EMPIR Call 2020 – Fundamental, Industry and Normative

Selected Research Topic number: **SRT-i07**
Version: 1.0

Title: Quantum traceability of nanoscale magnetic field measurements

Abstract

Magnetic field measurements at the nanoscale are required in fundamental science and in industrial applications such as data storage, positioning control and ultra-precise machining. However, the development of high-resolution magnetic microscopy techniques is limited, and traceability from quantum standards through to industry is lacking. Proposals are sought to establish and validate a traceable European infrastructure for nanoscale magnetic field measurements based on nitrogen-vacancy (NV) centre quantum magnetometry.

Keywords

Nitrogen vacancy centres, NV-centre, magnetometry, magnetic force microscopy, quantum standard, nanoscale resolution

Background to the Metrological Challenges

There is a growing demand for quantitative characterisation of magnetic micro- and nanostructures, particularly in the miniaturisation of electronic devices. However, the ability to quantitatively characterise magnetic fields at the nanoscale with high resolution, sensitivity, and minimal invasiveness remains a key challenge. While macroscopic magnetic field measurements can be traced back to quantum standards using nuclear magnetic resonance (NMR), quantum-based metrology for nanoscale magnetic fields is not well established and lacks traceability through to industry, hindering the development of applications such as advanced and miniaturised magnetic sensors for the automotive sector.

EMPIR project 15SIB06 NanoMag developed the first steps towards quantitative nanoscale magnetic field imaging, including traceable scanning magnetic field microscopy tools with spatial resolution down to 500 nm, a technique for magnetic force microscopy (MFM) calibration with spatial resolution below 50 nm and calibration artefacts suitable for on-site calibrations. It contributed to the development of the first international draft IEC standard for traceable nanoscale magnetic field measurements. However, these measurements are not yet connected to a traceability chain based on a primary quantum standard at the nanoscale. Novel atomic sensors using nitrogen vacancy (NV) centres in diamond, have the potential to increase spatial resolution and field resolution down to the nanometre scale and have been incorporated recently into the first commercial scanning NV-magnetometers. Metrological validation and international standardisation of such equipment is lacking; no NV-centre magnetometry is currently implemented at NMIs within Europe and no metrology for NV-centre magnetometry is available, inhibiting a metrological and industrial exploitation of this promising technique.

A primary quantum standard is therefore needed for magnetic field measurements that would be applicable directly to nanoscale volumes, and a traceability chain including calibration services, validated reference materials and guidelines, must be established and validated at European NMIs in order to provide a European metrology infrastructure for this market.

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 protocol.

The JRP shall focus on the traceable measurement and characterisation of nanoscale magnetic fields for the provision of primary quantum standards at European NMIs.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

The specific objectives are

1. To develop methods, tools and reference materials for the characterisation and validation of NV-centre based magnetic quantum sensors for spatially resolved magnetometry with 50 nm spatial resolution and 1 μT field resolution. These should include a full uncertainty budget including field uncertainty, measurement field range, and positioning uncertainty of the sensors.
2. To establish the European capability for NV-centre based nanoscale spatially resolved quantum magnetometry of magnetic stray fields via the setup and validation of complementary metrological tools at European NMIs with field resolution down to 1 μT including (i) mapping of magnetic field distributions with spatial resolution below 25 nm; (ii) fast magnetic field imaging with spatial resolution down to 250 nm and (iii) exploring the potential for super-resolution wide-field magnetic field imaging with spatial resolution below 250 nm.
3. To establish the quantum traceability of nanoscale spatially resolved scanning field metrology for end users, by validating a traceable calibration chain from atom-scale NV-centre quantum magnetometers to nanoscale magnetic field measurements of end users, based on quantum validated reference materials.
4. To facilitate the take up of the technology, measurement infrastructure and guidelines developed in the project by the measurement supply chain, standards developing organisations (IEC) and end users (magnetic sensor, data storage, pharmaceutical and biomedical industries).

Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

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 EMPIR project 15SIB06 NanoMag and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 30 % of the total EU Contribution across all selected projects in this TP.

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 nano-magnetics and nano-electronics 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.