Analytical expression including fractional derivative for the dynamic magnetic power loss: generalization

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This study presents analytical expressions for predicting dynamic magnetic power loss in ferromagnetic materials under alternating or rotating magnetic fields. The method, validated against extensive experimental data from a wide range of ferromagnetic materials, demonstrates high accuracy and reveals that rotational fields double the power loss compared to alternating fields. The findings simplify material loss prediction to a single parameter, offering significant implications for the design of electromagnetic converters.

Keywords: Fractional derivative, viscoelasticity, power loss

1. Introduction

This study introduces a novel analytical approach for predicting the dynamic magnetic power loss in ferromagnetic materials subjected to alternating or rotating magnetic fields. The proposed method utilizes fractional derivative analytical expressions of trigonometric functions [1], providing a computationally efficient and accurate tool for core loss prediction. The study's analytical expressions are validated against a large amount of experimental data from state-of-the-art setups [2, 3], demonstrating a high level of accuracy with a relative Euclidean distance below 5% for most tested materials and always below 10% (see Fig. 1 for illustration) [4].

Key findings include the observation that the dynamic power loss contribution under a rotating magnetic field is precisely two times higher than that under an alternating field under standard sinusoidal flux density conditions. This insight is crucial for the design and optimization of electromagnetic converters such as transformers, inductors, and motors, where magnetic losses can significantly impact efficiency, performance, and reliability. The research also highlights that by understanding the material's electrical conductivity, the dynamic magnetic power loss can be simplified to a single parameter—the fractional order—which is consistent for both rotational and alternating contributions.

The paper further discusses the implications of these findings on the selection of appropriate ferromagnetic materials for specific applications, contributing to the development of environmentally friendly technologies that consume less energy and reduce the overall environmental impact. The study confirms the viscoelastic behavior of the magnetization process in ferromagnetic materials, thereby validating the use of fractional derivative operators for their simulation. This work offers a significant advancement in the understanding and prediction of magnetic losses in electromagnetic systems, with potential applications in various industries where compact and lightweight converters are critical, such as in portable electronic devices and aerospace systems.

2. Experimental data

The experimental results used in this study were drawn from state-of-the-art literature [2], providing a solid benchmark for validating the analytical expressions. These results include both unidirectional and rotational magnetic field stimulations applied to the same specimens, allowing for a comprehensive assessment of dynamic magnetic power losses. By leveraging well-established experimental datasets, the study ensures a robust comparison between simulated and measured losses, highlighting the influence of field orientation on magnetic dissipation mechanisms.

3. Results and discussion

Fig. 1 below depicts a first comparison simulation/ measurement. Experimental data were extracted from [2]. Iron-cobalt-vanadium $Fe_{49}Co_{49}V_2$ (FeCo), known as permendur, is tested first for up to 5 kHz in rotational and alternating conditions. The quasi-static contribution P_{stat} under alternating and rotational conditions is not simulated but calculated from the f = 5 Hz experimental measurements. Then, an optimization process based on the relative Euclidean distance (RED(%) [4], is run to determine the best couple of simulation parameters (n and ρ).

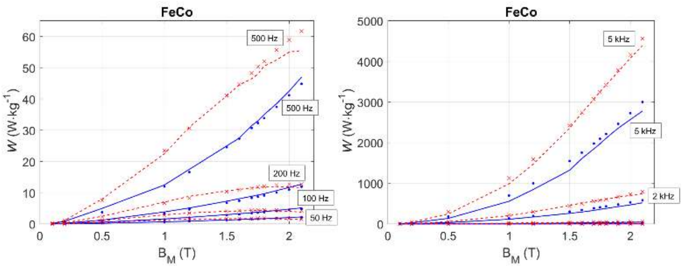

Figure 1: Comparisons simulation/measurement [2] under alternating and rotational magnetization for FeCo materials.

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