

Title: Fibre optic thermometry

Abstract

Fibre-optic thermometry is an emerging technology that can improve the measurement of temperature in extreme environments for energy providers and the industry sector due to distributed sensing and immunity to electromagnetic fields. A coordinated European calibration infrastructure is essential to ensure reliability and traceability. Building on results from the previous research, proposals addressing this topic should further develop and characterise several technologies for distributed and point temperature sensing and demonstrate the use of these technologies in highly relevant case studies. Advanced fibre optic thermometry techniques will offer unique advantages such as electromagnetic immunity and distributed measurements, making them the perfect choice for many key applications.

Keywords

fibre optic thermometry, distributed temperature sensing, reliability, traceability, clean energy, thermal energy storage, electrical grid resilience, industrial processes optimisation

Background to the Metrological Challenges

The need to transform the European energy system away from fossil fuels and towards an efficient and flexible low-carbon system is associated with technological and metrological challenges. Improved measurement solutions are needed for heat storage and district heating, operation of the electricity grid and efficiency of energy intensive high-temperature processes in the industry. The development of innovative, cost-effective temperature measurement and control techniques uses advanced fibre optic thermometry (FOT) that offers unique advantages such as immunity to electric fields, distributed temperature sensing (DTS), long cable lengths, low thermal mass and suitability for harsh environments. The EMPIR project 22IEM07 INFOTherm addressed key challenges to wider FOT adoption, such as the lack of SI traceable calibration infrastructure and user guides, both essential for critical industries and energy infrastructure. However, further development of advanced FOT techniques and improved calibration infrastructure is needed in several high impact areas to support European industry better.

Many FOT applications require certification-based quality management. To support these applications, establishing a coordinated European infrastructure offers the best approach for further developing and implementing international calibration and testing services. Cross-sensitivity remains a challenge in fibre optic sensing. The results from EMPIR project 22IEM07 INFOTherm suggest that the most effective method of mitigating strain and humidity effects is to measure all relevant parameters simultaneously (hybrid sensing), by using optical fibres with different sensitivity characteristics or additional sensors for correction. The EMPIR project 22IEM07 INFOTherm also highlighted the need to extend knowledge on special measurement fibres beyond standard fibre types. Optical properties like reflection, chromatic and polarisation dispersion are temperature sensitive. Establishing metrological test-benches to calibrate and validate optical components traceably is crucial. Additionally, correlating these optical properties with fibre ageing may enable in-situ calibration.

Nuclear energy plays a key role in the transition to net-zero emissions, requiring underground repositories for radioactive waste. Since significant thermal energy dissipates from stored waste, temperature monitoring of such buried structures is essential to ensure their integrity and radiological containment. Therefore, in-situ temperature calibration systems need to be implemented and tested. The same need applies to geothermal boreholes used for heat pumps, thermal storage, or direct geothermal energy use. EMPIR project 22IEM07

INFOTherm revealed the need to develop on-site calibration artefacts and solutions to maintain accuracy over long periods of time. The former developments must be advanced to enable practical on-site calibration and to investigate correlations between optical property changes and fibre ageing. Also, the progress in the thermal storage solutions and temperature mapping must continue to increase measurement density, establish a spatial measurement grid, and align temperature sensing with complex geometric structures (e.g. heat exchangers). Enhanced Brillouin or Raman interrogators will enable more detailed temperature mapping.

Reliable, traceable temperature monitoring is essential for grid stability. Studies indicate that operating electrical infrastructure beyond its rated current can relieve grid congestion and improve power utilisation, but this requires precise, time- and location-resolved temperature monitoring. Traditional sensors are inadequate as they are prone to electromagnetic interference. By contrast, DTS offers spatial resolution and immunity to interference, making it ideal for cable monitoring. Fibre-based point sensors complement DTS for monitoring transformers and other network components. These advancements and techniques require further development and characterisation, as well as prototype interrogators for case studies.

Increasing the efficiency of energy-intensive, high-temperature processes (e.g. glass production, additive manufacturing) as well as widely used processes around room temperature can make a significant contribution to the reduction of energy consumption [1, 2]. EMPIR project 22IEM07 INFOTherm has facilitated the transition from widely used thermocouples to more suitable fibre optic sensors. These sensors, as well as special fibres (e.g. fibres with no core-dopants or completely core-free fibres), now need further development. Accurate temperature monitoring in the -70°C to 150°C range covers most industrial applications such as cold storage (food and medicine) and monitoring of machines or processes. Distributed or quasi-distributed FOT systems enable comprehensive monitoring using a single fibre, but measurement uncertainty must be reduced to below 100 mK for meaningful data. Increased data sampling is also needed to enhance temporal resolution without additional equipment. Many monitoring applications rely on retrofitted contact surface temperature measurements, where non-circular fibres are ideal due to their minimal heat capacity and conductivity. These sensor technologies need to be further optimised, characterised, calibrated and their application demonstrated.

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 proposal shall focus on the development of new advanced techniques and delivering fit-for-purpose measurement solutions for key applications in fibre optic thermometry.

The specific objectives are

1. To establish measurements methods to characterise optical parameters (e.g. reflection and dispersion) of fibre optic sensors and their effect on temperature sensing. To develop methods for accurate optical calibration of the interrogators with the target of $U(k=2) < 1$ pm and to develop and validate accurate fibre optic humidity measurements with the target of $U(k=2) < 3$ %RH. In addition, to develop and characterise methods to minimise cross sensitivities of fibre optic sensors (e.g. to strain and humidity) by simultaneous reference measurements.
2. To develop and validate methods for practical in-situ calibration of temperature sensing systems with pre-installed optical fibres (e.g. geothermal boreholes or radioactive sites) and demonstrate them in at least 2 case studies. Additionally, to develop and validate methods for temperature mapping of thermal storages and of complex geometric structures (e.g. heat exchangers) and demonstrate them in at least 2 case studies.
3. To develop and characterise enhanced FOT methods for temperature monitoring of the electrical infrastructure (e.g. cables and transformers) and to demonstrate them in at least 3 case studies. This includes advanced distributed temperature sensing methods that improve spatial resolution and range (> 50 km) and point sensing methods that enable directly more cost-effective interrogation.
4. To develop and validate improved techniques for monitoring high temperature processes with sensors based on special silica and sapphire fibres at temperatures above 700°C and 1700°C respectively. To develop and validate distributed or quasi-distributed FOT for accurate temperature measurement around room temperature range with the target of $U(k=2) < 100$ mK from -70°C to 150°C , specialised techniques for increased data sampling (> 100 Hz) and contact surface

temperature measurement. To demonstrate these techniques in at least 5 key industrial applications.

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 (calibration laboratories, certification and accreditation bodies), standards developing organisations (IEC, CEN) and end users (sensor manufacturers, industry and energy sectors).

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. Where relevant, proposals are encouraged to build on, or seek collaboration with, existing projects and develop synergies with other relevant European, national or regional initiatives and funding programmes. In particular, links are encouraged with (i) the projects funded under earlier relevant topics of the Horizon Europe programme; or (ii) other relevant European Partnerships.

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 22IEM07 INFOTherm and how their proposal will build on this.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.1 M€ and has defined an upper limit of 2.6 M€ for this proposal.

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 proposal's 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 industry and the energy 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 Metrology 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.

Timescale

The project should be of up to 3 years duration.

Additional information

The links provided in this section are only correct at the time of publication up until the end of the Call year.

The references below were provided by PRT submitters; proposers should therefore establish the relevance of any references.

- [1] EMN for Clean Energy Orientation Paper 2025 All Calls
<https://www.metpart.eu/applicants-2025/integrated-metrology-call-2025-s1.html>
- [2] EMN for Smart Electricity Grids Strategic Research Agenda
<https://www.euramet.org/research-innovation/metrology-partnership/strategic-research-and-innovation-agendas>