Neural-Network-Based Identification of Material Law Parameters for Fast and Accurate Simulations of Electrical Machines in Periodic Regime

Florent Purnode, François Henrotte, Gilles Louppe, and Christophe Geuzaine
Department of Electrical Engineering and Computer Science,
University of Liège, Belgium
E-mail: florent.purnode@uliege.be

Ferromagnetic lamination stacks are ubiquitous in electrical engineering applications. Despite thin laminating, significant losses develop in the ferromagnetic material that are detrimental to the overall efficiency of the machine. An accurate knowledge of those iron losses is highly valuable in a design phase, but their explicit modelling is computationally prohibitive as it requires a hysteresis vector model and homogenization techniques.

Building upon (F. Henrotte, S. Steentjes, K. Hameyer and C. Geuzaine, "Pragmatic two-step homogenisation technique for ferromagnetic laminated cores", in IET Sci. Meas. Technol., pp. 1–8, July 2014), this paper presents an efficient alternative simulation approach with little overheads with respect to a conventional 2D magnetic vector potential formulation. Based on mild simplifying assumptions (periodicity in time, large aspect ratio of the laminations), the technique is able to reliably feed the effects of the complex inhomogeneous fields inside the laminations, back into the macroscopic finite element model by means of a lossy homogenized parametric material law $\tilde{\mathbf{H}}(\mathbf{B}, \dot{\mathbf{B}}, p_k)$.

For the sake of accuracy, the parameters p_k of this law (p_0 to p_5) are identified elementwise (rather than domainwise) on basis of the local knowledge of the magnetic field $\mathbf{H}(t)$ in each finite element and, for the sake of fast evaluation, the mapping $\mathbf{H}(t) \mapsto p_k$ is realized with a specifically trained neural network (NN).

The training data consists of pairs of sequences $(\mathbf{H}(t), \mathbf{B}(t))$ over one period, where $\mathbf{B}(t)$ is the homogenized dynamic response, accounting for hysteresis and eddy currents, of a ferromagnetic lamination model subjected to a boundary field $\mathbf{H}(t)$. For the learning of the NN, the error $|\mathbf{H}(t) - \tilde{\mathbf{H}}(\mathbf{B}(t), \dot{\mathbf{B}}(t), p_k)|$, with the parameters p_k obtained from the NN evaluation, is evaluated and back-propagated.

Once the training is completed, the NN is able to provide with a very small computational time (about 17 seconds for the evaluation of 10^5 sequences), fitted elementwise p_k parameter values accounting for arbitrary local field waveforms, in particular waveforms with higher field harmonics due to switched power electronics. Designers eventually dispose with this technique of a fast and robust model with a controlled accuracy, and properly taking into account the irreversible phenomena in play in ferromagnetic laminations.