Motion and Interaction of Magnetic Particles for Advanced Materials

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Abstract. New research frontiers in multifunctional materials are rapidly moving toward the generation of novel nanocomposites based on magnetic nanoparticles that play the role of fillers embedded into a polymeric matrix. In such materials the interaction between particles during manufacturing and the interaction of the embedded particles with a surrounding magnetic field, is of major importance for performance enhancement. This paper focuses on the mutual interaction of single nanoparticles that have an intrinsic magnetic dipole as well as on the magnetic field – embedded group of particles interaction, evaluating the space-time parameters and forces involved. The work is performed with a computational and an experimental approach.

Introduction

Magnetic nanocomposites are among the most innovative materials emerging in recent years since they allow the achievement of unprecedented multiple functions [1]. The material design is conceived as magnetic nanoparticles embedded in a hosting matrix to allow shape control through an external magnetic field. In general, nanocomposites manufacturing is known to be challenging since the material properties and performance are deeply affected by slight variations of the nanoparticles distribution within the hosting matrix. Typically manufacturing consists of multiple steps. A nanofiller powder is sonicated directly with a polymer solution or, when such a solution is excessively viscous, it is first sonicated with solvents. Sonication is also critical because it influences the final nanoparticles distribution, which should be highly uniform for optimal material properties. In the case of magnetic particles this step becomes more complex because such particles are affected by a significant mutual interaction due to their dipole moments. In a fully manufactured nanocomposite, the particles-magnetic field interaction is affected by their relative configuration within the polymer chains. A full understanding of the interaction among single particles and of the interaction of a trapped group of particles with a magnetic field is thus critical and is the focus of this paper.

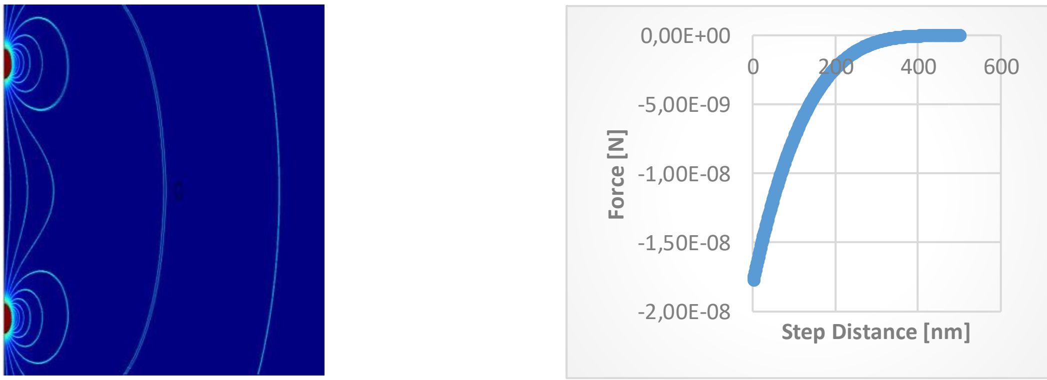

Figure 1: Interacting magnetite nanoparticles placed at a 500nm initial distance.

Results and Discussion

The interaction between point-like Fe_3O_4 magnetite dipole particles was simulated through Comsol Multiphysics by exploiting Keesom forces with the hypothesis that the permanent dipoles align with each in such a way that the positive pole of a molecule is directed towards the negative pole of another nearby molecule [2]. Focus was given to the interacting force variation as a function of the particles distance. Such force was found to be highly nonlinear as in Figure 1. The experimental study also shows a strong nonlinear motion of nanocomposite spheres made of Fe_3O_4 particles embedded in a PMMA matrix and exposed to a permanent magnetic field. The motion was monitored with the support of an ultra-high-speed video camera which acquired 1600 frames per sec. The sphere was capable to cover a 3.5 cm distance in a time step as low as 52 ms with the highest acceleration reached in proximity of the magnetic field source.

References

[1] Kim Y., Yuk H., Zhao R., Chester S. A., Zhao X. (2018) Printing ferromagnetic domains for untethered fast-transforming soft materials. Nature 558: 274-279

[2] Fjellsträm M., Hedman D. (2013) Modeling the interactions between magnetic particles, Project in Computational Methods and Physics (F7033T) at Luleå University of Technology

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