



# Noninvasive laminated magnetic core characterization

Benjamin Ducharne, Aurélie Solignac

## ► To cite this version:

Benjamin Ducharne, Aurélie Solignac. Noninvasive laminated magnetic core characterization. 26th Soft Magnetic Materials Conference, Prague 2023, Sep 2023, Prague (CZ), Czech Republic. ⟨hal-04613693⟩

**HAL Id: hal-04613693**

**<https://hal.science/hal-04613693v1>**

Submitted on 17 Jun 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

# Noninvasive laminated magnetic core characterization

Benjamin Ducharne<sup>a</sup>, Aurélie Solignac<sup>b,\*</sup>

<sup>a</sup>ELyTMax IRL3757, CNRS, Univ Lyon, INSA Lyon, Centrale Lyon, Université Claude Bernard  
Lyon 1, Tohoku University, Sendai, Japan

<sup>b</sup>SPEC, CEA, CNRS, Université Paris-Saclay, CEA Saclay, 91191 Gif-sur-Yvette, France

Real-time magnetic core condition monitoring is a promising technique for rapid fault detection. In this domain, significant progress is forecasted by achieving precise local measurements. In this study, we propose an innovative solution to measure local magnetic properties, which is well suited to real-time monitoring and magnetic circuit evaluation. The proposed sensor is a one-piece device that is flat enough to be placed noninvasively between the laminations at distinct positions in the magnetic core. It measures the magnetic excitation and induction fields in two dimensions, which can be used as local inputs for real-time condition monitoring.

**Keywords:** local defect, magnetic lamination stack, magnetic sensor, predictive maintenance

## 1. Introduction

Magnetic cores used for energy conversion are made of electrical steel sheet stacks. Electrical steel is an iron alloy designed for specific magnetic properties such as low power loss and high permeability. Stacking and coating electrical steel laminations allow for improving the conversion efficiency considerably. However, during the machining processes, undesirable edge burrs can appear, leading to interlaminar faults (ILFs) and deteriorating the magnetic core efficiency. Other defects can occur during working time for many reasons, such as wearing out of insulation coating, vibration of loose windings, arcing from winding failure, ineffective cooling, transportation, and/or installation. Magnetic core condition monitoring (MCCM) has been proposed to improve performance and durability. It consists of a real-time inspection of the magnetic circuit's performance. Current MCCM is always performed by controlling the input and output electrical signals. This simple approach limits the magnetic core diagnostic to average quantities and makes localizing defects impossible. Embedding any instrumented measuring system inside a laminated magnetic core has always been impossible. However, in [1], we used printed sensors to perform such measurements.

In this new study, significant instrumentation improvement has been made. The resulting sensor became a one-piece device that is flat enough to be placed noninvasively between the laminations at distinct positions in the magnetic core.

## 2. Local characterization

The Magnetic Needle Probe Method (MNPM) is used to record magnetic flux variations in a laminated ferromagnetic core by surface measurement (details in

[1]). MNPM is limited because of weak electromotive forces, especially in the low-frequency range. However, considerable advances in analog and digital electronics have made MNPM viable for laminated core characterization. In our design, the test probes are replaced with a printed conductive layer, which results in a negligible leakage flux. The thickness of the whole sensor (a conductive layer,  $\approx 30 \mu\text{m}$ ) makes it unnoticed when embedded in stacks of steel sheets.

MNPM measures a local directional flux density. For a complete hysteresis cycle plot, the tangent surface field should be recorded as well. For this, we used giant magnetoresistance (GMR) sensors. GMRs allow detecting up to less than a few nanoteslas beyond substantial frequency and temperature ranges. GMRs consist of multiple thin layers, including two ferromagnetic deposited thin films isolated by a metallic nonmagnetic spacer. The total active part thickness is typically smaller than 100 nm. Fig. 1 below depicts the resulting sensor. A silicon substrate can be used and will lead to a 300  $\mu\text{m}$  thickness after polishing but becomes very fragile. Flexible Kapton can be used as well for improved mechanical properties and lower thickness ( $\approx 50 \mu\text{m}$ ).

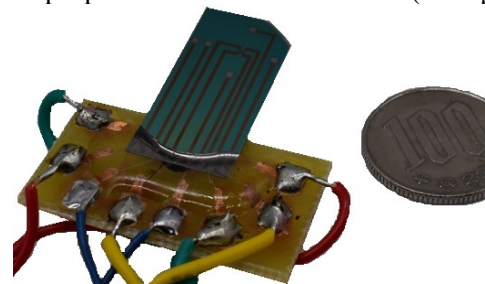


Fig. 1 Single patch sensor.

## References

- [1] S.H. Nguedjang Kouakeuo, B. Ducharne, A. Solignac, L. Morel, M.A. Raulet, B. Toutsoy, Y.A. Tene Deffo, P. Tsafack, "Non-invasive local magnetic hysteresis characterization of a ferromagnetic laminated core," J. Magn. Magn. Mater., vol. 527, 167783, 2021.

\* Corresponding author: [benjamin.ducharne@insa-lyon.fr](mailto:benjamin.ducharne@insa-lyon.fr)