Publishable Summary for 18RPT03 MetForTC
Traceable measurement capabilities for monitoring thermocouple performance

Overview

The aims of this project were to develop novel scientific and technical capabilities to provide both the dissemination of the International Temperature Scale of 1990 (ITS-90), which is an important concept in both developed and emerging NMIs/DIs, and, in addition, accurate low uncertainty temperature measurements using a thermocouple, which is the most frequently used temperature sensor. These objectives were achieved by developing novel practical methods and devices for monitoring thermocouple performance. The new concept of dual-type thermometers developed enables in-situ monitoring of thermocouple drift, whilst our small fixed point cells can be relatively easily attached to existing thermocouple probes, also enabling validation of thermocouple performances in situ. Two novel devices for testing thermocouple inhomogeneity and drift were also developed that utilize the Curie-point technique for maintaining known and stable temperatures.

Need

Knowledge of the lifetime and drift of thermocouples in industrial applications is not very well known and usually, thermocouples are periodically replaced to ensure continuity in process control quality. However, it can often be very difficult for the user to detect inadequate thermocouple performance. There are no standardised traceable methods that would enable thermocouple performance verification in-situ. The stability, homogeneity, and drift of thermocouples have been investigated throughout several EMRP and EMPIR projects: 14RPT05 Eura-Thermal, 14IND04 EMPRESS, SIB10 NOTED, etc. However, more comprehensive work on this topic is still required.

This project developed novel methods and techniques, traceable to the ITS-90, that can significantly simplify and improve testing of thermocouple drift and inhomogeneity in calibration laboratories as well as in other measurement sights. These techniques are beneficial to users as they enable increase of confidence in results of thermocouple performances tests as well as decrease in the uncertainty of temperature measurement by thermocouples. As a result, the efficiency of industrial processes utilizing thermocouples for temperature measurement and control can be increased.

Through collaboration on the design and validation of new temperature measurement methods and equipment all the project participants gained new knowledge and experience. It can be concluded that the project has helped to promote greater consistency in temperature metrology at the European level by enhancing capabilities of emerging European NMIs in the field of temperature measurement, improving their readiness for active participation in the future research projects.

Objectives

The overall objective of the project was to develop novel methods and techniques that significantly improve knowledge and facilities to provide confidence in the verification of thermocouple performance and improvements in temperature measurement and control capability. The project has contributed to establishing low measurement uncertainty and reproducible process control in Europe.
The specific objectives are:

1. To develop and test novel methods and devices for the monitoring of thermocouple drift in-situ in the temperature range up to 1100 °C. These methods have to be suitable for implementation in critical industrial processes in order to assist the users in maintenance and replacement decisions.
2. To develop and test easy-to-operate methods and instruments for the assessment of inhomogeneities of thermocouples for secondary calibration laboratories in the temperature range from 230 °C to 1100 °C.
3. To design and construct novel measurement facilities that can provide confidence in the verification of thermocouple performance and to identify and quantify the range of drift of the thermocouples. The

new facilities, targeting primary calibration laboratories, should have the ability to measure the physical changes and behaviour of thermocouples under typical conditions of production and distribution processes with a target uncertainty of less than 1.5 °C.

4. For each participant, to develop an individual strategy for the long-term operation of the capacity developed, including regulatory support, research collaborations, quality schemes and accreditation. They will also develop a strategy for offering calibration services from the established facilities to their own country and neighbouring countries. The individual strategies will be discussed within the consortium, with other EURAMET NMIs/DIs and with a broad spectrum of stakeholders, through questionnaires and workshops organised in the local language. The individual strategies will lead to an overall strategy document to be presented to the EURAMET TC-T, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

Progress beyond the state of the art

At all levels of the traceability chain, from final user to the primary laboratory there was a lack of practical methods and devices for thermocouple performance metrics.

Objective: 1 To develop and test novel methods and devices for the monitoring of thermocouple drift in-situ to 1100 °C

The new concept of dual-type thermometers was developed within the framework of the project. Based on the analysis of the results of experimental tests, it was confirmed that the concept enables continuous monitoring of thermocouple drift in-situ, at arbitrary temperatures. This was not possible with self-validating thermocouples, that are commonly used for the purpose, where drift can be determined only at specific temperature of phase transition of metal implemented into thermocouple probe, and only when temperature of the probe passes through this melting-point temperature. Throughout testing in various laboratories it was shown that new method is sensitive in detecting temperature measurement errors caused by sources other than drift.

Objective 2: To develop and test easy-to-operate methods and instruments for the assessment of inhomogeneities of thermocouples from 230 °C to 1100 °C.

A designs for miniature cells enabled the mounting of removable miniature fixed-point cells around the hot junctions of the thermocouples and suitable for ITS-90 contact thermometry in the temperature range from the Sn FP (232 °C) to Cu FP (1084 °C) were developed. TUBITAK and FSB drafted designs and related technical documentation of the miniature fixed-point cells developed, one design having immersion depth of approx. 100 mm (slim cells) and the other of 17 mm (mini-cells). A miniature FP cells have been constructed and used for the experimental characterisation under different thermal conditions in heat-pipe furnaces and dry-block calibrators. Special attention had been paid to the needs of the secondary laboratories as well as to the flexibility of the design that gives the possibility for these cells to be used in-situ and in the furnaces already existing in laboratories. Slim fixed point cells were developed that can be relatively easily attached to existing thermocouple probes, also enabling validation of thermocouple performances in situ. These cells are novel as they are not an integral part of single thermocouple probe, so they can be used in combination with different temperature probes.

Objective 3: To design and construct novel measurement facilities for the verification of thermocouple performance and to identify and quantify thermocouple drift.

Industrial calibration services currently have uncertainties of approximately 2 °C to 5 °C in the temperature range 232 °C to 1100 °C. The results of this research lead to reductions of uncertainties at secondary level to 1.5 °C. Thus, the methods and facilities provided by this project have improved national calibration services in participating primary and secondary calibration laboratories that are at the apex of their respective traceability chains. Accredited and industrial calibration laboratories will therefore benefit through having access to calibration services that are more accurate.

Two novel devices for testing thermocouple inhomogeneity and drift were developed that utilize Curie-point technique for maintaining known and stable temperatures required for these tests. The Curie-point devices are novel since they are self-regulating the temperature inside their working zones, while achieving low temperature gradients and high temperature stability that can be maintained over long periods. Additional device was also designed that utilizing series of electrical heaters for determination of thermocouple drift. It is unique as it does not contain moving components and it allows independent heating of different parts of thermocouple probes to different temperatures at different heating rates. This allows users high flexibility when the device is used for determination of thermocouple inhomogeneity. For example, inhomogeneity can be tested at different temperatures, with different portions of thermocouple heated to different temperatures, that is not achievable with the methods that are commonly used for the purpose.

Objective 4: To develop individual strategies for the long-term operation developed capabilities to support SI traceability and accreditation services

This project has built research capacity at each of the emerging NMIs/DIs through collaboration and dissemination of knowledge between partners, including practical hands-on training delivered by experts from developed NMIs/DIs. The knowledge acquired during the project will be used to improve the dissemination of the ITS-90 in the participating emerging EU member states. All partners have been actively engaged in development of the concept of dual-type thermometers and construction of related temperature probes, thus gaining substantial knowledge and experience necessary for engaging in similar activities in future research projects.

Finally, all of the project's participants from EU emerging countries have developed a strategy for providing calibration services using their own project upgraded facilities, in accordance with their user community needs.

Results

The results of this project provide new temperature sensing techniques for better control of high-value manufacturing and other processes.

Objective 1 Development of novel dual-type temperature sensors and methods for in-situ determination of thermocouple drift

The new method for in-situ determination of thermocouple drift was developed and its performances were investigated. Project partners have designed several versions of dual-type temperature probes and created detailed technical documentation for three types of dual-type temperature probes:

- dual-type temperature probe utilizing platinum resistance temperature sensors as a reference, for use in temperature range between -50 °C and 650 °C
- dual-type temperature probes utilizing noble metal thermocouples as reference sensors, for use in temperature range between 0 °C and 1084 °C
- dual-type temperature probes utilizing fiber-optic temperature sensor, for use in a temperature range between 550 °C and 1000 °C

Experimental results obtained through investigation of performances of the new method indicate that approximate accuracies of in-situ determination of thermocouple drift were ±1.0 °C for the dual-type temperature probes utilizing platinum resistance sensor as a reference and ±1.8 °C for dual-type temperature probes utilizing thermocouples as the reference sensors. It was also observed that the new method is sensitive to sources of measurement errors other than drift.

Investigations on the dual-type temperature probes utilizing fiber-optic temperature sensors revealed drift of the fiber-optical part in the range of 3 °C, which was roughly comparable to industrial thermocouples. Future work on improving such sensors is required for gaining better results.

A manuscript containing detailed descriptions of the methods for in-situ determination of thermocouple drift by using dual-type temperature sensors was submitted to a peer-reviewed journal.

The RMG2 work was done by a researcher from the National Metrology Institute of Albania (DMP), in the Temperature laboratory of TUBITAK UME. Project Coordinator guided the RMG2 researcher during 3 months of continuous joint work. The research was carried out on the construction and assembly of prototype of dual-type thermometers with three thermocouple wires. While dual-type thermometers with two separate temperature sensors were investigated within the project, the RMG research was oriented towards an investigation of thermocouples consisting of three wires connected in one tip for in-situ determination of drift. The validation was performed in a comparison between the drift of the type K thermocouple wires, determined using the third wire made of type S, and the same drift was determined through calibrations in a fixed-point cells. The accuracy of the drift determination using the novel 3-wire thermocouples, developed within this RMG, reached ± 2.5 °C.

Objective 2 Development of traceable novel devices and methods for characterisation of thermocouple inhomogeneity for secondary calibration laboratories

Two set of slim and mini-cells of Tin, Zinc and Copper FP cells have been constructed, characterised and successfully validated in three zone furnace in the secondary calibration laboratory of TUBITAK UME while CMI worked on the set of Tin, Zinc and Aluminium slim cells. TUBITAK UME validates the home-made "slim" cells by analysing their melting and freezing curves obtained by reference SPRT. In validation study, direct comparison between the home-made tin cell and the reference cell was carried out and the difference was found to be –15 mK with an associated comparison uncertainty of 2 mK. The results show that this method can be used for validation of slim cells. Additionally, TUBITAK UME home-made mini-cells were successfully validated by analysing their melting and freezing curves obtained by associated reference thermocouples. The results have shown high reproducibility and repeatability of the mini-cells. Calculated average drift value of Sn melting plateau after one month usage of mini-cell -0,016 °C.

After finishing the measurements at TUBITAK UME the mini cell was prepared for measurements in dry block furnace in ME (Montenegro) secondary laboratory. Calculated average drift value of Sn melting plateau at different temperature profile after two month usage of mini-cell was max 0,28 °C at first measurements and fall down to 0,22 at the end of the cycle.

CMI's constructed Al slim cell was prepared for measurements in Oberon heat-pipe furnace at IMBIH secondary laboratories under typical conditions of use. The results have shown high reproducibility and repeatability of the miniature fixed-point cells. The IMBIH and CMI measurements for Al fixed point temperature value agreed within stated uncertainties, for different setups and equipment used. It was shown that "slim" fixed points can be used to estimate the inhomogeneity and drift of thermocouples in situ for most industrial purpose, especially on melting plateaus because they are stable enough and can be obtained quickly enough even outside laboratory conditions (e.g. in the small heat-pipe OBERON furnace).

The RMG1 Researcher from Institute of Metrology of Bosnia and Herzegovina spent 3 months on the joint research work at TUBITAK UME in the Temperature laboratory. The Project Coordinator from TUBITAK UME guided the RMG1 researcher to during the construction, characterization and validation of high quality two slim silver (Ag) FP cells of 5N and 6N high purity silver metal. Moreover, continuous joint work during the construction, validation, comparison of fixed points and calculation of uncertainty for a new design of fixed point cells gave an additional value of 3 month practical work and training in the laboratory. The 6N Ag FP miniature cell was at first characterized and then compared with TUBITAK Ag FP standard cell according to TUBITAK's procedure for comparison of ITS-90 fixed-point cells. The calculated measurement uncertainty was 0,005 °C. The second 5N Ag FP was also tested at TUBITAK.

Objective 3 Design and construction of novel measurement facilities suitable for thermocouple performance investigation in primary calibration laboratories

Two facilities have been designed and constructed by BFKH in order to improve the evaluation of thermocouple performance. The principle of the developed technique is based on the Curie-point, which is a certain temperature at which the ferromagnetic material loses its magnetic properties, resulting in a constant temperature. To achieve a self-regulation process while utilizing the Curie point effect, a consistent relationship between the frequency and the diameter needs to be defined.

The concept behind the development of thermocouple inhomogeneity monitoring facility (TIMF) is to characterize the thermocouple performance by moving a miniature Curie-point furnace along the thermo element. Keeping the two junctions of the sheathed thermocouple at the same ambient temperature, the electrical voltage given by the thermocouple is expected to be neglectable. Therefore, the variation in electrical voltage appertained to the section of the thermo-element under test gives the magnitude of its inhomogeneity. The TDMF facility, due to its long-lasting temperature plateau, is suitable for determination of thermocouples drift. Different temperatures can be realised by changing the type of the ferromagnetic material of the metal block. Due to the self-adjustment property of the furnace, the Curie-point furnace has fast heating period, stabilization without overheating, uniform temperature distribution and high temperature stability. A manuscript containing detailed description of the method for determination of thermocouple inhomogeneity and measurement results with S and K type thermocouples was published in a peer-reviewed journal.

One of the advantages of the developed method is of meeting wider range of users as the fixed-point method, since fixed-point cells are not required for its operation. Another advantage is providing end-less temperature plateau. Furthermore, the material remains solid, hence it is less sensible to pollution and pressure changes. The importance of these methods is related to a relatively cheap and simple solution for monitoring thermocouple performance.

A novel device for testing thermocouple inhomogeneity by using a set of heaters was developed. This device is unique since it has no moving components and it enables simultaneous heating of different portions of the thermocouple probes at different temperatures. All the components of the heating modules can be made of materials tolerant to high temperatures which enables in-situ testing of thermocouple inhomogeneity.

Objective 4 To develop individual strategies for the long-term operation of developed capabilities to support SI traceability and accreditation services

Partners MER, BIM, INM, BRML and FSB have updated their strategy documents. IMBiH prepared the overall consortium strategy for the long-term development of research capabilities in temperature field. The overall strategy document aims to coordinate the strategies of the partners to ensure maximum awareness of each partner's plans, thereby reducing duplication of efforts and enhancing cooperation on common goals.

Impact

To promote the uptake of the temperature calibration services, and to share insights generated throughout the project, results are being shared broadly with scientific and industrial end-users.

To date, two papers have been published in international journals, including an open-access paper in the Proceeding of 19th International Congress of Metrology.

Presentations were made at conferences, including the 50th European TEMPMEKO & TEMPBEIJING 2019 International Conference, in 2019. The project partners have given presentations at:

- CIM 2019, International Congress of Metrology, 24-26 September, Paris, France, and the main project objectives have been published in the Proceeding by EDP Sciences.
- TEMPMEKO & TEMPBEIJING 2019 International Conference, 10-14 June 2019 Chengdu, China.
- Symposium and Exhibition of Measurement Science, 20-22 November 2019,İZMİR, Turkey
- 15th Laboratory Competence Conference (CROLAB 2019), Cavtat, Croatia.
- "2020 XXX International Scientific Symposium Metrology and Metrology Assurance" held on 07-11 September 2020, Sozopol, Bulgaria
- International Metrology Congress (CIM 2021), Lyon, France
- 16th Laboratory Competence Conference (CROLAB 2021), Brijuni, Croatia

The Project's website has been regularly updated with new information and project progress: http://metfortc-empir.org. Workshops for stakeholders and partners were organized by: FSB in February 2020, BIM (online) in June 2021, IMBIH (online) in March 2022, BFKH in September 2022 and JV in May 2023.

Workshop presentations provided attendees with the basic principles of temperature measurements when using thermocouples, uncertainties associated with thermocouple calibrations, project objectives and activities as well as information on the project designs for dual-type thermometers. During the workshops a discussion about the existing and future customer needs in the area of temperature measurement was initiated. A visit to the national measurement standards for temperature, and humidity was also included in the workshops at FSB, BFKH and JV.

The stakeholders were representatives from accredited and non-accredited laboratories that are already working, or are planning to start working, in the field of temperature measurements.

During the workshops the RMG researchers presented their work related to:

- RMG1 Researcher in design of temperature fixed-point cells (presentations at the IMBIH, BFKH and JV organized workshop)
- RMG2 Design of a novel type of dual thermometer (presentation at the IMBiH organized workshop)

A technical collaboration was organised by BFKH after the workshop, from 6th to 7th September, on order to make common measurements using the novel facilities for verification of thermocouple performance, developed by BFKH.

Researchers from the Institute of Metrology of Bosnia and Herzegovina (IMBIH) and the Norwegian National Metrology Institute (JV) had worked together on evaluating a newly designed triple-type thermometer (TTT) consisting of two thermocouples (type S and N) and an optical fiber used as a sensor of the drift assessment device for one week in the laboratories of the JV in Kjeller, from 28th November to 1st December 2022.

At the second technical visit, in April 2023, researchers from the IMBIH and the JV worked together in the IMBIH laboratories in Sarajevo. Measurements were carried out on the newly designed DTT thermometers, which consist of two thermocouples in a common housing, designed by FSB, Croatia.

Impact on industrial and other user communities

This project's activities have been designed to meet the needs of secondary calibration laboratories, manufacturers of temperature sensors and accreditation agencies in participating emerging countries.The organized workshops were of great importance for the partner labs, as well as for the stakeholders, as a way to initiate networking and cooperation in the field of temperature measurement. Workshop presentation materials for industrial stakeholders have been placed on the website. These materials are available to all partners for download should they wish to run a similar training course.

Impact on the metrology and scientific communities

The project supported active participation and influencing in key European temperature related committees such as the EURAMET Technical Committee on Thermometry TC-T and COOMET TC1.10.

The technical committee EURAMET TC-T was contacted in 2021 in the mid-time of the project and one presentation including objectives, developed novel devices designs and early outputs and impact of the MetForTC project were presented.

The project activities and results were presented during the COOMET TC1.10 meeting in November 2021 by INM. Due to the nature of the work carried out in the MetForTC project, it is only at the end of the project that sufficient results were obtained and analyzed, which could be of interest to the standards committees identified

There are a high number of smaller NMIs in the consortium and their participation in this project substantially contributed to capacity building, particularly in the area of thermocouple calibration and the facilities and skills required to assess thermocouple performance.

Impact on relevant standards

The participations were built on activities already established by the consortium, who are highly influential in national and international metrology and standards committees and were used to facilitate greater awareness of the projects outcomes.

The project aims and results were presented to EURAMET TC-T contact persons on many occasions, two times during the annual meetings of the EURAMET Technical Committee for Thermometry, during the conferences as well as through private conversations. The participants of the Working group, responsible for writing guidelines, are aware of the project and they are free to consider the project results when writing or updating the related guidelines.

Longer-term economic, social and environmental impacts

Knowledge transfer, from experienced NMIs (TUBITAK, BKHF, CMI, and JV) to those less experienced (IMBiH, FSB, INM, BRML, BIM and MER), in how to use and develop new capabilities in temperature field was very beneficial. The beneficiary countries have obtained the skills and knowledge necessary to improve their capabilities in the field of temperature measurement. Improved capabilities are beneficial to stakeholders that use the services provided by laboratories that participated in this project.

The project strengthened the collaboration between European NMIs, and increased their competitiveness with NMIs outside Europe. It also increased partners readiness for the active participation in future research projects. Another impact was an increase in cooperation and liaisons anticipated with the scientific community, users' associations, manufacturers, and other stakeholders, in order to provide guidance to traceability and good practice in secondary thermometry.

List of publications

1. N. Arifovic, et al *A new EMPIR Project "MetForTC" for Developing Traceable Measurement Capabilities for Monitoring Thermocouple Performance,* Proceedings 19th CIM 2019, 18006 https://doi.org/10.1051/metrology/201918006
2. N. Arifovic, et al "TÜBİTAK UME'de Yeni EMPIR Projesi: Isılçift Performansının Gözlenmesi için İzlenebilir Ölçüm Yeteneklerinin Geliştirilmesi", Proceedings Symposium and Exhibition of Measurement Science, 2019, IZMIR/TURKİYA http://www.olcumbilim.org/wp-content/uploads/bildiriler/2019-15.pdf

3. Nedialkov, S., Spasova, S. and Aldev, K. 18RPT03 MetForTC Traceable Measurement Capabilities for Monitoring Thermocouple Performance, Metrology and Metrology Assurance 2020–Proceedings http://metrology-bg.org/fulltextpapers/Proceedings_MMO_2020.pdf
4. E. Turzo-Andras et al, Determination of Thermocouple Inhomogeneity Using Miniature Curie-point Furnace, JP Journal of Heat and Mass Transfer, Volume 34, 2023, http://dx.doi.org/10.17654/0973576323034

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

<table>
<tr><td colspan="2">Project start date and duration:</td><td>June 2019, (36 + 6 + 6 = 48 Months)</td></tr>
<tr><td colspan="3">Coordinator: Narcisa Arifovic, TUBITAK Tel: +90 262 679 5000 - 3406 E-mail: narcisa.arifovic@tubitak.gov.tr
Project website address: http://metfortc-empir.org</td></tr>
<tr><td>Internal Funded Partners:
1. TUBITAK, Türkiye
2. BFKH, Hungary
3. BIM, Bulgaria
4. BRML, Romania
5. CMI, Czech Republic
6. FSB, Croatia
7. IMBiH, Bosnia and Herzegovina
8. JV, Norway</td><td>External Funded Partners:
9. INM, Moldova, Republic of
10. ME, Montenegro</td><td>Unfunded Partners:
-</td></tr>
<tr><td colspan="3">RMG1: IMBiH, Bosnia and Hercegovina (Employing organisation); TUBITAK, Turkey (Guestworking organisation)
RMG2: DPM, Albania (Employing organisation); TUBITAK, Turkey (Guestworking organisation)</td></tr>
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