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Mathematical modelling of frequency-dependent hysteresis and energy loss of FeBSiC amorphous alloy

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ABSTRACT

The aim of this paper is to present a novel mathematical model of frequency-dependent magnetic hysteresis. The major hysteresis loop in this model is represented by the ascending and descending curve over an arctangent function. The parameters of the hysteresis model have been calculated from a measured hysteresis loop of the FeBSiC amorphous alloy sample. A number of measurements have been performed with this sample at different frequencies of the sinusoidal excitation magnetic field. A variation of the coercive magnetic field with the frequency has been observed and used in the modelling of frequency-dependent hysteresis with the proposed model. A comparison between measured and modelled hysteresis loops has been presented. Additionally, the areas of the obtained hysteresis loops, representing the energy loss per unit volume, have been calculated and the dependence of the energy loss on the frequency is shown. Furthermore, two models of the frequency dependence of the coercivity and two models of the energy loss separation have been used for fitting the experimental and simulation results. The relations between these models and their parameters have been observed and analysed. Also, the relations between parameters of the hysteresis model and the parameters of the energy loss separation models have been analysed and discussed.

1. Introduction

Fe-based amorphous alloys are characterised by excellent magnetic properties such as high saturation induction, high relative permeability, low coercivity, and low power loss [1–4]. When these materials were first introduced, they were used in the manufacture of energy-efficient power transformers. Nowadays, these materials are widely used in transducers, sensors, high frequency devices, electric power conditioning, electronic power supplies, magnetic recording heads, in telecommunications, in the automotive industry and in other branches of industry [1–4]. Often, their application in a wide range of frequencies is desirable. Such an application requires an adequate mathematical model of the dynamic characteristics of the material during the magnetisation process.

Recently, an extension of the Jiles-Atherton model of hysteresis has been proposed for modelling the frequency-dependent characteristics of amorphous alloy [5]. In that paper, the frequency dependence of two model parameters was considered to obtain a better representation of the hysteresis loops at different frequencies. The most visible change in the hysteresis loop with the increase of the frequency is the increase of the coercivity. Based on this fact, a new mathematical model of frequency-dependent hysteresis (based on the model presented in [6]) is proposed in this paper. Variation of only one model parameter with the frequency is suggested. This model is closely related to the Bergqvist hysteresis model with the dry friction-like hysteresis mechanism [7], but it has a simplified mathematical form and method of computation.

With the aim of calculating the hysteresis model parameters, a number of hysteresis loops have been measured with the $Fe_{81}B_{13}Si_{14}C_2$ amorphous alloy sample at frequencies in the range of 50–1000 Hz. Three model parameters have been obtained from the hysteresis loop measured at 50 Hz and kept constant during the calculations, while the fourth parameter takes the value of the coercive magnetic field and varies with the frequency. A comparison of the measured and modelled loops has been presented.

The observed dependence of the coercivity on the frequency has been mathematically represented using two models [8,9]. The relations between the parameters of these two models have been analysed. Furthermore, simulated frequency-dependent hysteresis loops have been used in the calculation of the energy loss per unit volume. The obtained energy losses have been separated into the static-hysteresis loss and the eddy current loss, as well as the excess loss, using two mathematical models [9,10]. The relations

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