3D rotational dynamics of ferromagnetic nanorods in viscous liquids

*Palkar, V[1]., Aprelev, P[1]., Mckinney, B[2]., Kuksenok, O[3]. and Kornev, K.[4]

Graduate Student, Department of Materials Science and Engineering, Clemson University; Undergraduate Student, Department of Materials Science and Engineering, Clemson University; Associate Professor, Department of Materials Science and Engineering, Clemson University; and Professor, Department of Materials Science and Engineering, Clemson University

kkornev@clemson.edu; https://cecas.clemson.edu/kornevlab

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Abstract: Magnetic rotational spectroscopy (MRS) is a microrheology technique used to characterize rheological properties of small amounts of liquids from motion of elongated magnetic nanoparticles driven by external magnetic fields. Under the action of a planar rotating magnetic field, magnetic nanoparticles perform two kinds of planar rotational motions – synchronous and asynchronous. However, scientific literature has reported 3D rotational motions possibly caused by external bias fields (such as the earth's magnetic field). In this work, we aim to develop a 3D model for ferromagnetic nanorods rotating in Newtonian liquids under the action of external torques to further understand these dynamics. The theoretical model is developed based on a torque balance approach. The model shows dependence on two experimental parameters – frequency of rotating magnetic field and magnitude of the bias field. Phase portrait approach helps us categorize different kinds of dynamics. Stability analysis helps us theoretically quantify time needed to attain stabilization. We have also performed MRS experiments with Ni nanorods in viscous liquids. The analysis shows that similar to the planar case, a critical transition from synchronous to asynchronous regime is observed in the 3D dynamics but the asynchronous dynamics stabilize with time. The bias field causes faster stabilization of these asynchronous dynamics and for the range of values considered, the bias field has no impact on the final synchronous state. This work has lead to development of better understanding of the out-of-plane dynamics of elongated nanoparticles subjected to planar rotating fields. This opens up avenues to study these dynamics for particles in non-Newtonian fluids and thus further extend the MRS technique.