A dynamical energy-based model for iron loss calculation in laminated cores

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In a ferromagnetic sample subjected to a time varying applied magnetic field $\mathbf{h}(t)$, several mechanisms are responsible for the apparition of induced currents at different level of the microstructure. In particular, two geometrical scales should be distinguished. Currents directly induced by the variation of the external magnetic field are called eddy currents. They depend on the geometry of the sample and on the rate of variation $\partial_t \mathbf{h}(t)$ of the applied field. On the other hand, microscopic currents are also induced locally due to the broken (jerky) motion of Bloch walls (Barkhausen effect). The dynamics of this motion is ruled by certain features of the microstructure, and it determines the intensity and the distribution of the microscopic currents, whose associated Joule losses are conventionnally called hysteresis losses. Hysteresis losses density does not depend on the geometry of the sample, neither on the frequency of the applied magnetic field (hysteresis is a quasi-static phenomenon), but it depends on the local maxima attained by the field $\mathbf{h}(t)$ all through the magnetisation history of the sample.

The term iron losses covers the sum of these two intertwined phenomena. Conventional hysteresis models like Preisach or Jiles-Atherton model, however, address one (hysteresis) independently of the other (eddy currents). On the contrary, we present in this paper a strongly coupled model that addresses both phenomena simultaneously, so that the interplay between skin effect (i.e. eddy currents) across laminations and hysteresis can be resolved accurately (Such coupled models are seldom reported in the literature). With this model, material parameters for laminated structures can be identifed from measurements on a rigorous theoretical basis, in order to be exploited afterwards in the modelling of macroscopic devices (e.g. electrical machines) by means of a homogenization approach like the one proposed in (I. Niyonzima et al, *"Computational homogenization for laminated ferromagnetic cores in magnetodynamics"*, proceedings of CEFC 2012).

Practically, the proposed model consists of a 1D vector finite element modelization across half a lamination thickness. A h-field formulation is used to solve the eddy current problem, together with an implementation of the energy-based hysteresis model described in (F. Henrotte, A. Nicolet and K. Hameyer, *"An energy-based vector hysteresis model for ferromagnetic materials"*, *COMPEL*, vol. 25, pp. 71-80, 2006). It is shown that this across-lamination model describes the metrological characteristics of non-oriented electrical steel accurately and allows an exact material parameter identification from Epstein Frame or Single Sheet Tester measurements at any frequency.