Multi-Scale and Macroscopic Modeling of Magneto-Elastic Behavior of Soft Magnetic Steel Sheets

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Soft magnetic materials do not only exhibit a strong magneto-mechanical coupling, they are also inherently anisotropic due to their heterogeneous and multi-axial composition. The magneto-mechanical coupling, manifesting as the *Villari* effect (external mechanical stress modifies the magnetic behavior) and the *magnetostriction* effect (external magnetic field modifies the mechanical behavior and eigenstrain), must be considered in the design and simulation of high-performance electrical devices.

Phenomenological material models are based on empirical constitutive laws and require a large number of parameters to be identified based on a large number of measurement results. Such models have difficulties or even fail to model the heterogeneous and multi-axial material behavior, in particular outside the measurement range. *Micro-magnetic* models, related to solid-state physics inherently contain all relevant material features but may be computationally expensive.

In contrast, multi-scale models enriching the macroscopic material description by observations at finer scales account for the heterogeneity and multi-axiality of the magneto-elastic coupling. Among others, the energy-based model proposed by L. Daniel et al. (L. Daniel et al., "A multiscale model for magneto-elastic behaviour including hysteresis effects,"*Archive of Applied Mechanics*, vol. 85, iss. 9-11, pp. 1307-1323, 2014.) describes the evolution of the microstructure including the *phenomenological* Hauser hysteresis model.

In previous work, we proposed a multi-scale model considering hysteresis at the grain scale solely based on fundamental material data. In this paper, we compare this model to the multi-scale model of L. Daniel et al. and a simplified macro-scale model based on the Helmholtz free energy (P. Rasilo et al., "Modeling of Hysteresis Losses in Ferromagnetic Laminations under Mechanical Stress," *Magnetics, IEEE Transactions on*, no.99, pp.1-4, 2015). Our results indicate that even without tedious parameter identification the material behaves as expected by the classical theory of the magneto-elastic effect. The non-monotonic effect of an applied tensile stress, occurring in FeSi3%, is further discussed and investigated.