ICEM 2026
27th International Conference on Electrical Machines
Funchal, Madeira, Portugal | September 6-9, 2026

Tutorial on

State-of-the-Art Assessment of Additive Manufactured Soft Magnetic Materials for Electrical Machines through Comprehensive Characterization

Tutorial Presenters

- **Stefano Nuzzo**, University of Modena and Reggio Emilia, Italy, stefano.nuzzo@unimore.it
- **Lukasz Mierczak**, Brockhaus Measurements, Poland, Lukasz.Mierczak@brockhaus.com
- **Paolo Bolognesi**, University of Pisa, Italy, paolo.bolognesi@ing.unipi.it

Biographies of the Presenters

Stefano Nuzzo (S'17-M'18-SM'23) received his MSc degree in Electrical Engineering from the University of Pisa in 2014, and his Ph.D. degree in Electrical and Electronic Engineering in 2018 from the University of Nottingham, Nottingham, U.K. He is currently an Associate Professor in Electric Machines and Drives within the Department of Engineering "Enzo Ferrari" of the University of Modena and Reggio Emilia. His research interests are the analysis, modelling and optimization of electrical machines, with focus on sustainability and reliability design approaches of synchronous drives based on radial and axial flux machines for industrial and traction applications. In addition, his interests include the magnetic characterization of unconventional magnetic materials and innovative manufacturing methods. Stefano Nuzzo is currently an Associate Editor for the IEEE PES Transactions on Energy Conversion and an Area Editor (Electrical Machines and Drives) for the IEEE PELS Transactions on Transportation Electrification. Since January 2025, he is the Secretary of the IEEE PELS Electrical Machines, Drives and Automation Technical Committee (TC3).

Lukasz Mierczak is an expert in magnetic materials and measurement technologies. He earned his PhD in Electrical Engineering at the Wolfson Centre for Magnetics, Cardiff University (UK). He currently leads BROCKHAUS Polska, developing advanced test systems for magnetic materials and electric motor components.
His career includes roles as: Principal R&D Engineer at BROCKHAUS Measurements (2017-2023), Motor Design Engineer at E-propelled (2012-2017), Research Assistant at Cardiff University (2008-2012). Dr. Mierczak is also a frequent speaker at international conferences and author of several scientific publications and patents in the field.

Paolo Bolognesi received his M.Sc. degree cum laude in Electrical Engineering in 1995 and his Ph.D. with power electronics curriculum in 1999, both from the University of Pisa, Italy. He joined then the same University as a Junior Researcher and finally as a Senior Researcher and Appointed Professor in 2001. His research interests focus mainly on modelling, analysis, design and control of electromagnetic devices, including innovative electric machines and electromechanical actuators, as well as on innovative topologies for static converters and associated modulation/control solutions. He is also interested in the related technologies and applications, including unconventional magnetic materials, electric and hybrid vehicles, industrial automation, power generation from renewables.

Abstract

Nowadays, the development of electric machines is mainly driven by the strong push towards sustainable mobility and a high energy efficiency. Although well established, traditional design criteria and manufacturing technologies for electric motors have some intrinsic limits and drawbacks. In recent years, the push to overcome these limits has led to significant advances in both new materials and cutting-edge production techniques.

One of the most promising techniques is Additive Manufacturing (AM). Thanks to the possibility to build components layer-by-layer, AM unlocks an unprecedented design flexibility, paving the way for innovative solutions and a tight functional integration. However, a comprehensive and accurate magnetic characterization of the producible components is essential in order to assess and optimize the quality of the manufacturing process.

This tutorial will first present the standard and advanced characterization techniques of magnetic laminations and electrical machine laminated stacks, focusing on the equipment and methodologies developed by Brockhaus Group.

A comprehensive experimental characterization of different alloys produced via AM will follow, aimed at assessing the state-of-the-art of AM-produced soft magnetic materials and evaluating their suitability for electrical machine cores. The effects of build orientation and heat treatment on test samples will be discussed, not only through magnetic characterization, but also through electrical resistivity measurements and microstructural analyses. The experimentally derived properties will be then used to virtually test the potential impact of the adoption of AM in a number of electric motor technologies by using finite element analyses.

Finally, some innovative machine layouts made feasible by the extra design degrees of freedom enabled by AM will be examined, also presenting experimental demonstrations and life cycle assessment considerations, permitting to highlight pros and cons of such manufacturing technology for electric machines magnetic cores applications.

List of contents

- Experimental characterization of magnetic laminations for electrical machines
  - Standard and advanced characterization methods
  - Impact of DC bias, PWM excitation and realistic flux density distributions on magnetic properties of rotor and stator core materials
  - Influence of applied and residual stresses from conventional manufacturing processes on material properties and electrical machine performance
- Experimental characterization of additive manufactured soft magnetic materials
  - Review of additive manufacturing of soft magnetic materials in electrical machines
  - Characterization of ring samples made of different materials
    - Magnetic performance
      - Effects of build orientation
      - Effects of heat treatments
      - Effects of Silicon content
    - Electrical resistivity measurements
    - Microstructural characterization
  - Testing of AM-built FeSi2.9 rings using different dimensions: guidelines for accurate magnetic characterization
- Applications in electrical machines
  - Electrical machine performance assessment using solid AM cores
    - Case study 1: radial-flux machine

- Case study 2: axial-flux machine
- Performance improvements through innovative core geometries enabled by AM
- Life cycle assessment considerations
- Test results