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

Selected Research Topic number: **SRT-n06**
Version: 1.0

Title: Support for the standardisation of nanoscale magnetic field measurements

Abstract

Europe's high-technology industries require nanoscale traceable magnetic fields measurements. As such, the rapid development of increasingly miniaturised magnetic devices and the application of nanostructured materials must be accompanied by basic and applied research, which critically depends on the further refinement of traceable characterisation methods. Subsequently, IEC TC 113 has developed a technical specification, TS 62607-9-1, which is the first international standard in the field of quantitative magnetic force microscopy (qMFM). However, it is based only on qMFM under ambient conditions with a spatial resolution down to 50 nm. This standard should be extended further to take into account advanced traceable high-resolution qMFM, in vacuum (VqMFM)), with improved sensitivity. In addition, end users require clear guidance on the application of the technical specification to their specific measurement along with validated data sets and worked examples for qMFM measurements. Proposals addressing this SRT should therefore address these requirements.

Keywords

Nanoscale magnetic field measurements, quantitative magnetic force microscopy, nanomagnetic materials, reference materials, validated datasets

Background to the Metrological Challenges

IEC's work programme for TC 113 (Nanotechnology for electrotechnical products and systems) includes the further development of TS 62607-9 series on spatially resolved magnetic field measurements, in liaison with European and international standards developing organisations. Reliable measurements of industrially relevant magnetic material parameters must be traceable to the SI, via measurements of the stray fields of their magnetization distribution in units of A/m for magnetic field or in unit T for magnetic flux density. Subsequently, IEC TC 113 specified the requirement for the advancement of the qMFM standard in accordance with industrial needs.

European high-tech industries (such as information and communications technology, and magnetic sensors manufacturers) as well as biomedical applications require reliable magnetic measurements on the nanometre scale. Given that the absolute stray field of magnetic nanostructures scales with their size, a higher field and spatial resolution is necessary to underpin reliable development and production control for present and future downscaled nanomagnetic materials and devices. Due to the fast decay of nanoscale magnetic stray fields, the dominant factor limiting spatial resolution is the field sensitivity. In vacuum, magnetic force microscopy measurements, with a higher quality factor of the cantilever oscillation can enhance the sensitivity by orders of magnitude.

In EMPIR 15SIB06 NanoMag, a technical specification (IEC TS 62607-9-1) was developed that covers the mathematical and physical backgrounds of qMFM measurements of nanoscale stray field distributions and defines a calibration and analysis procedure. In particular, this technical specification enables reliable quantitative magnetic field measurements down to the 50 nm scale, based on qMFM under ambient conditions. In contrast, vacuum based non-contact qMFM allowing higher spatial resolution down to 10 nm and order of magnitude higher field resolution below 100 $\mu T/\sqrt{Hz}$ are not yet covered by the technical specification. Co/Pt multilayer films with stripe domain patterns have been established as refence materials for qMFM measurements howeer, other possible reference materials with specific applications and guidelines for their fabrications are not yet available. Coordinated research activities of NMIs, research institutions and industry are required to cover the development needs thereto ranging from data analysis algorithms to the fabrication

and characterisation of reference materials and measurement procedures and thus to contribute to a revision of the existing technical specification. Since industrial measurands are often secondary parameters, end-users also need clear strategies and guidelines on the application of technical specifications to their specific measurements. Additionally, validated datasets of advanced reference samples and worked examples should be available to enable a broader use of IEC TS 62607-9-1, and to relate the highly spatially resolved traceable magnetic field measurements that are relevant for material parameters (such as grain size, pole width of magnetic scales, domains size of magnetic sheets, or the magnetic moment distribution of magnetic nanoparticles for biomedical applications).

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 metrology research necessary to support standardisation in quantitative magnetic force microscopy (qMFM) to enable harmonised and reliable magnetic field measurements on the nanometre scale, with improved sensitivity and higher spatial resolution, suitable for high-tech industries and biomedical applications.

The specific objectives are

1. To develop tools, methods, algorithms (including AI), and measurement procedures for advanced quantitative magnetic force microscopy (qMFM) measurement techniques in vacuum conditions (VqMFM) with a target of sub 10 nm spatial and sub 100 $\mu T/\sqrt{Hz}$ field resolution. Additionally, to carry out a round robin comparison to validate all of the above, and produce detailed guidelines on the validated and traceable VqMFM measurements.
2. To develop reference materials for advanced VqMFM measurements (e.g. adapted magnetic multilayers, skyrmion hosting materials, or multilayer cross sections) and to assess their stray field distributions by micromagnetic simulations. Additionally, to carry out a round robin comparison to validate the reference materials and produce validated datasets of the reference materials with guidelines on the fabrication of reference materials.
3. To provide documented worked examples of ambient qMFM and advanced VqMFM measurements, using scientifically and technologically relevant materials and devices (e.g. magnetic scales and sensors, magnetic nanoparticles, skyrmions, or domain wall devices with characteristic length scales in the micrometre to nanometre range).
4. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (calibration laboratories), standards developing organisations (IEC, ISO) and end users (manufacturers of ICT devices and magnetic sensors). In particular, to contribute to the revision of IEC TS 62607-9-1 by providing the data, methods, guidelines and recommendations, which are necessary for the standardisation of advanced nanoscale magnetic field measurements, together with worked examples to IEC TC 113.

The proposed research shall be justified by clear reference to the measurement needs within strategic documents published by the relevant Regulatory body or Standards Developing Organisation or by a letter signed by the convenor of the respective TC/WG. EURAMET encourages proposals that include representatives from industry, regulators and standardisation bodies actively participating in the projects. The proposal must name a “Chief Stakeholder”, not a member of the consortium, but a representative of the user community that will benefit from the proposed work. The “Chief Stakeholder” should write a letter of support explaining how their organisation will make use of the outcomes from the research, be consulted regularly by the consortium during the project to ensure that the planned outcomes are still relevant, and be prepared to report to EURAMET on the benefits they have gained from the project.

Proposers should establish the current state of the art and explain how their proposed research 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 0.8 M€ and has defined an upper limit of 1.2 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 30 % 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,
- Transfer knowledge to the high-technology and medical 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.