Critical aspects in micromagnetic computation of hysteresis loops of nanometer particles

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I. Introduction

The hysteresis loops of magnetic nanostructures can be numerically evaluated by solving the Landau-Lifshitz-Gilbert (LLG) equation for discrete values of the external field. However, this procedure is often time-consuming and no univocal set of equilibrium states can be found, if a non-correct convergence criterion is imposed. To evidence this critical aspect, we present a parametric analysis based on the numerical space-time solution of the LLG equation. The effective field spatial reconstruction is obtained by a nodal 3-D finite element method [1], computing the magnetostatic field through the Green formula integration. For what regards magnetization time evolution, different geometric integration schemes, able to preserve the non-convex constraint, will be compared in the full paper [2, 3].

II. Numerical Analysis

The attention is focused on small magnetic particles (some tens of nanometers), for which quasi-coherent rotation is expected. To compute the static hysteresis loop, the simulation starts from an initially uniform magnetization state pointing in a given direction *x*, then a sufficiently high external field is applied along the same direction and reduced in sufficient small steps until the magnetization is reversed. For each step of the applied field, the simulation goes on until the equilibrium state, which is assumed to be reached when the maximum nodal value of the misalignment between magnetization and effective field $\tau = |\boldsymbol{M}\times\boldsymbol{H}_{eff}|/M_S^2$ is lower than a threshold Θ. However, if Θ is not sufficiently small, the applied field is changed when the system lies in the basin of attraction of an equilibrium point, but it has not reached it yet. Depending on the state manifold, the system begins to move towards a new equilibrium point, which not necessarily coincides with the correct successive one. It results that the hysteresis loop prediction is altered.

Due to the numerical approximation, several parameters can affect the determination of the equilibrium state set: field step number, convergence criterion, time integration method, and also damping coefficient α. Figure 1a reports the hysteresis loop descending branch for a permalloy square film, with size and thickness respectively equal to 50 nm and 5 nm. The simulations are performed varying parameters α and Θ, and adopting the mid-point rule for the time integration. The numerical approximation introduces an asymptotic behavior at the increase of α; the loops approach the correct prediction by sufficiently reducing Θ. This can be explained by analyzing the relaxation processes between two successive equilibrium points A and B, as indicated in Fig 1a. The corresponding time evolutions of the spatial average value of magnetization component M_x and of quantity τ are shown in Fig. 1b, for two values of α. The time behavior of τ exhibits a minimum (τ_{min}), which reduces at the increase of α. When imposing a threshold Θ smaller than this minimum, a false equilibrium state is computed, since the system is still far from the next equilibrium state.

The dependence on α of τ_{min} and of the limit threshold Θ that leads to the correct prediction of equilibrium state B is evidenced in Fig. 2..The two curves separate for low values of α, since the dominance of precessional phenomena leads to strong oscillations of the magnetization, increasing the torque and slowing down the reaching of equilibrium [4]. In particular, Θ shows a non-monotonic behavior.

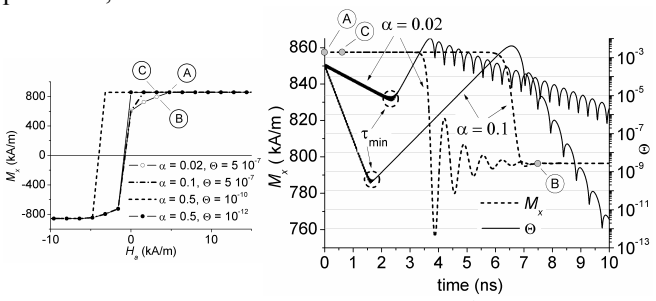

Fig. 1 (a) Descending branches of hysteresis loops of a permalloy square film, computed for different values of α and Θ. (b) Relaxation processes between equilibrium points A and B for α equal to 0.02 and 0.1. The time evolution of τ shows a minimum value (τ_{min}).

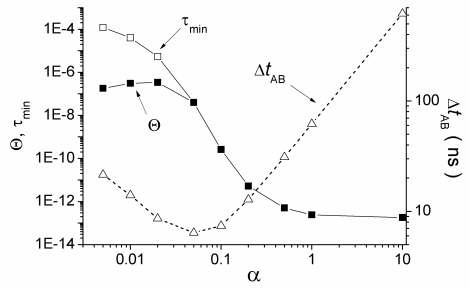

Fig. 2 Role of α on the limit value of Θ leading to correct loop prediction, quantity τ_{min} and time required to evolve from equilibrium state A to B (Δt_{AB}).

III. References

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