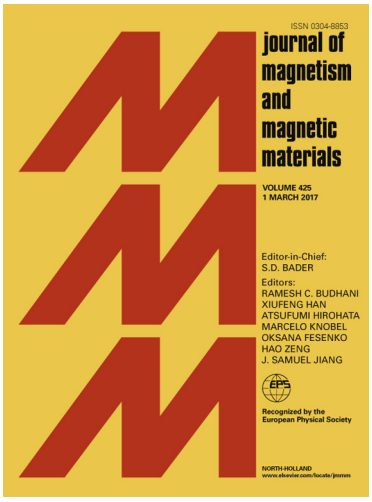

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Effect of multi-axial stress on iron losses of electrical steel sheets

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Abstract

The effect of multi-axial stress on the iron losses of a non-oriented electrical steel sheet under alternating magnetization is analyzed. Multi-axial magneto-mechanical measurements on a M400-50A grade non-oriented electrical steel sheet are performed by using a custom made single sheet tester device. The measured losses are separated into hysteresis, classical and excess loss components by using statistical loss theory, and the effect of various stress configurations on the hysteresis and the excess loss components is analyzed. By utilizing the statistical loss theory, an equivalent stress model and a magneto-elastic invariant based model are derived. These models can be used to predict the iron loss evolution under multi-axial stress even if only uniaxial stress dependent measurements are available. The accuracy of both models to predict the multi-axial stress dependent iron losses is found to be satisfactory when they are identified only from uniaxial stress dependent measurements. The invariant based model is shown to be slightly more accurate for the studied material.

Keywords:
Excess loss, hysteresis loss, magneto-mechanical, multi-axial stress, single sheet tester.

1. Introduction

The magnetic properties of electrical steel sheets widely used in electrical machine cores are known to be highly stress dependent. During the manufacturing processes and operation of these devices multi-axial stresses are exerted on the core laminations [1–6]. The performance of the electrical machines is significantly affected by these multi-axial loadings [7–12]. Therefore, in order to be able to design more efficient devices and analyse existing ones with better accuracy, the dependency of the core losses on the multi-axial stresses should be studied comprehensively.

Previously, several studies on the interaction between the different components of the core losses in electrical steel sheets and the mechanical stress have been performed [13–17]. For instance, in [13] the effect of uniaxial stress on different loss components was studied according to the statistical loss theory of [18]. It was found that the hysteresis and excess losses increased under compression and high tensile stress, and reduced under low tensile stress. A similar study with wide range of data has been performed in [14]. In both studies it was reported that the uniaxial stress has similar effect on the hysteresis and excess loss components. On the other hand, in [15] uniaxial tension dependent core losses are separated into hysteresis, excess and non-linear loss components. It was shown that the tensile stress affected the hysteresis and non-linear loss components, whereas the effect on the excess loss component was insignificant.

The aforementioned studies rely on fitting the loss model parameters to the measured losses only under various uniaxial magneto-mechanical loadings. Although they can be accurate in describing the losses within the fitted uniaxial stress ranges, they do not describe or predict the stress dependent losses under multi-axial loadings as it occurs in electrical machines. Due to the practical difficulties of performing multi-axial magneto-mechanical experiments, only a few experimental studies on non-oriented electrical steel sheets were performed in the past to study the multi-axial stress dependency of the iron losses [19–22]. For instance in [19–21], effect of uniaxial and shear stress on magnetic properties and iron losses of non-oriented electrical steel sheets was studied. However in these

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