

Characterization and model of soft magnetic materials by magnetic spectroscopy: from Cole-Cole model to fractional high amplitude dynamic hysteresis model.

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Magnetic materials are highly nonlinear and frequency dependent, different options exist for the simulation of these materials: Space Discretization Techniques (SDT) like finite elements method (FEM) lead to very accurate results but require huge memory space and simulation times [1]. In [2]-[5], FEM are replaced by a lump model simulating the average induction B variations versus the surface tangent excitation field H . Accurate behavior on a large frequency bandwidth are obtained using a fractional derivative dynamic term. In the lump model equation, the fractional time derivative of the average induction field B multiplied to a material constant ρ behaves as an equivalent magnetic excitation field H_{equ} (eq. 1).

In ferroelectricity, the dielectric spectroscopy (variation of the dielectric properties of a medium as a function of the frequency) is widely employed as it gives interesting information about the material constitution and the polarization behaviour [6]. By analogy, in [7][8] for physical interpretation, authors use magnetic spectroscopy (also called inductance spectroscopy), i.e. variations of the imaginary part versus real part of the magnetic permeability as the frequency is increasing. Characteristics semi-circle are obtained easy to model with the magnetic equivalent fractional Cole-Cole model.

In this article, we show how assuming harmonic evolution of the magnetic induction field, it is very simple to establish the link between our time domain high amplitude fractional hysteresis model and the frequency domain fractional magnetic Cole-Cole model. For both models, α the fractional order keeps the same value and a relation between τ (the relaxing time) and ρ (the material constant) can be set (eq. 3).

Experimental results performed on a typical soft ferromagnetic (Fe-Si) material validate our theory. Correct comparison simulations/measures can be obtained by setting the parameter under weak amplitude Cole-Cole simulations and conserving it for high amplitude dynamic hysteresis model (fig. 1). The dynamic behaviour of a ferromagnetic sample can be set under weak amplitude excitation with the impedance meter and conserved for the simulation of high amplitude dynamic hysteresis cycles.

$$\rho \cdot \frac{d^\alpha B(t)}{dt^\alpha} = H_{dyn}(t) - f_{static}^{-1}(B(t)) \quad (1)$$

$$\mu^*(\omega) = \mu'(\omega) - j\mu''(\omega) = \mu_\infty + \frac{\Delta\mu}{1 + (i\omega\tau)^\alpha} \quad (2)$$

$$\tau^\alpha = \mu_s \cdot \rho \quad (3)$$

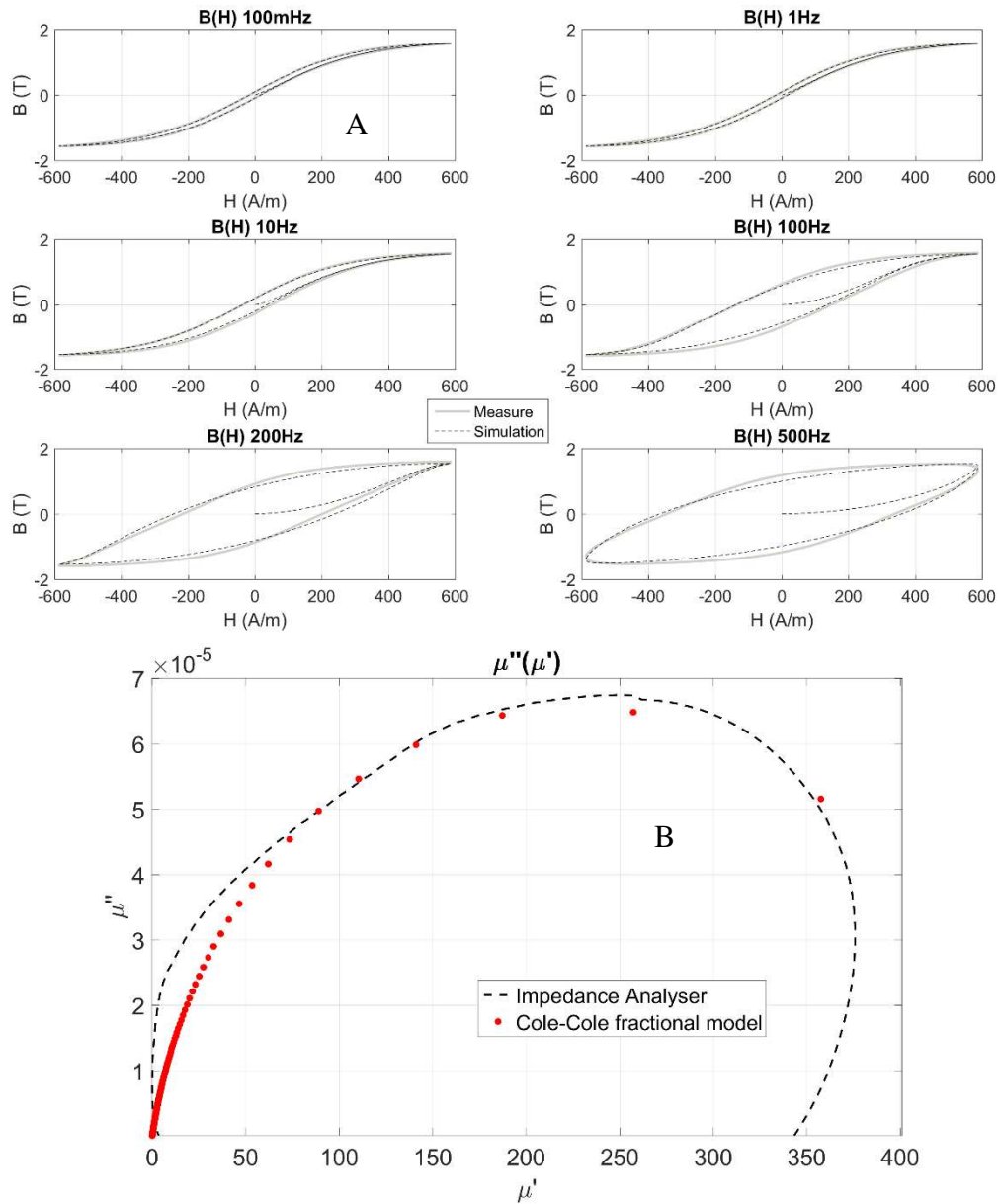


Fig. 1 Comparison Simulation/Measure, hysteresis cycle (A), Cole-Cole plot (B) ($\alpha = 0.8$, $\rho = 0.2$)

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