Publishable Summary for 20SIP04 qMOIF
Standardisation of a quantitative Magneto-Optical Indicator Film based magnetic field measurement technique

Overview

The aim of this project is to standardise the quantitative magneto-optical indicator film-based technique for quantitative spatially resolved magnetic field measurements (qMOIF) that was developed in the EMPIR project 15SIB06 Nanomag. The project will provide concrete advice on how to make best use of the standardised qMOIF technique for characterising micromagnetic materials by producing documents that describe the quantitative MOIF approach including worked examples. A qMOIF Technical Specification will be submitted to the IEC TC 113.

Need

Industrial users need traceable quantitative characterisation tools for magnetic materials on the micrometre to centimetre scale to perform ISO 9001 compliant quality management of their products and production processes. To address this need, EMPIR project 15SIB06 Nanomag for the first time established high-resolution magnetic field measurement techniques, culminating in a quantitative magnetic force microscopy (qMFM) based field measurement standard. While qMFM can be regarded as the gold standard for nanoscale magnetic field measurements with extremely high spatial resolution, its technical application is often hindered by several drawbacks: qMFM is slow, has a limited imaging area and can only deal with samples flat on a 100nm scale. On the other hand, established NMR based SI standards for magnetic field measurements can only be applied to centimetre scale macroscopic objects. This leaves a gap on length-scales from micrometres to millimetres, where no standardised measurements are available. However, industrially relevant magnetic materials like precise magnetic encoders and high-quality electrical steel sheets often combine micrometre scale magnetic features with sample dimensions in the millimetre range and show rough surfaces, leading to a poor applicability of the qMFM based standard to many industrially relevant materials. The primary supporter of this project, IEC TC 113 *Nanotechnology for Electrotechnical Products and Systems*, sees the need to bridge the standardisation gap to such industrial applications as part of its overall aim of ensuring the standardisation of the technologies relevant to electrotechnical products and systems in the field of nanotechnology.

qMOIF is a fast (sub second resolution) imaging technique that allows a one-shot characterisation and thus high throughput of samples with areas of several square centimetres. Additionally, it can be used under harsh environmental conditions and for rough samples without the need for surface treatments. The EMPIR project 15SIB06 NanoMag established and validated qMOIF techniques with the capability to detect fields from the millitesla (mT) to the tesla (T) range with sub µm spatial resolution. This project will amend the existing qMFM standard to include a Technical Specification for traceable qMOIF and to provide guidance to end-users how to use qMOIF to measure relevant material parameters.

Objectives

The overall goal of the project is to incorporate the qMOIF measurement technique developed and validated within the EMPIR project 15SIB06 NanoMag into the existing IEC standard on nanoscale field measurements and to embed it into the industrially relevant metrological framework.

The project addresses the following objectives:

1. To embed qMOIF into the existing normative framework. This will entail (a) defining the applicability range of qMOIF, (b) establishing a unified vocabulary including Key Control Parameters (KCPs), (c)

defining unified terms and definitions describing the measurement and analysis process, and (d) identifying typical industrially relevant parameters and relating them to the MOIF KCPs.

2. To provide written advice and guidance to end users in the form of a Best Practice Guide for qMOIF including worked examples.
3. To extend the existing standard in nanoscale magnetic field measurements to the micro- and centimetre-scales by drafting a Technical Specification for qMOIF and submitting it to the IEC TC 113.
4. To ensure a high awareness of the standard in the scientific and industrial communities.

Results

Embedding qMOIF into the existing normative framework

To prepare the future Technical Specification, a literature review on the state of the art of quantitative magnetic field measurements, based on magneto-optical indicator film technologies, with a focus on the classification of measurement techniques and measurement conditions was performed and a comprehensive review report on the state-of-the-art was prepared and published as an article in a peer-reviewed journal.

To provide a unified vocabulary on qMOIF, which is required for a clear and unequivocal description of the measurement and analysis process, the qMOIF "Terms and Definitions", "Key Control Parameters (KCPs)" and application ranges were defined and published open access on the PTB OAR (Open Access Repository) as "Magnetic field measurements with magneto optical indicator films (MOIF): Terms and Definitions, Key Control Parameters (KCPs) and typical values"

To guide end-users to potential applications, secondary parameters of magnetic scales were related to MOIF measurements and example measurements were performed. The list of parameters and examples of measurements were compiled into a document and uploaded to the PTB OAR as "Secondary Parameters of technologically relevant materials and their relation to quantitative MOIF measurements"

Best Practice Guide for qMOIF

A Best Practice Guide for MOIF was compiled, using the input from the above described documents. It was used to produce a first draft of the technical specification for qMOIF.

Technical Specification for qMOIF

Based on the initial outputs from the project, a New Work Item Proposal for a qMOIF standard document was prepared, uploaded to the IEC and circulated under 113/657/NP. The project was approved by a vote in July 2022 and a project team was established. In November 2022, a first Committee Draft (CD) was circulated as 113/761/CD. Taking into account the Compilation of Comments on the CD (113/793/CC) that was compiled by the IEC TC113, the draft was revised. The revised future Technical Standard IEC/TS 62607-9-2 was submitted to the IEC for preparation of the final draft by the IEC Editing Service and will be circulated as a Draft Technical Specification (DTS) for a final vote from February 2024 to May 2024.

Ensuring high awareness of the standard in the scientific and industrial communities

The project has progressed with raising awareness in the scientific and industrial communities of its initial outputs and the activities towards standardisation of the qMOIF techniques. A stakeholder committee (SC) of four members, representing large and small enterprises and academia has been established, which has been a means for both receiving input on the documents produced in the project as well as their dissemination to end-users. The possibility of applying the new standard to the characterisation of magnetic steel sheets with time-resolved qMOIF within another EMPIR project has been discussed with its coordinator. High awareness of the qMOIF standard and the quantitative MOIF characterization technique is further ensured through a peer-reviewed publication, several conference and trade fair presentations as well as a seminar on "Quantitative spatially resolved magnetic field measurements" aimed at industrial and academic stakeholders and members of standardisation bodies.

Impact

The IEC TC 113, the SIP Primary Supporter, aims at standardisation of the technologies relevant to

electrotechnical products and systems in the field of nanotechnology. By initiating the process of incorporating the qMOIF technique into an existing series of IEC Technical Specifications under IEC TC 113 and by defining a unified vocabulary as well as Key Control Parameters (KCPs), this project addresses both the standardisation of the nanomagnetic measurement techniques and of the nomenclature, and thus directly supports the strategic objectives of the Primary Supporter.

The project has made an immediate impact by initiating a new work item and submitting a draft Technical Specification as New Work Item Proposal (NWIP) to the IEC TC 113. The NWIP was approved, a committee Draft was prepared and comments were collected. The document was revised and the revised document was submitted to the IEC for the preparation of the final draft by the IEC Editing Service. It will be circulated as DTS for a final vote from December 2023 to March 2024.

The EMPIR project 15SIB06 NanoMag developed traceable calibration procedures for qMOIF. The standardisation of these techniques will close the measurement and standardisation gap for field measurements on the micrometre to centimetre length scale. Thereby, the project outcomes will open a path towards reliable, robust, quick and cheap characterisations of a large number of industrially relevant innovative magnetic materials and components.

The outcomes of this project will directly facilitate the uptake of the traceable qMOIF field measurement technique by industrial users via a standardised measurement approach referring to relevant parameters using terminology common to end-users and by providing guidance for the complete measurement process. Examples are measurements on magnetic encoders and steel sheets, the quality of which will improve as a result. As examples of early uptake of the project outputs, a project partner and a member of the SC are collaborating on a technology transfer project on the application of standardised qMOIF in industry. Furthermore, project partners are involved in the drafting of a new DIN SPEC on the characterization of magnetic scales that is expected to include qMOIF as one possible characterization technique.

A major goal of the EU is a 32.5 % increase of energy efficiency and a corresponding reduction of greenhouse gas emissions by 2030. High-quality electrical steel sheets for low-loss conversion generators and for efficient power generation will lead to increased energy conversion efficiency in utility transformers, wind turbines and motors including electric cars. Additionally, improved magnetic sensor technologies will help to further improve the efficiencies of non-electric motors, which for many areas cannot be replaced by electrical technologies in the foreseeable future.

List of publications

Dorosinskiy, L.; Sievers, S. *Magneto-Optical Indicator Films: Fabrication, Principles of Operation, Calibration, and Applications*. Sensors 2023, 23, 4048. https://doi.org/10.3390/s23084048

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:	01 July 2021, 36 months	
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Primary Supporter: Norbert Fabricius, International Electrotechnical Commission, TC 113: Nanotechnology for Electrotechnical Products and Systems		
Internal Funded Partners: 1. PTB, Germany 2. TUBITAK, Turkey	External Funded Partners: 3. INNOVENT, Germany 4. ISC, Germany	Unfunded Partners: