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

Selected Research Topic number: **SRT-s15**
Version: 1.0

Title: Applications of double-ended interferometry in accurate dimensional metrology to support advanced manufacturing

Abstract

Industrial manufacturers in fields such as precision engineering, automotive and aerospace as well as in the semiconductor industry are placing increasing demands for lower tolerances and hence lower measurement uncertainties to remain competitive both in Europe and on a global scale. Innovative and improved methods for accurate dimensional metrology are required. Calibration of gauge blocks and reference spheres using double-ended interferometry offer many advantages over traditional techniques however appropriate measurement techniques and investigations into the systematic effects across the entire traceability chain are lacking. The proposed project aims to improve the metrological capability for highly accurate double-ended (i.e., bidirectional) interferometry in dimensional metrology as well as review longstanding standards such as EN ISO 3650 to ensure compatibility with advances in techniques.

Keywords

Interferometry, bidirectional optical probing, gauge block length, length change, material properties, sphere form, diameter, advanced manufacturing

Background to the Metrological Challenges

The semiconductor industry needs advanced materials for further miniaturisation and the automotive industry relies on improved materials to further reduce energy consumption. Dimensional measurement of manufactured parts and calibration artefacts is key for the quality management of interchangeable manufacturing chains however industrial manufacturers are placing increasing demands for lower dimensional tolerances. To meet these demands lower measurement uncertainties are needed.

Gauge blocks calibrated using optical interferometry, are widespread material measures in industry. To lower measurement uncertainty systematic effects such as optical domain roughness, phase shift and wavefront error along the entire traceability chain need to be characterised and corrected. Therefore, the development of new and application of existing appropriate measurement techniques is required. Double-ended optical probing presents many advantages over the classical wringing method. It avoids scratches and wear of the gauge blocks' faces and as a result greatly reduces the duration of the calibration process. Gauge blocks are standardised by EN ISO 3650 but this standard does not sufficiently consider single or double ended calibration. The CCL DG1 (Discussion Group 1 of the Consultative Committee for Length) has begun work to improve the standard but further work is needed to ensure definition of the measurand is suitable for actual applications.

Knowledge of material properties such as coefficient of thermal expansion (CTE), compressibility, long-term stability, and piezoelectric strain, is key for the development of new materials and in the design of improved systems. Bidirectional interferometry can further improve this type of measurement compared to the measurements with unidirectional gauge block interferometers, where the process of wringing the samples to a backplate adds additional uncertainties. To enable measurements on materials which cannot be manufactured with optically flat and reflective surfaces, so-called optically 'non-cooperative' material samples, an appropriate sample holder could be used.

In the field of coordinate metrology, spheres are used to characterise and reduce systematic errors of the probing systems and their size and form errors need calibration. The capability for calibrating the topography of small spheres (diameter range of 1 mm to 30 mm) by a double-ended interferometer enables the reduction of the uncertainty with a higher measurement throughput compared to the existing methods. Moreover, comparisons of tactile and optical measuring approaches mutually support the identification of systematic errors.

For a successful transfer of the research results to metrology services offered by European NMIs it is necessary to develop guidelines and best practice documents and to adapt existing standards which were developed for unidirectional calibrations only. To guarantee that the research results and the new and improved calibration capabilities are sustainably made available to the advanced manufacturing stakeholder community, a close cooperation with the EMN for advanced manufacturing is needed.

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 development of metrology capability for highly accurate double-ended (i.e. bidirectional) interferometry in dimensional metrology.

The specific objectives are

1. To develop accurate methods for bidirectional interferometric calibration of gauge blocks without wringing capable of improving the measurement accuracy below the current state-of-the-art uncertainty. This should include the determination of systematic corrections (e.g., roughness, optical phase shift and wavefront error) and the comparability of mono and bidirectional measurements. In addition, to identify and formalise the updates required to EN ISO 3650 to ensure compatibility with the newly developed methods.
2. To develop accurate bidirectional interferometry methods for the measurement of length-related properties of materials, sensors and motion systems that contribute to drift phenomena (e.g. CTE, compressibility, long-term stability, piezoelectric strain), which need to be controlled in precision manufacturing applications.
3. To develop improved and smart bidirectional interferometry methods for the measurement of length-related properties of optically 'less- and non-cooperative' material samples (e.g. difficult surface materials or surface qualities). This should include the development of specific sample holders using tactile probing integrated in bidirectional interferometer setups with the ability to apply precisely controlled forces to the samples and complex devices under test.
4. To develop advanced solutions, including but not limited to bidirectional interferometry, for optical calibration of small spheres (target diameter range 1 mm to 30 mm) of at least 4 different materials (e.g., metal, ruby, ceramics, diamond) with a target measurement uncertainty below 10 nm. In addition, to determine the technical and measurement limits for the developed bidirectional interferometry technique.
5. 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, standards developing organisations (BIPM CCL DG1 and ISO/TC 213) and end users (manufacturing industry). In addition, to develop guidelines and best practice documents facilitating the take up of the research results and establish cooperation with EURAMET's EMN for advanced manufacturing and EURAMET TC-L.

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 sector.

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.