

## **Title: Advanced magnetic metrology for industry**

### **Abstract**

Many applications across industry and health, including magnetic resonance imaging (MRI) and energy production, use magnetic materials and magnetic fields which must be applied and monitored accurately. Reliable testing and traceable measurements for magnetic fields are also crucial to the development and standardisation of quantum technologies, as laid out in the CENELEC Focus Group on Quantum Technologies *Quantum Technologies Standardisation Roadmap* [1]. Thus, there is a need to develop fit-for-purpose magnetic field sensors suitable for use under extreme conditions, to develop new calibration methods, and to reduce measurement uncertainty in magnetic field calibrations. There is also a need for new primary tesla (T) standards based on water and hyperpolarised  $^3\text{He}$  nuclear magnetic resonance (NMR), and existing and new calibration capabilities require validation through comparison. Finally, traceability for de-facto industry standards must be established so that European end-users can benefit from improved medical diagnostics and enhanced green energy generation.

### **Keywords**

Magnetic flux density, AC magnetic field, DC magnetic field, permanent magnets, magnetic materials, magnetometry, Tesla, nuclear magnetic resonance, proton NMR

### **Background to the Metrological Challenges**

Numerous industries across Europe rely on the accurate application and monitoring of magnetic fields. For example, in medicine, MRI has become a common diagnostic tool due to its safe and non-invasive nature. However, the strong magnetic fields used during scans create complex boundary conditions which impact the sensors that monitor and control the field. To ensure continuous accurate monitoring, improved sensor systems with high spatial resolution and robustness against static and dynamic electro-magnetic background fields are needed.

Existing high precision magnetometers used for these measurements are based on NMR techniques using protons in polymer samples, which are considered de-facto industry standards. However, there is currently a lack of traceable calibration services above 0.2 T and no alternative calibration methods or advanced primary tesla standards. The development of new capabilities based on hyperpolarised  $^3\text{He}$  could extend the field range beyond 0.2 T, with significantly lower uncertainties than the current state of the art ( $10^{-4}$ ). There is also an urgent need to validate the de-facto standards currently being used in industry.

High performance permanent magnets and magnetic materials are also used in renewable energy production and high-efficiency engines (e.g., for electro-mobility). These applications are key for meeting the targets of the European Green Deal, which aims for a 55 %  $\text{CO}_2$  reduction in Europe by 2030. One of alternative energy technologies also being explored is nuclear fusion, in which plasma consisting of heavy hydrogen isotopes is confined and concentrated within the reactor core by high magnetic fields. Advanced magnetometry, able to operate at fields up to several tesla and under extreme temperatures and pressures, is extremely important to master this new technology.

Throughout industry, the precise characterisation of the magnetic properties of permanent magnets is required to ensure the proper functionality of many devices. One important parameter in this is the surface magnetic field, which depends on the type of magnet and the distance to the surface, ranging from 1 to 200 mT. For this range, the existing European metrology infrastructure has significant gaps, calibration methods for NMIs/DIs and certified laboratories are missing, and current traceability chains to primary Tesla standards have insufficient uncertainties (typically around 1 %).

## 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 advanced magnetic fields for use in industry.

The specific objectives are

1. To develop new DC magnetic field sensors for extreme conditions, including (i) sensors for high and ultra-high magnetic fields (0.1 T to 7 T) and (ii) magnetometers used at elevated temperatures (20 °C to 100 °C), in high field gradients, and for the high-precision detection of currents. Additionally, to develop new and improved calibration capabilities for magnetometers in high DC fields (0.1 T to 6 T) and under vector field rotation.
2. To develop specialised field-generating systems and calibration methods for advanced AC and DC magnetometry. This will include (i) AC magnetic field systems up to 10 mT at frequencies above 50 kHz and (ii) DC magnetic field coils with low distortion effects, superior field stability and superior homogeneity. Additionally, to develop improved DC magnetic field standards with lower levels of AC and DC background fields and lower measurement uncertainties, as well as by developing mobile primary tesla standards.
3. To perform a Round Robin comparison for fields in the range of 1 mT to 100 mT and to use it to validate the current European metrology infrastructure for the realisation of DC magnetic flux density. To establish traceability for de-facto industry standards in the 1 mT to 100 mT range.
4. To establish new primary standards for magnetic flux density at three European NMIs. These standards should be based on hyperpolarised <sup>3</sup>He samples for fields 2 mT to 100 mT (with a target 5-fold reduction below the current uncertainty of 10<sup>-4</sup>) and based on proton NMR for fields 10 µT to 50 mT. Then, to validate the standards with a target relative uncertainty of 10<sup>-6</sup>.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations (e.g., IEC TC68, CEN-CENELEC Focus Group on Quantum Technologies (FGQT Q04), IEEE Magnetics Society), and end users (e.g., EMN Advanced Manufacturing, EMN Quantum Technologies, EMN Smart Electricity Grids, MRI manufacturers, the energy sector, the transport sector).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. 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.

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 2.3 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 35 % 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,
- Feed into the development of urgent documentary standards through appropriate standards bodies,

- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the medical imaging, transport and 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.

### **Additional information**

[1] 005 CEN SECT-FGQT [Normative Call 2023 \(metpart.eu\)](https://metpart.eu)