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CR/AEL5

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Issue Call for master's thesis

Topic **A Simplified Prandtl-Ishlinskii Stop-type Vector hysteresis operator for Anisotropic Cases**

Description Real ferromagnetic materials exhibit complex hysteresis effects, which require memory-dependent constitutive mapping between the magnetic field $\mathbf{H}$ and the flux density $\mathbf{B}$ for solving low-frequency Maxwell's equations. While the thermodynamically formulated generalized Prandtl-Ishlinskii [1] stop-type vector hysteresis operator effectively captures hysteresis nonlinearities, it requires a local Newton iterative procedure to update each hysteron (or local hysteresis operator), resulting in considerable computational effort, particularly in finite element (FE) simulations.

For isotropic materials, a recent simplification [2] replaces the nonlinear mapping on the stop operator with an identity, such that the hysteresis operators are directly weighted through their outputs. This enables a fully analytical return-point mapping for the local operator update, thereby eliminating per-hysteron iterative updates and achieving significant runtime reductions with comparable accuracy. This work aims to extend the simplification to anisotropic materials, where the admissible domain of the dissipative element in each hysteron becomes an ellipsoid rather than a sphere, and a closed-form update is not straightforward. The core research direction is therefore to exploit the eigendecomposition of the anisotropy matrix (similar to [3]), reducing the local hysteron update to a scalar Newton solve, and to integrate the resulting constitutive mapping into an FE solver for validation.

The specific tasks are:

- Literature review on the generalized and simplified isotropic Prandtl-Ishlinskii stop-type model formulations within the thermodynamic framework
- Formulate operator simplification for the anisotropic case and derive a fast update of the local hysteresis operators
- Identify necessary parameters for the anisotropic simplified model using measured $\mathbf{B-H}$ data for reference hysteresis material
- Integrate the anisotropic simplified constitutive mapping into an existing FE solver and assess the accuracy and runtime performance against the generalized anisotropic model

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References:

- [1] X. Xiao, F. Müller, M. M. Nell and K. Hameyer, "*Modeling anisotropic magnetic hysteresis properties with vector stop model by using finite element method*," COMPEL, vol. 41, no. 2, pp. 752–763, 2022.
- [2] A. Shankar, K. Kuhnen, I. Kulchytska-Ruchka and S. Schöps, "*Simplification of the Isotropic Generalized Stop-Type Prandtl-Ishlinskii Vector Hysteresis Operator Using Analytical Return-Point Mapping*," in IEEE Trans. on Magn., doi: 10.1109/TMAG.2026.3731649, 2026.
- [3] D. Versino and K. Bennett, "*Generalized radial-return mapping algorithm for anisotropic von Mises plasticity framed in material eigenspace: Generalized radial-return mapping algorithm*," Int. J. Numer. Methods Eng., vol. 116, doi: 10.1002/nme.5921, 2018.