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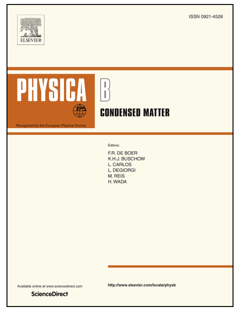

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Prediction of angular variation of specific total loss of Goss oriented electrical steel

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ABSTRACT

Electrical steel (ES) is the optimal material for magnetic cores of large electrical machines and transformers. This material is graded according to the value of its specific total loss (P_S). The anisotropy of its magnetic properties is also crucial in the selection for applications. This paper presents a new method of modeling angular properties of P_S in Goss oriented ES. Additionally, the proposed method can be combined with the three components P_S loss model and the angular behavior can be analyzed in a frequency domain. This approach can limit labor-intensive measurements necessary to describe angular properties of P_S of ES with Goss texture. It may be also a useful tool for designers of magnetic cores of electrical devices.

Index Terms— Soft Magnetic Materials, Magnetic anisotropy, Goss texture.

1. Introduction

Electrical steel (ES) is used in applications involving changing magnetic flux, such as in motor, generator and transformer cores where it consumes over 5% of all electrical energy produced as core loss. Over 10 million tons of ES is produced each year for use in the electrical industry so even small decreases in core loss can offer large energy savings [1, 2, 3, 4]. This can be facilitated by improvement of modeling of magnetic cores by better treatment of the anisotropy of the magnetic properties of ES. The anisotropy adversely affects some technical parameters of an assembled transformer or rotating machine core [5, 6]. GOES (Goss oriented electrical steel), widely used in power transformer cores, is highly anisotropic because of its unique grain structure. The influence of its anisotropy can be detected only at the final stages of core production. Taking better account of its anisotropic properties at the design stage can avoid material and energy waste due to incorrect designing.

Much research has been devoted to modelling the influence of anisotropy on magnetic properties of GOES as e.g. models based on co-energy concept [7], on a reluctivity tensor [8] or Néel's phase theory [9]. Another model is based on an Orientation Distribution Function (ODF) [10]. This uses three components of ODF function and data measured at magnetization angles x = 0°, 45° and 90° with respect to the rolling direction (RD) of the steel for obtaining the angular behavior of the specific total loss (P_S) [11]. However, this approach cannot be applied at high flux density at which GOES is often operated in transformer cores [4, 12, 13].

This paper presents results of analysis of angular behavior of P_S of five grades of GOES with different degrees of anisotropy due to textural differences. The analysis was carried out based separation of P_S into static hysteresis, classical eddy current and excess loss components [14]. The analysis of results leads to formulating a novel empirical model for the prediction of angular properties of P_S of GOES. It is demonstrated that only three experimental data are needed to accurately predict the variation of P_S with angle of magnetisation with respect to the RD up to saturation flux density.

2. Experimental results

2.1. Measurements

The anisotropy of magnetic properties was determined from Single Sheet Tester (SST) measurements on 100 mm square samples. It should be emphasized that the Epstein frame should not be used for measurements of anisotropy of magnetic properties because of its shape anisotropy [15, 4]. A group of conventional GOES grades M165-35S, M150-35S, M150-27S, M140-30S, M120-27S was chosen for this investigation. The grades of steel contain (3.1 ± 0.1)% of Si and their thicknesses vary between 0.27 mm and 0.35 mm. The specific total loss measured when magnetised along the RD at 1.7 T differ by about 30%.

Square sample (100 mm × 100 mm) were cut at x = 0º, 30º, 45, 36º, 54º and 63° to the RD. By rotating samples cut at x = 30°, 54° and 63° by 90º magnetisation cold be included at x = 60º, 36º, 27º and 90º to the RD to further increases the measurement points. This saves on material and cutting time.

The anisotropy of specific total loss $\Delta AP_{1.5}^{90-0}$ is determined

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