Spectral analysis and magnetic hysteresis of nanoparticles and thin films.

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Application-oriented properties of magnetic nanomaterials for biomedicine (such as nanoparticles and thin films), typically related to the features of major and minor hysteresis loops, are shown to be univocally derived from the frequency spectrum of the time-resolved magnetization signal. The main parameters related to the hysteresis loop (loop's area, magnetic remanence and coercive field) are extracted from the spectral harmonics of the magnetic signal generated by a sinusoidal magnetic field waveform without the need of doing ad-hoc measurements of the hysteresis loop itself.

Keywords: Magnetic nanomaterials; hysteresis loops; magnetic frequency analysis.

1. Introduction

Important functional applications of magnetic nanopmaterials such as Magnetic Particle Imaging and Spectroscopy are based on the analysis of the magnetization process in the frequency domain and make use of the spectral amplitudes of the periodic magnetization. However, spectral properties of the magnetic response of nanomaterials typically have to be complemented by information about their hysteretic properties. It is therefore desirable to deal with a method to get the magnetization loop of a nanomaterial by making use of the spectral harmonics of the picked up signal without the need of actually doing any additional measurement.

2. Results and discussion

We derive a univocal relation between the line spectrum of the periodic magnetization and the corresponding hysteresis loop at any frequency of the driving field.

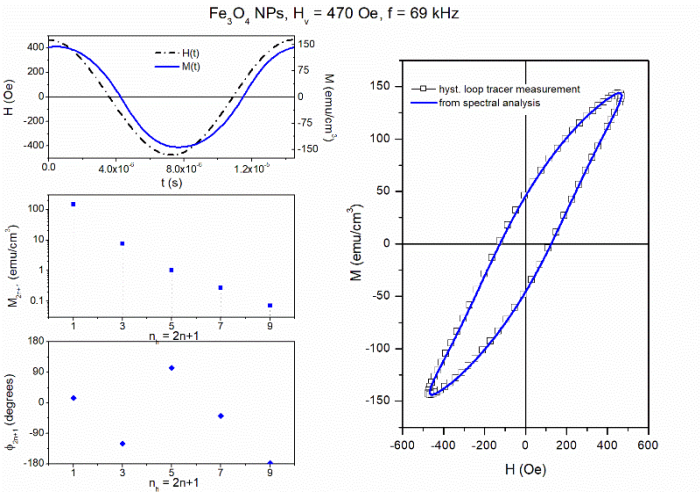

Figure 1: Top left: H(t) and M(t) for Fe_3O_4 nanoparticles at f = 69 kHz; centre/bottom left: amplitudes and phases of the significant spectral harmonics of magnetization; right: M(H) loop at f = 69 kHz (open symbols: measurement; full line: reconstruction from spectral harmonics).

The spectral harmonics of the frequency line spectrum are shown to be instrumental in reconstructing the magnetization curve in the (M, H) plane by using specific transformation formulas. In this way, important parameters such as loop's area, magnetic remanence and coercive field are obtained by simple manipulation of the amplitudes and phases of the harmonics.

In fact, the spectral harmonics resulting from frequency analysis of the dynamic magnetization M(t) (or alternatively of the induced voltage V (t)) contain a complete information about the magnetization process in the nanomaterial and allow the user to easily reconstruct the actual hysteresis loop under the most common driving-field waveshapes.

The reconstructed hysteresis loops are proven to accurately reproduce all features and details of the ones observed through standard magnetic measurements in the time domain, independently of driving field frequency, of the value of the vertex field and of the actual loop shape. The ability of the reconstruction technique and the adequacy of the transformation formulas have been experimentally verified in a number of nanoscale materials; an example involving high-frequency measurements of magnetite nanoparticles is reported in Figure 1.

In addition, the simple transformation formulas proposed in this work allow the user to directly calculate the most important parameters of the hysteresis loop from amplitude and phase of the odd harmonics of the magnetization. It is important to remark that the power spectrum and the amplitude spectrum of the magnetization signal, by themselves, are not enough to derive the magnetic parameters of interest: in fact, the phases of the measured harmonics are shown to play a role as important as the amplitudes in the transformation formulas.

References

[1] G.Barrera, P.Allia, P.Tiberto, Journal of Physics: Materials 6, 035007 (2023)