Hysteresis losses of simulated magnetic nanoparticles with coupled magnetic and mechanical processes

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Exploiting the often unwanted side-effect of heating due to hysteresis losses for magnetically induced hyperthermia, e.g. for cancer treatment, is the subject of many recent studies. In order to analyze the occurring heating processes in more detail, we simulate magnetic nanoparticles in a viscous medium influenced by an alternating field [1].

The shape and size of the area of the hysteresis loop is not only determined by the magnetization dynamics of the particle but also its mechanical rotation. The mechanical equation of motion of the particle is derived from the equation of internal and external torques acting upon it. Coupled with the magnetization dynamics dictated by the Landau-Lifshitz-Gilbert equation including the additional Barnett field [2], a more complex steady state behavior of the system emerges. In order to evaluate and separate the different components of the energy losses, the hysteresis loops can be evaluated for different components of the effective field. In the laboratory frame of reference the hysteresis loops with the external field will result in the total losses of the nanoparticle. On the other hand, if calculated with the effective field it will result in the magnetic losses only and the losses due to friction can be calculated with the anisotropy field. The friction losses are also confirmed by directly calculating the friction losses from the viscous torque.

We primarily simulate the system with a single spin but further extended the simulations by resolving the particle with multiple spins using micromagnetics [3] for larger particles. We will present the underlying equations and variables and the impact on the shape of the hysteresis loops as well as present two examples of rotating single-domain spheres and a disk with coupled antiferromagnetic layers in more detail.

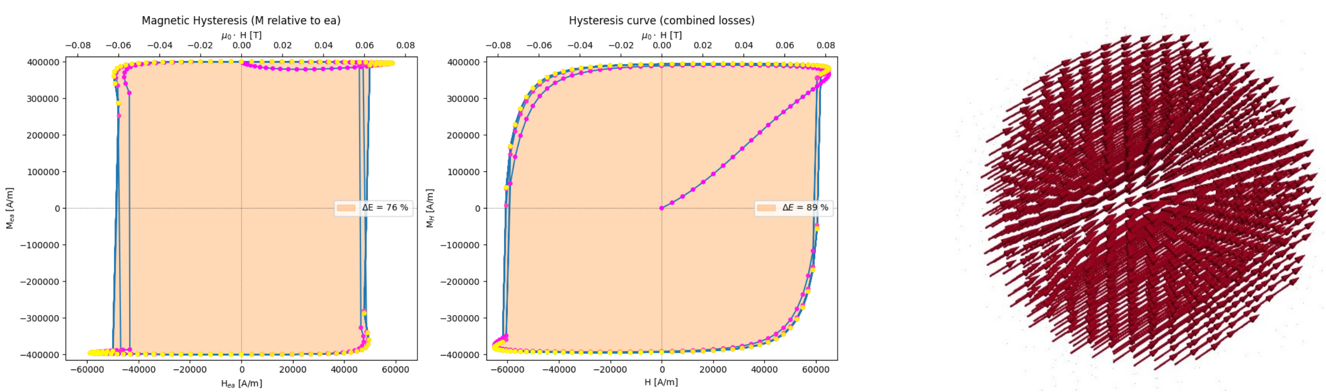

Figure 1: The hysteresis loops of the same simulation once calculated with the effective field (left) for the magnetic losses and once calculated with the external field only (middle) for the total losses of a micromagnetic simulation of a sphere (right).

References

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