# Abstract

The efficient use of electrical energy is crucial for the industrial development worldwide and, in particular, for the emerging countries. Generation, transmission, and conversion of the electrical energy all require the use of soft magnetic cores. At the same time, a dramatic increase of the electrical and electronic applications in the car industry, including hybrid and electric cars, and trends towards the more electric aircraft are posing compelling requirements on the efficiency of the cores, be their used as nuclei in a variety of devices and drives or as stators/rotors in electrical motors. In order to design highly efficient components and machines, it is necessary to achieve excellent understanding of the magnetization process and good predicting capabilities of the behaviour of the soft magnetic materials, with special attention devoted to the phenomenology of energy losses, under conventional and non-conventional excitation conditions.

This thesis lays a foundation for the analysis of the National Nature Science Foundation of China project. It provides systematic, physically based, and quantitative investigation of the broadband loss behaviour of different types of soft magnetic materials, ranging from the conventional non-oriented Fe-Si sheets to nanocrystalline ribbons.

A few main innovative points can be highlighted:

(1) The definite demonstration, against recent criticism in the literature, of the general validity of the loss decomposition method formulated with the Statistical Theory of Losses (STL). It regards, in particular, the role of the classical loss and its formulation below the limit for the skin effect. Wide-band experimental characterizations on a variety of non-oriented silicon steel sheets and low carbon steels are fully and consistently described by the STL. This occurs, in particular, for high-induction values and near-squared hysteresis loops, a predictable condition for adopting the alternative Saturation Wave Model (SWM), which fails instead to account for the experiments

(2) The analysis of magnetic losses under nonconventional magnetic induction waveform, such as PWM, symmetric and asymmetric triangular wave, is performed over a broad range of frequencies. It is shown that, by generalized application of the Statistical Theory of Losses and the related concept of loss separation, an accurate prediction can be made starting from standard results obtained with sinusoidal induction. This is a quite unique and general feature of our approach, because the prediction is done by simple analytical physically based methods, in contrast with the persisting use of empirical numerical methods in the present-day literature. Non-oriented Fe-Si and Fe-Co sheets, nanocrystalline Finemet–type ribbons, and Mn-Zn ferrites have been investigated up to $f$ = 1 MHz and duty cycles ranging between 0.5 and 0.1. The intrinsic shortcomings of the popular approach to loss calculation of inductive components in power electronics, based on the empirical Steinmetz equation and its numerous modified versions, are overcome by the here described method.

(3) The effect of cutting on magnetization curve and losses in non-oriented Fe-Si sheets is measured from DC and 400 Hz and assessed by a simple model, considering the evolution of the magnetic properties on the width of the cut strips (30 mm – 5 mm). The analysis shows that the normal magnetization curve and the quasi-static magnetic losses evolve with the width of the strip according to a

hyperbolic law. This permits one to predict, using minimum pre-emptive information, the evolution of curve and hysteresis loss from indefinitely wide to narrow fully degraded strip.

KEYWORDS: Soft Magnetic Material; Broadband Frequency analysis; Magnetic Characterization; Loss Separation; The Statistical Theory of Losses