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Forced rotation of a ferromagnetic fine particle in a viscous carrier: the stationary probability density

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Ferrrofluids are the complex systems with high potential application, which are widely spread from engineering to biomedicine. Most descriptions of these media are grounded on the concept of ferrohydrodynamics [1], where ferrofluid is considered as a continuous media. But a lot of effects can be described properly only in terms of the microscopic structure of ferrofluid. In particular, the problem of the AC-field absorption and further ferrofluid heating for the case of rather fine dispersed nanoparticles was investigated within the framework of the complex magnetic susceptibility [2]. But, when the magnetic energy is comparable with the thermal one, one should to account the individual Brownian rotation of each particle.

For practical purposes, the probability density function of the nanoparticle rotational states is the main characteristic with respect to its rotational motion. The above mentioned function is the solution of the appropriate Fokker-Plank equation [3]. We suppose that the particle is under the action of the field $\mathbf{H} = h(\mathbf{e}_x \cos\Omega t + \mathbf{e}_y \sin\Omega t) + \mathbf{e}_z h_z$. Here h and Ω are the rotating field amplitude and frequency, respectively, h_z is the static field value, $\mathbf{e}_{x,y,z}$ are the unit vectors of the Cartesian coordinates, t is the time. The approximate stationary solution of the Fokker-Planck equation has the following form:

$$P(\theta,\Phi) = P_0 \cdot \left[1 - \frac{\tau^2}{2\tau_r} h\Omega \sin\theta \sin\Phi + \frac{\tau^3}{24\tau_r^2} h\Omega \left(h_z \sin 2\theta \sin\Phi + h \sin^2\theta \sin 2\Phi\right)\right], \qquad (1)$$

where $P_0 = C \sin\theta \exp\left[-W\tau/\tau_r\right], W = -h \sin\theta \cos\varphi - h_z \cos\theta, C$ is the normalization constant, θ, φ are the angular coordinates of the nanoparticle magnetic moment, $\Phi = \varphi - \Omega t$, $\tau_r = 6\eta/M^2, \tau = 6\eta V/k_{\mathrm{B}}T$, η is the liquid viscosity, M is the nanoparticle magnetisation, V is the nanoparticle volume, k_{B} is the Boltzmann constant, T is the temperature. Our analytical findings were confirmed by the numerical simulation.

References

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