Title: Nano-scale traceable magnetic field measurements

Abstract

Macroscopic magnetic field measurements are traceable to magnetic resonance quantum standards. However, important European high tech industries require traceable and reliable measurements of magnetic fields and flux densities on the micro- or nanometre scale, which are presently unavailable. To address this need, proposals against this SRT should develop, evaluate, and validate metrological methods for traceable micrometre and sub-micrometre spatially resolved magnetic field measurements. They should also provide calibration artefacts and guidelines for traceable high resolution field measurements, aligned with identified stakeholder needs.

Keywords

Magnetic field metrology, scanning Hall magnetometry, magneto optical indicator film, magnetic force microscope

Background to the Metrological Challenges

Magnetic field measurements on the macroscopic scale can be traced back to SI quantum standards based on nuclear magnetic resonance (NMR) of the proton. NMR relates the applied flux density (unit Tesla) to the NMR frequency via a natural constant, the gyromagnetic ratio of the proton. However, these calibration chains only refer to field measurements over macroscopic volumes or surface areas down to the sub millimetre scale and micro- and nano-scale magnetic measurements lack reliable traceability.

For local stray field measurements with a resolution range below 100 µm, different measurement techniques are available, e.g. local (scanning) Hall magnetometry, Hall array field mapping, or magneto optical indicator film (MOIF) field mapping. These methods have the potential to enable traceable local field measurements from 50 µm down to 500 nm resolution. However, calibrations for these methods have never been validated by comparison of different local stray field mapping techniques and the uncertainties are not known.

Magnetic force microscopy (MFM) can be considered the standard tool for imaging the local magnetic properties of magnetic nanostructures, thin films and devices. Although there are other techniques that reveal higher resolution (like spin-resolved scanning tunnelling microscopy), they generally do not offer the versatility of MFM. Despite its widespread use, MFM measurements are generally purely qualitative and the measurement signal strongly depends on the stray field and magnetic moment distribution of the magnetic tip. Several approaches for traceable MFM calibrations have been suggested, however, the validity and uncertainty of the different approaches still need to be evaluated and a path for traceability of end user MFM measurements is still lacking.

International standardisation bodies such as IEC TC 68 "Magnetic alloys and steels" address macroscopic measurements of magnetic materials, while IEC TC 113 "Nanotechnology standardisation for electrical and electronic products and systems" addresses various non-magnetic aspects of nanotechnology. However, despite the ever increasing importance of micro- and nanomagnetics, there are no national or international standards related to reliable measurements in this field.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP-Protocol.

The JRP shall focus on providing joint, sustainable, and coordinated European metrology capabilities that extend reliable and traceable measurements of spatially resolved magnetic fields down to the micrometre and nanometre length scale.

The specific objectives are

1. To provide metrology tools and methods suitable for traceable measurements of the local stray field distribution of permanent magnets and magnetic encoder scales with spatial resolution from 50 µm down to 500 nm to underpin ultra-precise magnetic position sensing; to evaluate different local stray field measurement techniques with respect to traceability and uncertainties; and to establish traceability of local stray field measurements to macroscopic SI standards and to evaluate their uncertainties;
2. To provide validated calibration techniques to ensure SI traceability of magnetic force microscopy with spatial resolution below 50 nm; to develop, test and validate different calibration approaches; to establish traceability to macroscopic SI standards and to evaluate their uncertainties;
3. To provide calibration artefacts suitable for traceable on-site calibrations to underpin reliability of micro- and nano-scale traceable magnetic field measurements of end-users;
4. To facilitate the uptake of new advanced high resolution magnetic field metrology techniques by the measurement supply chain, ensuring traceability of measurement results to the users of metrology services and contribute to the development of standards by the international (IEC) standardisation committees concerning nano-scale magnetic measurements or nano-electronics.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the iMERA-Plus project T4.J02 Nanospin and EMRP project EXL04 SpinCal and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.8 M€, and has defined an upper limit of 2.1 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 21 % of the total EU Contribution to the project. Any deviation from this must be justified.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the magnetic devices and nanotechnology sectors.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”.

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.