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Magnetic and Mechanical Resonance of a Single Ferromagnetic Nanoparticle in a Viscous Fluid

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Resonance is a widely spread phenomenon in our life. The mathematical apparatus for this phenomenon was developed absolutely, and a lot of examples, both desirable and undesirable were studied in detail. Thus, in particular, the resonance behavior of the nanoparticle magnetic moment driven by an external alternating field was scrutinized in [1]. Here the nanoparticle was considered to be embedded into a solid matrix. As it was expected, when the field frequency approaches to resonance frequency $\omega_r = H_a\gamma$ (where H_a is the effective anisotropy field, γ is the gyromagnetic ratio), the resonance was observed. But there is a crucial question: how this behavior changes when the easy axis becomes free?

The situation, when the particle is not fixed rigidly, is actually not unique and is typical for nanoparticles, contained in a ferrofluid. Every nanoparticle here is viscously coupled with a carrier and the nanoparticle easy axis can be involved into motion due to anisotropy field H_a. The description of the nanoparticle rotation and the magnetic dynamics into the rotated nanoparticle was performed in the way, represented in [2]. Further we utilized the linear approximation [1] to obtain analytical expressions for trajectories of the nanoparticle easy axis and the nanoparticle magnetic moment.

The trajectories obtained were analyzed for different system parameters. Special attention paid to the energy, which is dissipated through the viscous rotation of the particle and damping precession of its magnetic moment. It was established that the damping magnetic dynamics makes main contribution into the dissipated energy. But the easy axis oscillations can essentially affect the magnetic dynamics and the resulting energy dissipation. While the viscosity value remains large enough, the asynchronous motion of the magnetic moment and the easy axis takes place. It leads to the dissipation enhancement. But while the viscosity value is small, in contrary, the magnetic moment and the easy axis are rotated synchronously, and the suppression of the dissipation is observed.

1. K.D. Usadel and C. Usadel, *J. Appl. Phys.* **118**, 234303 (2015).
2. T.V. Lyutyy, et. al, *Phys. Rev. B* **91**, 054425 (2015).