EFFECTIVE LANDAU-LIFSHITZ-GILBERT EQUATION FOR A CONDUCTING NANOPARTICLE

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We study the role of conductivity in the magnetization dynamics of single-domain ferromagnetic particles. Our approach is based on the coupled system of Maxwell's and Landau-Lifshitz-Gilbert (LLG) equations. We show that the effective LLG equation for a conducting particle contains two additional terms compared to the ordinary LLG equation. One of them is responsible for the conductivity contribution to the damping parameter. By analytically solving Maxwell's equations, we determine this contribution and demonstrate the importance of conduction effects for large nanoparticles.The Landau-Lifshitz (LL) equation and its modification, the Landau-Lifshitz-Gilbert (LLG) equation, are the basic equations for studying the magnetization dynamics in ferromagnetic materials. We have studied a number of thermal effects in the magnetization dynamics driven by the rotating magnetic field [2-4]. In the case of conducting single-domain particles, the LLG equation should be supplemented by Maxwell's equations, which determine the eddy-current contribution to the effective magnetic field [5]. It is usually assumed that this contribution is negligible for nano-sized particles. However, in this paper we show that if the particle size is close to the critical one then the eddy-current contribution to the Gilbert damping parameter can be comparable with that of non-conducting samples.

We consider a spherical particle of electrically conductive and ferromagnetic material. It is necessary to find the magnetic field $\mathbf{H}$ generated by the magnetization$\mathbf{M}$. To achieve this goal, we will solve the system of equations consisting of the LLG equation and Maxwell's equations

$$\frac{d\mathbf{M}}{dt} = -\gamma \mathbf{M} \times (\mathbf{H}_{\text{eff}} + \mathcal{H}) + \frac{\alpha}{M} \mathbf{M} \times \frac{d\mathbf{M}}{dt}, \qquad (1)$$

$$\operatorname{rot} \mathbf{E} = -\frac{4\pi}{c} \Theta(r) \frac{d\mathbf{M}}{dt}, \qquad \operatorname{div} \mathbf{E} = 0, \qquad (2)$$

$$\mathrm{rot}\,\mathbf{H} = \frac{4\pi}{c}\Theta(r)\mathbf{j}, \qquad \mathrm{div}\,\mathbf{H} = 0. \tag{3}$$

Having the necessary mathematical calculations, we were able to record the effective LLG equation

$$\frac{d\mathbf{M}}{dt} = -\gamma\mathbf{M} \times (\mathbf{H}_{\mathrm{eff}} + \bar{\mathbf{H}}_1) + \frac{\alpha+\alpha'}{M}\mathbf{M} \times \frac{d\mathbf{M}}{dt} \tag{4}$$

According to this equation, the influence of conductivity on the magnetization dynamics is accounted for by both the magnetic field $\mathbf{H}_1$, which modifies the external time-dependent magnetic field, and the additional contribution α' to the damping parameter.

CONCLUSIONS

We have derived the effective Landau-Lifshitz-Gilbert equation that describes the magnetization dynamics in conducting ferromagnetic nanoparticles. The influence of conductivity is accounted in this equation by two terms. The first accounts for the magnetic field of eddy currents that are induced by the external time-dependent magnetic field. The second term describes the influence of the magnetic field of eddy currents that are induced by the time-dependent magnetization. By solving the corresponding Maxwell's equations, we have shown that this influence is completely accounted by an addition contribution to the damping parameter. It has been established that for large nanoparticles a given contribution is essential and cannot be neglected.

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