A Hybrid Approach Based on the Jiles-Atherton Model and Artificial Intelligence for Modelling the Dynamic Hysteresis of Electrical Steels

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This study presents a hybrid approach combining the Jiles-Atherton (JA) physical model with a feedforward neural network (FFNN) to enhance the modelling accuracy and computational efficiency of magnetic properties in electrical steels. Traditional JA models face limitations in handling dynamic and multi-physical conditions. By integrating a neural network to correct the residual error of the JA model, the proposed method achieves significant improvements in predicting both static and dynamic hysteresis loops. Hyperparameter optimization reduces the error compared to standalone JA simulations. Results demonstrate that the prediction of the hybrid model maintains physical interpretability while leveraging machine learning for rapid adaptation to complex scenarios, achieving errors below 1% in static cases and robust performance in dynamic cases.

Keywords: Hysteresis; Jiles-Atherton model; Neural network; Magnetic properties; Mechanical constraints.

1. Introduction

Ferromagnetic materials, especially electrical steel, play a key role in electromagnetic energy conversion devices, such as electrical machines. During the design step, the non-linear magnetic properties of these materials, characterized by hysteresis phenomena, must be correctly accounted for in order to accurately assess the performance of electrical machines. Modeling these magnetic behaviors may be increasingly challenging when considering dynamic effects related to frequency variation and mechanical stresses that can substantially alter their magnetic performance.

In the literature, several approaches are proposed to model these complex behaviors, such as the Jiles-Atherton (JA) model [1], derived from energetic considerations, or the phenomenological Preisach model [2]. More recently, thanks to the progress of modern computational capacities, machine learning techniques, such as artificial neural networks (ANN) [3], have become an alternative in the modelling of magnetic hysteresis. Each of these methods comes with its distinct advantages and limitations. Physical models offer solid theoretical grounding but often fall short in accuracy when dealing with complex conditions, while neural networks can capture intricate behaviors but require substantial datasets.

This work addresses these gaps by proposing a hybrid JA-FFNN (feedforward neural network) model optimized for both static and dynamic regimes. The neural network corrects residual errors from the JA model, enabling precise predictions of hysteresis loops across frequencies, stress levels, and induction amplitudes.

2. Results and discussion

Our study shows the ability of a hybrid approach combining the JA model with FFNN for modeling magnetic properties of electrical steels. In static conditions (5 Hz), the hybrid model achieved remarkable accuracy with errors below 0.33% for training data compared to an error ranging from 5.76 to 13.80% (depending on the induction level) for the standalone JA model.

Also, an optimization of the NN hyperparameter has been performed in static case, showing that a simple network architecture with one hidden layer of 110 neurons using a hyperbolic tangent activation function performed best.

The hybrid approach (Figure 1) maintained excellent performance in dynamic conditions (5-150 Hz), with errors consistently below 1% even for validation frequencies not included in training data.

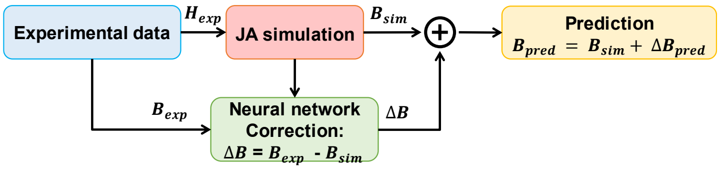

Figure 1: Schematic of the proposed hybrid approach.

Hysteresis loops at 1.4T-150Hz obtained from the different approaches, and compared to the experiment, are given in Figure 2. The proposed hybrid model JA+FFNN is able to accurately represent hysteresis behavior, particularly in saturation regions.

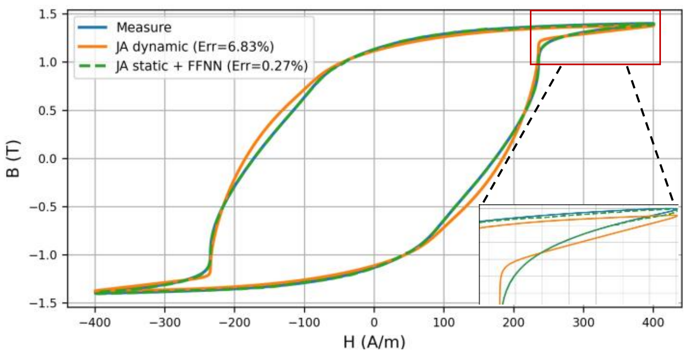

Figure 2: Comparison of different approaches with the experiment.

References

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