The universal behavior of dense clusters of magnetic nanoparticles

N.A. Usov[1,2], O.N. Serebryakova[1], S.V. Ermakov[2] and R.V. Shershnev[2]

[1]*Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation RAS 142190, Troitsk, Moscow, Russia*

[2]*Obninsk Institute for Nuclear Power Engineering, Branch of the National Research Nuclear University MEPhI, 249040, Obninsk, Kaluzhskaya obl., Russia*

Corresponding author: usov@izmiran.ru

The influence of magnetostatic interactions on the properties of assemblies of magnetic nanoparticles is an important problem that has to be studied in detail to optimize the performance of assemblies in a number of biomedical applications, such as magnetic nanoparticle hyperthermia or targeted drag delivery [1,2]. In the present report a detailed numerical simulation is carried out to study the quasistatic hysteresis loops of dense quasispherical clusters of interacting magnetic nanoparticles. Both the clusters of magnetically soft and magnetically hard nanoparticles are considered. The clusters are characterized by an average particle diameter D, the cluster radius Rc, the particle saturation magnetization M_s, and the uniaxial anisotropy constant K. The number of particles in the cluster varies between N_p = 30 - 120. A specific algorithm is developed to create nearly spherical clusters of single-domain nanoparticles with randomly distributed particle centers. The particles easy anisotropy axes are randomly oriented. It is suggested that the particles are covered by a thin non magnetic layers to protect them from oxidation. Therefore, the exchange interaction between closest nanoparticles is absent. The Landau-Lifshitz-Gilbert equation is solved as a function of external magnetic field to simulate the quasistatic hysteresis loops of interacting nanoparticles. It is shown that a rare assembly of random clusters of nanoparticles can be characterized by two dimensionless parameters: 1) the intensity of mutual magnetostatic interaction, K/M_s^2, and the average particle concentration within the cluster, $\eta = VN_p/V_c$. Here V is the nanoparticle volume, and V_c is the volume of the cluster, respectively. For magnetically soft nanoparticles, $K/M_s^2 << 1$, the universal hysteresis loops of the assembly are constructed. In the variables (M/M_s, H/M_s) these hysteresis loops depend only on the particle filling factor η, which varies in the range $0 < \eta < 0.5$. The hysteresis loops of magnetically hard nanoparticles in the variables (M/M_s, H/H_a), where $H_a = 2K/M_s$ is the anisotropy field, are close to the standard Stoner-Wohlfarth hysteresis loop.

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[2] N.A. Usov, S.A. Gudoshnikov, O.N. Serebryakova, M.L. Fdez-Gubieda, A. Muela and J.M. Barandiarán. Properties of dense assemblies of magnetic nanoparticles promising for application in biomedicine. J. Supercond. Nov. Magn. **26** (2013) 1079.