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A Compensated Mini-Permeameter for Localized Magnetic Loss Measurements on Magnetic Laminations

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Accurate magnetic loss characterization in permeameter-based systems is strongly affected by the magnetomotive force (MMF) drop in the flux-closing yokes, particularly in compact geometries where only a limited portion of the specimen is magnetized. In this work, a compensated mini-permeameter capable of magnetizing the central 60 mm region of a single Epstein strip is presented. MMF compensation is implemented through an auxiliary compensation winding and a feedback control scheme, enabling accurate determination of the magnetic field from the magnetizing current. The system is experimentally validated by comparison with local tangential H-coil measurements on a non-grain-oriented electrical steel with a thickness of 0.35 mm. Magnetic loss and hysteresis loops measurements performed at 50 Hz show that compensation effectively reduces systematic loss overestimation, yielding good agreement with the reference measurements. The proposed approach provides a compact and reliable solution for localized magnetic loss characterisation and can be readily extended to standard and non-standard single-sheet testers.

***Index Terms*—Magnetic loss measurement, mini-permeameter, MMF compensation, electrical steels, H-coil.**

I. Introduction

Accurate measurement of magnetic losses in soft magnetic steels is crucial for the design and optimization of electrical machines and electromagnetic devices. In permeameter-based measurement setups and Single Sheet Testers (SSTs), the magnetic field strength is commonly inferred from the magnetizing current by assuming a well-defined effective magnetic path length [1-2]. However, the magnetomotive force (MMF) drop in the flux-closing yokes introduces systematic errors, leading to overestimation of the magnetic field and losses, particularly for high-permeability materials and thicker magnetic samples. Several studies have compared magnetizing current-based (MC) and H-coil-based (HC) field-determination methods, showing that the MC method is inherently indirect and dependent on tester geometry. In contrast, the HC method provides a more direct measurement of the internal magnetic field at the expense of increased experimental complexity and low signal levels [3]. The application of MC methods requires high-quality yokes to ensure stable, low losses, relative to the power loss dissipated by the specimen [2]. A promising solution is MMF compensation techniques, which use physical compensation or robust correction schemes to achieve reference-grade accuracy. A notable contribution is reported in [4], which introduced a compensation scheme that uses the yoke itself as a zero-MMF indicator, combined with a feedback-controlled auxiliary compensation winding. In recent years, increasing attention has been devoted to miniaturized and localized magnetic testers aimed at characterizing limited regions of a sample or reduced material volumes [5]. In such compact geometries, MMF-related errors are exacerbated, further reinforcing the need for compensation-based approaches. In this work, a compensated mini-permeameter magnetizing only the central 60 mm region of a single Epstein strip is presented. The system is experimentally validated by comparison with local tangential H-coil measurements on a non-grain-oriented material, with samples cut along the rolling (RD) and transverse (TD) directions. With MMF drop compensation, the loss figures and hysteresis loops obtained from the MC method closely match the H-coil measurements.

II. Compensated Mini-Permeameter

The proposed mini-permeameter, illustrated in Fig. 1, was originally developed at Laboratoire SATIE. It accommodates a single Epstein strip that is magnetized only in its 60 mm length central region. As a consequence of this localized magnetization, the MMF drop in the flux-closing yokes represents a non-negligible fraction of the total MMF that must be compensated to ensure accurate magnetic field determination. MMF compensation is achieved by introducing an auxiliary compensation winding on the bottom yoke and implementing a feedback control loop that suppresses the MMF drop outside the 60 mm magnetic path length defined by the sample. Under compensated conditions, the magnetic field within the magnetized region of the strip can be accurately derived from the magnetizing current, independently of the magnetic properties of the yokes.

III. Experimental validation

Experimental validation was carried out on an NGO Fe–Si lamination with a thickness of 0.35 mm. Both longitudinal (L) and transverse (T) directions were considered. Measurements were performed under sinusoidal flux at 50 Hz. The magnetic losses and the hysteresis loops were evaluated over a range of peak polarization values. Local magnetic field measurements were obtained using a calibrated tangential H-coil placed within the magnetized region of the strip, providing a reference for the determination of magnetic losses and hysteresis loops.

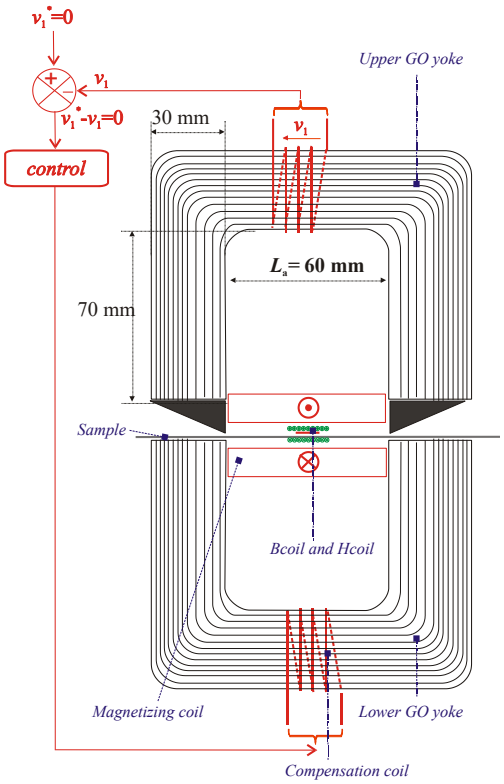


Fig. 1. Compensated Mini-Permeameter. It accommodates a single Epstein strip that is magnetized over its central region, defined by a magnetic path length of 60 mm. MMF compensation is achieved by using a compensation coil on the bottom yoke and a feedback control that suppresses the MMF drop outside the defined magnetic path, as measured by the sensing coil on the upper yoke. Under compensated conditions, the magnetic field within the magnetized region of the strip can be accurately derived from the magnetizing current.

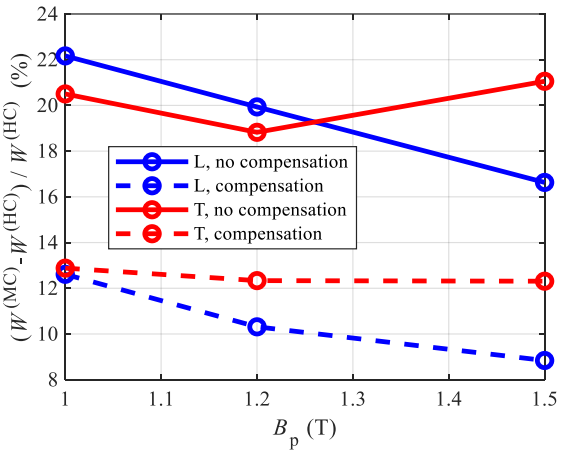


Fig. 2: Relative difference of the measured loss between the MC and HC methods as a function of B_p, in the L and T directions, without and with MMF compensation.

Magnetic loss figures obtained using the MC method with and without MMF compensation were compared with the loss measurement obtained with the H-coil-based reference. The relative differences are shown in Fig. 2. Without MMF drop compensation, the relative difference is lower in the T sample because its lower permeability results in a lower relative influence of the yoke.

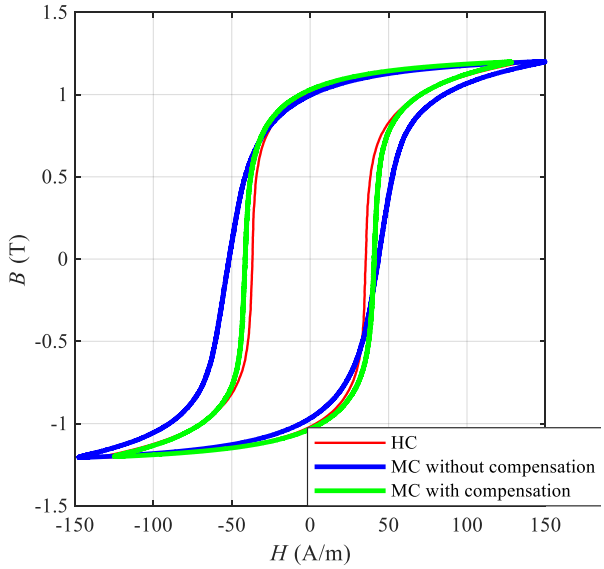


Fig. 3. NGO Fe–Si sheets cut in the L direction. J_p = 1.2 T and f = 50 Hz. Comparison of the hysteresis loops measured by the H-coil method and by the current measurement method, with and without compensation.

Moreover, the smaller the peak induction, the higher the error becomes in all cases (the ratio of the sample to yoke reluctances increases with B_p). The MMF drop compensation significantly affects the measured losses, bringing them much closer to those from the HC method. Note that with this small permeameter, a perfect match is unfeasible because of the non-homogeneity of the applied field. A comparison of the hysteresis loops measured at 50 Hz and J_p = 1.2 T using the different methods further confirms the effectiveness of the compensation scheme, showing much better agreement between the compensated current-based measurements and the local H-coil results.

The presented results demonstrate that MMF compensation is essential for accurate localized magnetic loss measurements in compact permeameter systems. The proposed mini-permeameter provides a simple and robust solution for single-strip characterization, enabling reference-grade measurements without resorting to full-scale SST setups. Finally, the same compensation principle could be directly applied to standard and non-standard full-scale SST systems.

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