Large amplitude precessional magnetization dynamics

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The application of spin electronics devices and materials for magnetic memory, data storage or radio frequency requires a detailed understanding of the magnetization dynamic processes under short field or short spin polarized current pulses. In many cases these involve large angle trajectories to induce magnetization reversal or to stabilize steady state oscillations.

These trajectories are investigated in this tutorial in a macrospin approach as a solution to the Landau-Lifshitz-Gilbert (LLG) equation which contains two terms, a precession term and a damping term. It is complemented by a third term to take spin transfer effects into account.

$$\frac{d\mathbf{M}}{dt} = \boxed{-\gamma\,(\mathbf{M}\times \mathbf{H}_{eff})} + \boxed{\frac{\alpha}{Ms}\mathbf{M}\times\frac{d\mathbf{M}}{dt}} + \boxed{\frac{\gamma\, a_J(\theta)}{Ms}\mathbf{M}\times(\mathbf{M}\times\mathbf{P})}$$

Precession **Damping** **Spin torque (ST)**

We start by examining the precession term and its solutions in relation to the underlying energy surface to derive the stable points and the dynamic solutions. Details of the constant energy trajectories are discussed for a uniaxial thin film geometry, which is the geometry most often encountered in experiments. Knowledge about these trajectories will provide a strategy to define a fast reversal scheme under short field pulses that are applied perpendicular to the easy axis. This is the so-called precessional reversal. We then discuss some further aspects of this precessional reversal and compare it in a next step to the magnetization dynamics inside a domain wall during domain wall propagation. The third aspect considered here are the steady state oscillations induced by spin momentum transfer. We will investigate details of these auto-oscillations such as the existence range and the corresponding frequencies as a function of the control parameters current and field. Finally, we also consider fast reversal under current pulses.

The analysis of the trajectories based on the LLG equation of motion will be complemented in a practical to provide the necessary tools to apply the understanding to other geometries.

Some selected papers on the topic:
1) G. Bertotti et al, *Physica B* 343 (2004) 325–330, “Analytical solutions of Landau–Lifshitz equation for precessional dynamics”
2) C. Serpico et al., *J. Mag. Mag. Mat.* 290–291 (2005) 48–54, “Nonlinear magnetization dynamics and magnetization switching in uniformly magnetized bodies”
3) C. Serpico et al., *J. Appl. Phys.* **93**(10), 6909 (2003), “Analytical solutions of Landau–Lifshitz equation for precessional switching”,
4) M. Bauer, et al., *Phys. Rev. B* **61**, 3410 (2000), ”Switching behavior of a Stoner particle beyond the relaxation time limit”
5) T. Devolde et al., *Eur. Phys. J. B* **36**, 57–64 (2003) ”Precessional switching of thin nanomagnets: analytical study”
6) G. Bertotti et al., Phys. Rev. Lett. **94,** 127206 (2005), “Magnetization Switching and Microwave Oscillations in Nanomagnets Driven by Spin-Polarized Currents”

7) M. D. Stiles and J. Miltat, in *Spin Dynamics in Confined Magnetic Structures III*, edited by B. Hillebrands and A. Thiaville, Springer, New York, 2006.
8) U. Ebels, Phys. Rev.B **78**, 024436 (2008) "Macrospin description of the perpendicular polarizer-planar free-layer spin-torque oscillator"