The exclusion-based generalization of the anhysteretic magnetization model for anisotropic soft magnetic materials

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Anisotropic soft magnetic materials are widely used in the inductive cores of high-performance transformers and inductive chokes. The functional properties of such materials require accurate simulation tools, where the Jiles-Atherton model [1] remains a standard approach for describing magnetic hysteresis. However, the correct definition of the anhysteretic magnetization curve for anisotropic media is necessary for the reliability of such models. Moreover, previous mathematical formulations often fail the thermodynamic consistency test in the isotropic limit due to the incorrect multiplication of probability weights.

On the other hand, a promising method of ensuring physical rigor is the statistical treatment of magnetic domain orientations as mutually exclusive states. This paper presents the results of an investigation into modeling anhysteretic magnetization using a generalized exclusion-based approach.

In opposition to the original approach to the anhysteretic magnetization model [2, 3]:

$$M_{ah} = M_S \left[\frac{\int_0^{\pi} e^{\frac{E(1)+E(2)}{2}} \sin\theta \cdot \cos\theta \cdot d\theta}{\int_0^{\pi} e^{\frac{E(1)+E(2)}{2}} \sin\theta \cdot d\theta} \right] \tag{1}$$

a partition function based on the summation of Boltzmann weights for two disjoint orientation families is proposed:

$$M_{ah} = M_S \left[\frac{\int_0^{\pi} \left(e^{E(1)} + e^{E(2)}\right) \sin\theta \cdot \cos\theta \cdot d\theta}{\int_0^{\pi} \left(e^{E(1)} + e^{E(2)}\right) \sin\theta \cdot d\theta} \right] \tag{2}$$

It should be highlighted that the energy-description functions of axially anisotropic material for both models remain the same:

$$E(1) = \frac{H_e}{a}\cos\theta - \frac{K_{an}}{M_s \mu_0 a}\sin^2(\psi - \theta) \tag{3}$$

$$E(2) = \frac{H_e}{a}\cos\theta - \frac{K_{an}}{M_s \mu_0 a}\sin^2(\psi + \theta) \tag{4}$$

The paper also presents the modeling results for axial and grain-oriented (GO) anisotropic materials, whose experimental characteristics have been previously reported in the literature.

References:

[1] D. C. Jiles, D. L. Atherton, Journal of Magnetism and Magnetic Materials (1986) 61, 48
[2] A. Ramesh, D. C. Jiles, Y. Bi, Journal of Applied Physics (1997) 81, 5585
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