A Quasi-Magnetostatic Volume Integral Method for Simulating Non-Linear Hysteretic and Magnetostrictive Materials

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The analysis of a quasi-magnetostatic field in the presence of non-linear, magnetic materials is an extremely challenging problem. The magnetic materials are generally anisotropic and inhomogeneous, and hysteretic. This is further complicated by the fact that external mechanical stresses change the magnetic properties due to magnetostriction [Schneider & Richardson, J. Applied Physics, vol 43, pp. 8136-8138, 1982]. To accurately analyze such problems, robust models for the magnetic and magnetostrictive properties of the magnetic material must be identified, that are accurate over a broad range of driving fields and forces. Efficient and accurate non-linear solution techniques that that can predict the induced magnetization and eddy currents in the ferrous material must also be derived.

In this paper, the solution of the quasi-static magnetic fields in the presence of non-linear hysteretic and magnetostrictive materials based on a volume integral equation (VIE) is presented. A high-order discretization based on the Locally-Corrected Nystrom (LCN) method is derived [J. Young, *et al.*, IEEE Trans. Magnetics, vol. 47, pp. 2163-2170, 2011]. The non-linear magnetic hysteresis properties of the magnetic material is modeled using C. Schneider's Cooperative Hysteresis Model [C. Schneider, IEEE Trans. Magnetics, vol. 48, pp. 3371-3374, 2012]. The Cooperative model is a physics based model, rather than an interpolative model, and provides an accurate model for both major and minor loops over a broad range of magnetic fields.

In order to model the magnetostrictive properties of the magnetic material, C. Schneider's Cooperative Model is extended to modeling magnetostriction. To this end, the device under test is simulated using both an LCN solution of the quasi-static volume integral equation, as well as a high-order finite-element solution of the elastostatic equation to simulate the stress-induced magnetization. A non-linear stepped solver is introduced that computes simultaneously both the magnetic and stress-induced magnetization and eddy currents.

The proposed algorithm allows the computational method to be extended to very large problems in that only the diagonal block of the system matrix is updated at every non-linear time-step. Thus, the global system matrix need not recomputed at every time step. Secondly, a fast iterative solver, accelerated by the LOGOS method, is employed. The proposed method has been validated through comparison against measured data, demonstrating its ability to predict both induced and permanent magnetizations due to dynamic field and stress changes over long time histories.