Improved Energetic Model Presentation in Both Centered and Non-centered Minor Hysteresis Loops

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The energetic model is known to be based on physical or energetic approaches that take into account the statistical behavior of magnetic domains. Additionally, it calculates the magnetic state of a ferromagnetic material by minimizing the total energy density. In this work, an enhancement of the energetic model is proposed based on minimizing the total magnetic field energy density to accurately represent and evaluate iron losses. Experimental analysis demonstrates the model's ability to successfully reproduce both centered and non-centered minor hysteresis loops of different types while enabling precise core loss calculations under various excitation scenarios. The reliability of the numerical simulations is verified through experimental measurements, validating the model's effectiveness.

Keywords: Hysteresis; ferromagnetic materials; iron losses; energetic model; harmonics; centered and non-centered hysteresis loops.

1. Introduction

The accurate evaluation of iron losses in electromagnetic devices requires precise modeling of hysteresis phenomena in magnetic materials. These losses are fundamentally influenced by the nature of the excitation source, which typically produces non-sinusoidal magnetic flux waveforms containing various harmonics. Depending on the amplitude and phase of these harmonics, the resulting magnetic induction waveforms exhibit different major hysteresis loop characteristics, often accompanied by minor hysteresis loops - both centered and non-centered types [1].

Current approaches to hysteresis modeling can be broadly categorized into physical models and phenomenological representations [2]. While these models provide useful approximations, they often lack comprehensive treatment of energy interactions in ferromagnetic materials. In this work, we present an enhanced energetic hysteresis model [3] based on minimization of total magnetic field energy density.

2. Energetic model

For a quasi-stationary magnetization process, the magnetic field H_{hyst} is determined by the superposition of three components: the demagnetizing field (H_d), the reversible magnetic field (H_r), and the irreversible magnetic field (H_I), expressed as:

$$H_{hyst}(B) = H_d + sgn(m)H_r + H_I \quad (1)$$

$$H_d = N_e M_s m \quad (1.a)$$

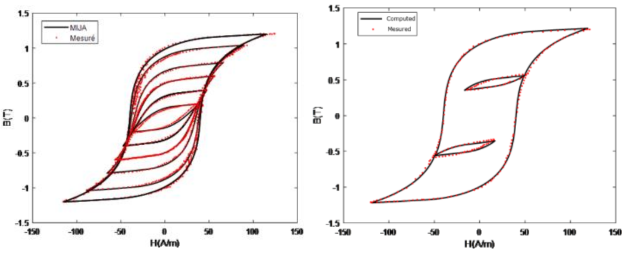
$$H_r = h(((1+m)^{1+m}(1-m)^{1-m})^{\frac{g}{2}} - 1 \quad (1.b)$$

$$H_I = \delta\left[\frac{k}{\mu_0 M_s} + c_r H_r\right]\left[1 - \kappa \exp\left(-\frac{q}{\kappa}|m - m_0|\right)\right] \quad (1.c)$$

With, $\delta = sgn(m - m_0)$.

$$\kappa = 2 - \kappa_0 \exp\left(-\frac{q}{\kappa}|m - m_0|\right) \quad (2)$$

The calculation begins at the demagnetization state (m=0, $\kappa = 1$). The relative magnetization "m" then increases incrementally according to Equation (1). Using the previous value κ_0 as input, the function κ is determined through Equation (2).



(a) *(b)*

Figure 1: (a) Measured and modeled centered minor loops at Bmax = 0.2 T to 1.2 T (step 0.2 T). (b) Comparison of modeled and measured non-centered minor hysteresis loops in the case of three harmonics in the excitation after model improvement.

Figure (a) shows the modeled results compared with measurements. As these plots demonstrate, the model effectively reproduces the centered minor hysteresis loops.

Figures (b) clearly presents that the non-centered minor loops are fully closed and exhibit excellent agreement with experimental measurements.

References

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