date: 22 June 2016
Accepted date: 23 June 2016

Cite this article as: Nasim Bazazzadeh, Seyed Majid Mohseni, Amin Khavasi Mohammad Ismail Zibaii, Seyed M. Sadegh Movahed and Gholam Reza Jafari Dynamics of magnetic nano-flake vortices in newtonian fluids, *Journal o Magnetism and Magnetic Materials* http://dx.doi.org/10.1016/j.jmmm.2016.06.066

Dynamics of Magnetic Nano-Flake Vortices in Newtonian Fluids

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Abstract

We study the rotational motion of nano-flake ferromagnetic discs suspended in a Newtonian fluid, as a potential material owing the vortex-like magnetic configuration. Using analytical expressions for hydrodynamic, magnetic and Brownian torques, the stochastic angular momentum equation is determined in the dilute limit conditions under applied magnetic field. Results are compared against experimental ones and excellent agreement is observed. We also estimate the uncertainty in the orientation of the discs due to the Brownian torque when an external magnetic field aligns them. Interestingly, this uncertainty is roughly proportional to the ratio of thermal energy of fluid to the magnetic energy stored in the discs. Our approach can be implemented in many practical applications including biotechnology and multi-functional fluidics.

Keywords: Brownian dynamics simulation, nano-flakes, magnetic vortex, nano-bio-magnetics.

1. Introduction

Magnetic nanostructures and nanoparticles[1–3] have great potential in many nano-bio-magnetic applications, including bio-sensing[4–6], cell separation[7], magnetic resonance imaging contrast-enhancement agents[8], targeted drug delivery[2], deep brain stimulation[9], and targeted cancer-cell destruction[10,11]. Among them, magnetic nano-flakes, with thickness below 100 nm and approximate radii well below a micron, a circularly-closed magnetzation profile, nominated as magnetic vortex, has shown great interest in multidisciplinary science including magnetism[12] and bio-technology[11]. The formation of topologically robust magnetization with in-plane component except with that having out-of-plane counterpart at the centre represents negligible stray field. This behaviour provides a different type of weak interacting particles analogue to that of superparamagnetic particles. Applying in-plane magnetic field can displace the vortex centre and results in large in-plane magnetization[12]. This leads to strong magnetic response of nano-flake vortices (NFVs) which gives them an advantage over superparamagnetic nanoparticles[13]. They show interesting properties, e.g. zero remanence and strong magnetic response. Albeit magnetic vortex is a deeply focused and important