Implementation of the energy-based model in finite element method for simulations of magnetic components for electric machines

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The energy-based (EB) model, also known as vector-play model, is a phenomenological magnetic model based on play-operators, similar to the Preisach model but much lighter computationally speaking, although sufficiently accurate in the reconstruction of the hysteresis behaviour. In the present research we implemented the EB model in a finite element method (FEM) software, identifying the phenomenological parameters by means of experimental data taken on a full toroidal sample of Fe-Si alloy 3.7% wt. Si at the frequency of 1Hz (negligible eddy currents), testing the model stand-alone, inverting the model and implementing it in the FEM software to simulate a toroidal sample with a partial section with air-gaps at a frequency of 50 Hz, in a fully predictive setup.

Keywords: hysteresis modeling, energy-based model, finite element method

1. Introduction

The energy-based (EB) model [1] represents a good compromise between accuracy and computational costs. In this model, the excitation field can be split in a reversible and irreversible part $\mathbf{h} = \mathbf{h}_i + \mathbf{h}_r$. The reversible part can be written as the weighted sum of the reversible fields of a defined number N of cells, where the weights $\{\omega_k\}_{k=1}^{N}$ are normalized to 1. The reversible magnetic field of each of the N cell is updated at each time step and it depends on the pinning energies $\{\kappa_k\}_{k=1}^{N}$. The magnetization is calculated from a scalar anhysteretic function $M_{an}(\|\mathbf{h}_r\|)$ to be determined, along with the weights and the pininng energies, from the experimental data measured on the material, a Fe-Si alloy 3.7% wt. Si @1Hz. Being intrinsically vectorial [2], the EB model is especially well suited to simulate electric machines [3]. To this end, it is necessary to perform finite element method (FEM) simulations [4]. The FEM simulations were performed on a partial section toroid with air gaps, at a frequency of 50 Hz. The simulated results were compared with the measurements carried out on a sample with the same geometry and at the same frequency of 50 Hz.

2. Results and discussion

In figure 1, the section of the partial section toroid used for the simulations with the distribution of magnetic induction field B in Tesla at a given time step.

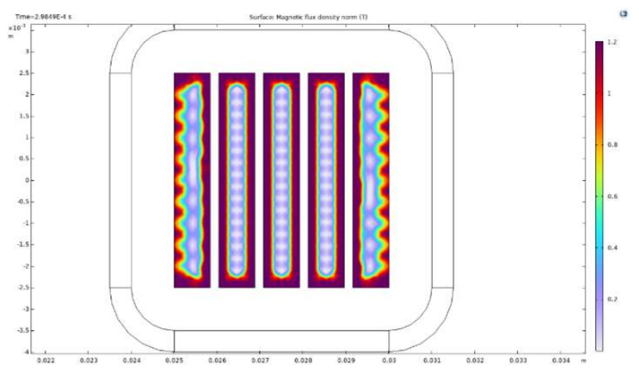

Figure 1: Distribution of the magnetic induction field B in Tesla at a given time step over a section of the sample.

In figure 2 we report the comparison of the hysteresis cycles simulated by the EB model and the measured ones, where we can highlight the good agreement with the experimental data, especially keeping into account the fully predictive simulation conditions.

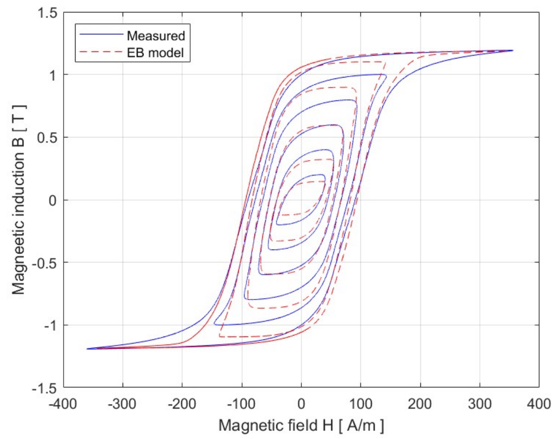

Figure 2: Comparison of the hysteresis cycles. Blue solid line: measured data. Red dashed line: EB simulated cycles.

References

[1] A. Bergqvist, "Magnetic vector hysteresis model with dry friction-like pinning", *Physica B* 233 (4) (1997) 342–347, http://dx.doi.org/10.1016/S0921-4526(97) 00319-0.

[2] F. Henrotte, A. Nicolet, K. Hameyer, "An energy-based vector hysteresis model for ferromagnetic materials", *COMPEL - Int. J. Comput. Math. Electr. Electron. Eng.* 25 (1) (2006) 71–80.

[3] F. Sixdenier, R. Scorretti, "Numerical model of static hysteresis taking into account temperature: Static hysteresis taking into account temperature", *Int. J. Numer. Modelling, Electron. Netw. Devices Fields* 31 (2) (2018) e2221.

[4] L. Dupre, J. Melkebeek, "Electromagnetic hysteresis modelling: From material science to finite element analysis of devices", *Int. Compumag Soc. Newsl.* 10 (3) (2003) 4–15.

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