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Clustering of Magnetically Soft Particles: Efficient Description beyond the Dipole Model

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Magnetic multi-domain particles typically exhibit a soft magnetic behavior with a pronounced sensitivity to the local magnetic field. Such particles as carbonyl iron or silicon iron are widely used in magnetorheological fluids, gels and elastomers. When two or more such particles approach each other in the presence of an applied field, they noticeably influence the magnetization of the others. In order to describe the magnetization distribution and the subsequent magnetic body forces among individual particles, a common way is to assign each particle a single point dipole. It is known that when particles are getting close to each other, the dipole approximation is no longer valid and strongly underestimates the true interactions [1]. Beyond the dipole approximation, only elaborate full-field methods can be used to capture these so-called near-field effects. Since these methods become quite complex when particles begin to cluster, precise calculations beyond the dipole model are computationally very costly.
Based on a compact function [1] for the two-body solution, we develop a quasi-analytic approximation scheme for many-body full-field interactions. The concept can be formulated in an equivalent way as known for the dipole description [2]. Likewise, also the computational effort is comparable to the classical dipole model, with the benefit that additional near-field effects are explicitly accounted for (see Figure).
Considering these corrections due to near-field effects, the process of cluster formation and dispersion among particles in either increasing or decreasing magnetic fields is significantly influenced. A fast and efficient description of full-field effects will represent a considerable improvement for the modeling of multi-domain particles.

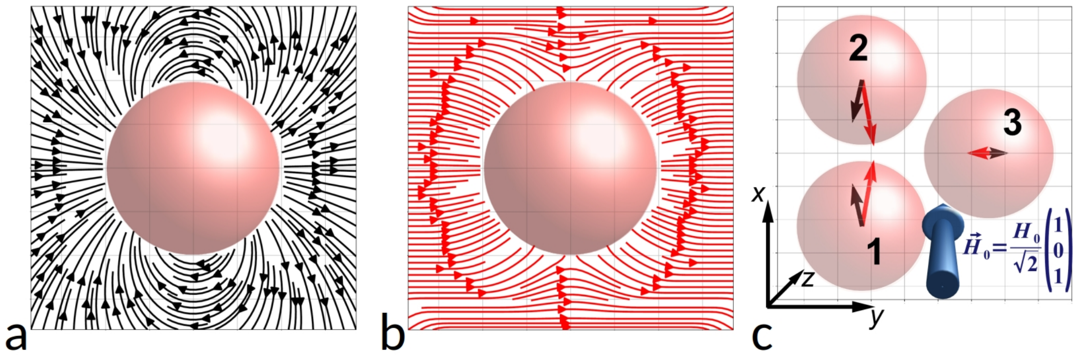

Figure 1: a) Streamlines illustrating the classical dipole field. b) Analogue streamlines to visualize the additional near-field effect. c) Example calculation for the magnetic body forces among 3 particles. Black arrows: Dipole results. Red arrows: Full-field results.

References

[1] A.M. Biller, O.V. Stolbov, Yu.L. Raikher. J. Appl. Phys. 116, 114904 (2014).

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