Study of Models and Methodologies for the Iron Loss Separation

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This paper presents an analysis of electrical steel loss separation models as well as methodologies for obtaining their parameter values. The classical approach of losses separation into three components: hysteresis, classical eddy current and excess is used. Four hysteresis loss models were analyzed. The classical equation for eddy current loss was discussed. Bertotti's approach for modeling the excess loss was employed. Based on the considered models, different methodologies for obtaining the parameter values were applied to experimental results from Epstein frame and toroidal samples. The methodologies are compared in terms of accuracy and a method for verifying it by the classical eddy current formulation is presented. The findings indicate that loss separation remains a subject of ongoing investigation.

Keywords: loss separation; iron loss models; hysteresis; eddy currents; excess losses.

1. Introduction

The iron loss is one of the main types of losses in electrical machines and the classical loss separation procedure is widely used in analyzing them.

One of the first models to predict the loss behavior was empirically developed by Steinmetz [1] and, later, other models were proposed where Bertotti's statistical approach for the excess loss is notable [2]. In the last decades, research efforts have been conducted to better suit the models in modern applications (higher frequencies and peak inductions) [3-4].

In this context, this paper analyses different recent approaches, focusing on the hysteresis loss modeling [5-7]. Recent developments in eddy current, excess and new saturation loss components were also evaluated and will be shown in the final version of this paper [8]. Moreover, methodologies for iron loss separation are discussed, with focus on its accuracy and applicability [2][6][9]. The experimental procedures were conducted on laminated and toroidal samples.

2. Results and discussions

2.1. *Hysteresis loss models analysis*

Three different hysteresis loss models [5-7] were compared with respect to Steinmetz equation. The model parameters were obtained using the Levenberg-Marquardt optimization algorithm, minimizing the mean squared percentage error (MSPE) between model-estimated values and experimental measurements at 1 Hz on laminated and toroidal samples.

Table 1 provides the MSPE values for each model in the third column, while the fourth column indicates their percentage difference compared to Steinmetz [1]. Model [5] exhibited only a small reduction in MSPE. Meanwhile, models [6-7] showed a substantial decrease, yielding similar results. This behavior was observed across all tested samples.

Table 1

Comparison between hysteresis loss models

Ref.	Model	MSPE	Rel. Diff. (%)
[1]	$W_h = k_h B_p^{\alpha}$	0,0023991	
[5]	$W_h = k_h B_p^{\beta B_p + \alpha}$	0,0023762	-0,95%
[6]	$W_h = k_h B_p^{\gamma B_p^2 + \beta B_p + \alpha}$	0,0006170	-74,28%
[7]	$W_h = k_h B_p^{\delta B_p^3 + \gamma B_p^2 + \beta B_p + \alpha}$	0,0004491	-81,28%

2.2. *Methodology analysis*

Three methodologies [2][6][9] to find the parameter values for losses separation were analyzed and compared. Elias [9] conducted experimental procedures at very low frequencies, providing a more accurate hysteresis loss evaluation. On the other hand, methodologies [2][6] may be more convenient when there are workbench low frequency limitations.

The methodologies were compared regarding their MSPE between model-estimated and measured values. Although [2][6] do not use low frequency tests, their results were relatively close to those of [9].

For methodologies that do not use the classical formulation, but the result of a curve fitting [6] or optimization [9] procedure to compute eddy current losses, the validity of the results can be accessed by isolating some parameter of the respective model equation, e.g. conductivity, and comparing it with direct measurement results on the lamination. This procedure conducted to large deviations and will be further explored in the final version of this paper.

Although loss separation is widely addressed in literature, this paper reintroduces the issue, indicating that it remains an open topic.

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