Model-based estimation of electrical conductivity based on analytical eddy current models for ring-shaped samples

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This paper presents the workflow for the model-based estimation of the electric conductivity using ring-shaped samples. Two different analytical eddy current models are employed and verified using time-harmonic finite element models. For the metrological investigations ring-shaped samples made out of three different soft magnetic steel grades, as well as para-, and diamagnetic ring samples made out of austenitic steel, aluminium and copper are at hand. The estimated electric conductivities are verified using van-der-Pauw measurements of clover-leaf like samples.

Keywords: Electrical Conductivity, Eddy Current Model, Model Based Estimation, van-der-Pauw measurement

1. Introduction

The characterization of the magnetization behavior of soft magnetic materials (SMMs) still pose challenges, even today, in industry and science. Widespread methods use the induction principle (e.g. Epstein frame, single sheet tester, ring core measurements, …) to gain insight on the material's properties. Still, results gathered with these methods can vary significantly, depending on the chosen procedure. In addition to numerous quasi-static "DC" magnetization curve measurement methods, there exists also a standardized procedure for the acquisition of the AC-magnetization curve (e.g. IEC 60404-6 for ring-shaped samples). However, due to eddy current (EC) effects and inhomogeneities in magnetization, results yielded with the AC method are dependent on the frequency and the geometry deployed. Efforts are made to estimate an intrinsic permeability, independent on frequency and geometry, by the means of an analytical EC model [1]. However, the method proposed in [1] needs knowledge on the electrical conductivity of the given SMM. This paper will address the EC model-based electrical conductivity estimation from measurement data and will present a characterization workflow.

2. Methodology

2.1. *Metrological Investigation*

For the metrological investigation, the authors choose ring-shaped samples. Ring samples are beneficial because of their closed form, and the advantages that exist regarding stray flux compensation [2]. Alongside samples made out of three different electrical steels grades, in six different geometries, the authors also have austenitic steel, aluminium and copper samples in four different geometries at hand. The benefit of the later samples is their well-known relative permeability, $\mu_r \approx 1$, while the intrinsic permeability of the SMM samples is generally unknown. For all samples, the magnetization curves and iron losses are characterized. In the case of the para-, and diamagnetic samples, the ideal magnetization curve with $\mu_r \approx 1$ is affected by the eddy currents' opposing field, while iron losses only consist of eddy current losses, since these materials show no hysteretic magnetization behavior.

2.2. *Eddy Current Model*

Two different EC models are employed to estimate the electrical conductivity. In the first step, only the conductivity of the para-, and diamagnetic samples will be estimated, since their intrinsic permeability is well known. Second, the analytical EC models estimate the SMM samples' intrinsic permeability and electrical conductivity.

2.3. *Finite Element Model*

With the material parameters gained from the analytical estimation process, finite element (FE) models are defined in 3D FEA software, using a harmonic EC solver. Using the same spatial dimension as for the metrological ring samples, the FE models give insight on the spatial field distribution in the ring specimen, allowing a comparison between the analytical and numerical FE results.

2.4. *Verification using van-der-Pauw characterization*

To verify the estimated electrical conductivities, not only datasheet values are used, but measured material parameters using the van-der-Pauw method are employed. The samples in use are manufactured in a "clover-leaf" like geometry, to reduce the characterization error [3].

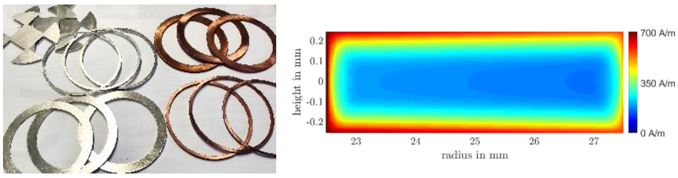

Figure 1: Left - Copper and Aluminium rings samples and clover-leafs. Right - Exemplary field strength distribution over the ring sample's cross section, calculated using an analytical EC model at an excitation frequency of 1kHz.

3. Outlook

The final paper will present a workflow to estimate the electrical conductivity of ring-shaped samples out of measurement data with the help of analytical EC models. Calculations using the FE method are used to verify the results of the EC models, and measurements of the electrical conductivity using van-der-Pauw technique are used to verify the estimated conductivity values.

References

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