European Partnership on Metrology
Call 2022 – Digital Transformation, Health, Integrated European Metrology, Normative and Research Potential

Selected Research Topic number: **SRT-s06**
Version: 1.0

Title: Coordinated European magnetic field metrology based on advanced quantum standards

Abstract

The European Green Deal targets at a resource-efficient and competitive European economy with no net emissions of greenhouse gases by 2050. The increase of renewable energy generation, as well as the maximisation of energy transformation efficiency, are both of great importance. Efficient electric motors and transformers rely on the characterisation and understanding of the magnetic behaviour and properties. This research aims to support the European magnetic field metrology through the establishment of an integrated European network, thus meeting the needs of the European stakeholders in the fields of renewable energy and cutting-edge technologies.

Keywords

magnetic flux density, magnetic field, Tesla primary standard, joint capabilities, traceability chains, free induction decay, quantum gas, spin polarized gas, ^{3}He magnetometry, nuclear magnetic resonance (NMR)

Background to the Metrological Challenges

World-class metrology in the areas of magnetic flux density and magnetic field measurements is a key factor towards meeting the European climate goals. This research aims to coordinate European efforts in magnetic field metrology and to develop an integrated European metrology infrastructure for realization, traceability, and dissemination of the magnetic flux density *B* in units Tesla. The number of calibration requests related to the magnetic flux density *B* has increased significantly in the last years. This is caused by a rise in magnetic sensor production due to societal and technological developments in the areas of renewable energy generation, electromobility, automotive driving, etc. Although, magnetic calibration services have already been provided by several NMIs, a consolidated EU-wide approach is necessary to aim for future calibration load with a common approach. At the same time, the requirements of stakeholders in terms of quality of calibration services have increased. In specific, there is currently high remand in an extended magnetic field range, higher precision, lower measurement uncertainty, as well as traceability to SI standards. However, incremental improvements of most widely-used proton NMR in water samples method is unable to match these requirements. Moreover, technological developments of magnetic sensors and materials push the limits of well-known metrological methods. Calibrations under extreme conditions, i.e. extremely low fields and extremely high fields, and at low temperatures down to 4 K, are anticipated in the future. In addition, new technologies including quantum computing and quantum sensing, will impose special conditions, like extreme environments on utilised techniques. Last, the evaluation of current primary standards of the magnetic flux density in the low field range 10 μT - 1 mT is overdue since several years. The validation of calibration techniques in the field range at 1 T has not yet been performed and traceability of existing calibration methods is currently missing.

The realisation of the magnetic flux density *B* is currently based on proton NMR techniques measuring the Lamor frequency that is directly proportional to *B* with proportionality constant γ. The proton gyromagnetic ratio γ is known with 10^{-8} precision from particle experiments. Thus, the determination of the Lamor frequency traces *B* back to the SI standard time. Currently, there is no primary standard for fields above 0.2 T. Commercial NMR magnetometers are available for a wide field range 15 mT to 30 T, but are not traceable to SI standards. At the same time, probes made of water, heavy water or soft polymers are well characterised, but not metrologically cross-validated. Also, different chemical bonding of the hydrogen atoms can cause the proton gyromagnetic ratio to vary slightly depending on the field range. Magnetic flux density measurements carried out with hyperpolarized gaseous ^{3}He-magnetometers offer a great opportunity to serve as advanced quantum standard in magnetic flux density measurements.

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 magnetic fields.

The specific objectives are

1. To validate the current European metrology infrastructure for the realisation of the magnetic DC flux density in a Round Robin comparison for 1 mT to 100 mT field range. To perform uncertainty evaluation of the obtained experimental results and to develop traceable and validated methods for the practical realisations of the Tesla (e.g. NMR on soft polymers, optical magnetometers) against primary standards based on Proton NMR in water.
2. To develop a coordinated European metrological infrastructure for DC magnetic flux density measurements for 10 µT to 1 T field range. To establish optimised European traceability chains from primary National Metrology Institute standards via secondary standards, with optimised uncertainties for end users, specifically, to improve the DC magnetic flux density uncertainty to less than 0.01 % at 100 mT.
3. To investigate NMR-based traceable methods based on hyperpolarized ^{3}He gas (^{3}He-NMR), for the development of a new primary standard for DC magnetic flux density. To develop ^{3}He-NMR samples with relaxation times beyond 100 s at 1 mT. To perform field distortion simulations for the validation of the developed ^{3}He-NMR methods and compare them with existing water-based primary NMR standards. Uncertainty budget evaluations and extreme conditions characterisation shall also be performed, e.g. at ultra-low fields < 1 µT, highest magnetic fields > 1 T, low temperatures and by utilising miniaturised sensors.
4. To demonstrate the establishment of an integrated European metrology infrastructure and to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (certified laboratories, research institutes, EMN quantum), standards developing organisations (ISO, CEN, IEC, CENELEC) and end users (industry manufacturers in the fields of quantum technology, renewable energy and electromobility).

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 both within and outside Europe, plus engagement with existing European research infrastructures and European Partnerships 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 and end users.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.6 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 25 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated 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,
- Develop an integrated self-sustaining European metrology infrastructure,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the advanced manufacturing sectors, including the quantum technologies, electromobility and renewable energy 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 the Partnership 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.