Adaptions of an energy-based vectorhysteresis model for vanishing rotational losses

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Energy-based (EB) vectorhysteresis models are thermodynamically consistent models which can be used in Finite Element simulations to accurately model magnetic hysteresis. However, a significant limitation of these models is their inability to accurately depict rotational losses, which are a primary cause of losses in certain parts of electric devices, such as the T-joint of power transformers and the teeth of electric machines. In this work, we discuss two heuristic approaches to correctly account for rotational losses in EB models, which can then be used for parameter extraction against measurements from a rotational single sheet tester (RSST), depicted in Fig. 1 and 2.

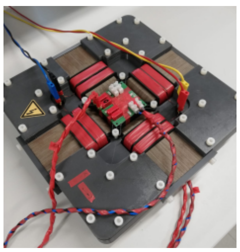

Figure 1: Rotational single sheet tester (RSST)

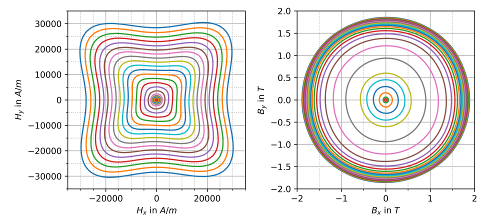

Figure 2: Measured $\mathbf{b}$- and $\mathbf{h}$-loci

The main idea behind these EB models is to split the magnetic field into a reversible $\mathbf{h}_{\text{rev}}$ (modelled as the derivative of the Helmholtz potential w.r.t. the polarization) and and irreversible part $\mathbf{h}_{\text{irr}} = \mathbf{h} - \mathbf{h}_{\text{rev}}$. Introducing the work of the pinning forces k, the irreversible field is given as $\mathbf{h}_{\text{irr}} \cdot \dot{\mathbf{m}} = |k\dot{\mathbf{m}}|$, which follows from the variation of the magnetic energy density and can be modelled via a dry-friction ansatz. The reversible part accounts for the magnetization $\mathbf{m}$ and is thus in phase with it, while $\mathbf{h}_{\text{irr}}$ is responsible for the dissipation and the phase lag between $\mathbf{h}$ and $\mathbf{m}$. Two different modifications to the classical model are investigated, which are briefly explained in the following.

The first approach involves dampening the pinning force k when the magnetization $\mathbf{m}$ approaches saturation m_{sat}, resulting in a vanishing $k(|\mathbf{m}|)$ in full saturation (Fig. 3 (1a) to (1c)) and therefore, vanishing rotational losses, depicted in Fig. 4. The second approach acts solely on the angle θ between $\mathbf{h}$ and $\mathbf{h}_{\text{rev}}$. A similar damping function as in the first case is used to scale the angle in accordance to the magnetization, depicted in Fig. 3 (2a) to (2c). Since this is a pure rotational operation, $\mathbf{h}_{\text{irr}}$ points (in full saturation) in the same direction as $\mathbf{h}_{\text{rev}}$ but remains non-zero, depicted in Fig. 3 (2a) to (2c), leading to vanishing rotational losses as shown in Fig. 4.

To validate these approaches, a splitting of the measurement data into a reversible and irreversible part will be performed and compared to the reversible and irreversible behavior of the model.

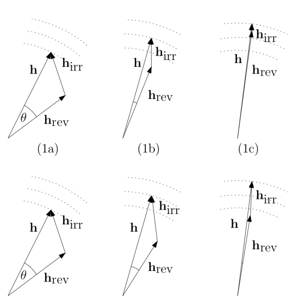

Figure 3: Damping strategies

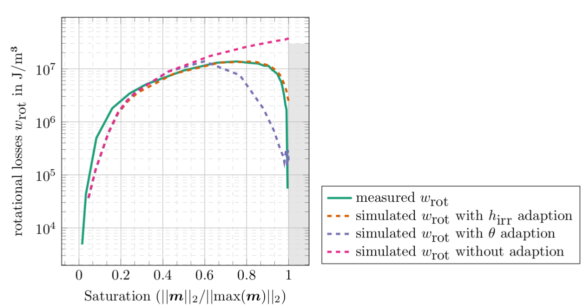

Figure 4: Comparison of w_{rot} with measurements