Modeling the Brownian relaxation of nanoparticle ferrofluids: Comparison with experiment

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Introduction: There are a significant number of applications for magnetic nanoparticles including their roles as tracer materials, biomarkers, and biosensors. An example is Magnetic Particle Imaging (MPI) based on the nonlinear magnetization of iron oxide tracers [1, 2]. The interaction of the magnetic nanoparticles with external magnetic fields, and the resulting changes in their magnetization, are the key to these applications. Magnetic Particle Spectroscopy (MPS) can provide insight into the dynamical properties of a nanoparticle ferrofluids by measuring the magnetization response and the harmonic signal spectrum of the tracer materials [3].

Materials and Methods: The Fokker-Planck (FP) equation provides a mathematical description of ferrofluid magnetization under the influence of external oscillating magnetic field [4]. We investigate several methods for numerically solving the FP equation when the viscous (or Brownian) effects are the dominate relaxation mechanism. We apply these numerical methods to models of nanoparticle ferrofluids and compare the results to recent experimental measurements of ferrofluids with different viscosities and containing nanoparticles with hydrodynamic diameters in the 40 – 120 nm range [3].

Results: We find good agreement (see Fig. 1) between the calculations and measurements provided that: 1) we use an accurate numerical integration of the FP equation and; 2) the spread in the hydrodynamic diameters of the particles (polydispersion) is included in the models. We find that that adiabatic approximation and the effective field approximation to the FP equations [4] were not sufficiently accurate for the entire range of frequencies, viscosities, and particle sizes used in the measurements.

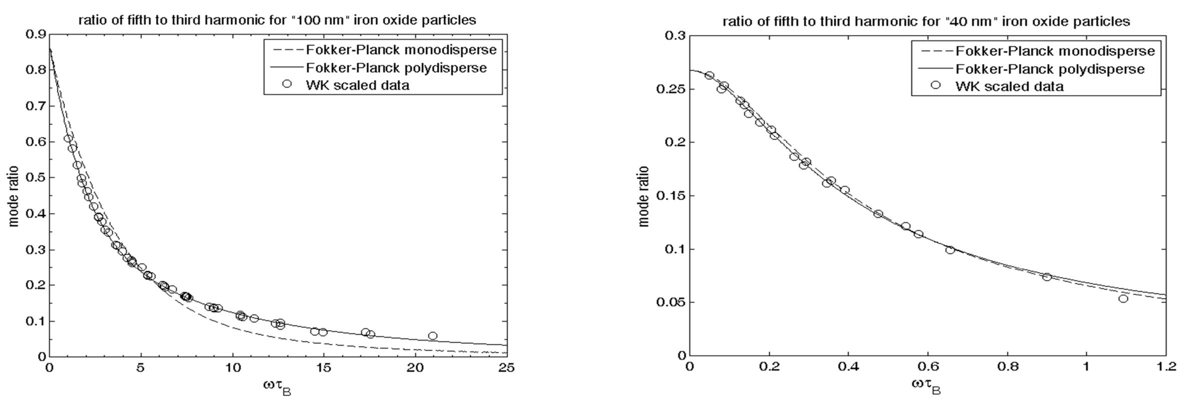

Figure 1: Measured and calculated ratio of the 5^{th} to 3^{rd} harmonics for the (a) "100 nm" and (b) "40 nm" iron oxide particles in glycerol-water ferrofluids. The measured values [3] (indicated by circles) are scaled as a function of $\omega\tau_B$ (the drive frequency ω times the Brownian relaxation time τ_B.) The dashed (solid) line is the harmonic ratio from the FP approach with a monodisperse (polydisperse) model.

References: [1] B. Gleich and J. Weizenecker, Nature 435, 1214-1217 (2005). [2] J. Weizenecker, B. Gleich, J. Rahmer, H. Dahnke, J. Borgert, Phys. Med. Biol. **54**, L1-L10 (2009). [3] J. B. Weaver and E. Kuehlert, Med. Phys. **39**, 2765-2770 (2012). [4] W.T. Coffey, Y.P. Kalmykov, J.T. Waldron, *The Langevin Equation*, 2nd ed. (World Scientific, Singapore, 2004).

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