Publishable Summary for 19RPT02 RealMass
Improvement of the realisation of the mass scale

Overview

In recent years, industrial and technological requirements for mass metrology, with uncertainties at, or beyond, the current state of the art, have increased. Key to meeting these requirements is the reliable and effective realisation of the mass scale, with appropriate uncertainties. However, this capability does not exist yet in some small and developing NMIs. The overall aim of this project is to improve calibration methods for the realisation of the mass scale in emerging countries in the range from 1 mg to 20 kg. In addition, the primary mass laboratories will be able to provide calibration services at a higher level with improved uncertainty budgets. This project will include the development of a guideline for the dissemination of the mass unit with respect to the new definition of kilogram and software tools for the determination of the calibration results and with respective uncertainties.

Need

The calibration of mass is one of the most important measurements worldwide. Many other SI units are traceable to the kilogram such as pressure, force or torque, therefore the need for precise mass calibrations emerges from the industrial requirements for the reliable and effective realisation of the mass scale, with appropriate uncertainties. However, this capability does not exist yet in some small and developing NMIs.

The weights used for the calibration are divided into several groups according to their deviation from the nominal value, density or quality of the surface, based on recommendations from the OIML R111 document. The limits for the deviation from the nominal value are very strict (deviation limit of 1 kg of class E1 is 0.5 mg) and the uncertainty limit has to be less than or equal to 1/3 of this limit (uncertainty of 1 kg of class E1 has to be 0.16 mg or less), which means that the mass laboratories have to be equipped with the best mass comparators in order to be able to provide calibration service for E1 class weights.

The standard method for calibration of weights is well described in the document OIML R111 together with the uncertainty evaluation. Only a few pages, with an unsatisfactory short description, are devoted to the dissemination of the mass unit without further explanation. The lack of widely available guidance and appropriate software tools means that emerging countries in the field of mass calibrations cannot provide the best possible service for industries such as the automotive or pharmaceutical sectors.

This project will meet the needs by analysing the schemes used by the partners and through the development of calibration procedures that can be widely adopted by other NMIs. These procedures will be supported by mathematical and statistical tools for determining the results and related uncertainties of the weights as well as by the calibration guide issued by EURAMET.

Objectives

The overall goal of this project is to develop metrological capacity in the realisation and dissemination of the mass scale in the range 1 mg – 20 kg with uncertainties of 0.001 mg – 3 mg or better. The project also aims to develop reproducible calibration methods and a EURAMET draft calibration guideline as well as suitable mathematical tools based on a least squares method and on the equipment used for the dissemination of the mass unit.

The specific objectives of the project are:

1. To analyse 3 selected calibration methods for the realisation and dissemination of the mass scale (e.g. 1 mg – 20 kg with uncertainties of 0.001 mg – 3 mg or better) including the impact from the recent redefinition of the kilogram, and to create an appropriate methodology in order to optimise different technical requirements and parameters (e.g. robustness, effectiveness, small uncertainty, properties of different weighing instruments, different types of weight sets, number of control weights or standards).
2. To develop and implement calibration methods to realise, improve and maintain the mass scale (e.g., from 1 mg to 20 kg with uncertainties of 0.001 mg – 3 mg or better) in countries where mass scale

measurement capabilities are less developed, taking into account the requirements and the metrological needs of stakeholders. New or improved measurement capabilities should be validated by interlaboratory comparisons to establish the degree of equivalence.

3. To develop advanced mathematical and statistical tools and software solutions to calculate the results from the dissemination of the mass unit in the range 1 mg – 20 kg and to evaluate the associated uncertainties (including correlations between standards and measurements, and the handling of outliers). To validate developed mathematical and statistical tools for calculation of results (via a least squares method) and uncertainties (via an expanded model for covariance matrices and accounting for buoyancy corrections) via simulated and experimental data.
4. To develop a draft EURAMET calibration guideline for the realisation of the mass scale in the range from 1 mg to 20 kg with uncertainties of 0.001 mg – 3 mg or better, including the establishment of reliable dissemination schemes and methods to check and improve the long-term mass stability (including examples involving different equipment and methods to be used to extend or reduce the calibration range) and to submit it to EURAMET for approval.
5. 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 should also develop a strategy for offering calibration services from the established facilities to their own country and neighbouring countries. The individual strategies should be discussed within the consortium and with other EURAMET NMIs/DIs including EURAMET TC-M, OIML TC SC9/SC3, COOMET TC 1.6, WELMEC WG2/WG6, and IMEKO TC3 and members of relevant EMNs or JRPs, 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

Objective1: Analysis of methods for the realisation and dissemination of the mass scale in the 1 mg – 20 kg range with uncertainties of 0.001 mg – 3 mg or better

The methods of dissemination of mass unit, which have been used so far, are based on a limited number of sources such as the procedure developed and published by PTB or the procedure described in OIML R111. Due to several factors, such as the involvement of robotic mass comparators or dimension limitations of the inner chambers of mass comparators this method is not widely used. This project will gather the methods that are currently used for the dissemination of the mass unit and it will analyse them with respect to the equipment used (different mass comparators with different types of operation, composition of the weight set for the calibration, dimension limits of the weighing position of the mass comparator etc.), time consumption and achievable uncertainties of 0.001 mg – 3 mg or better for the weights in the range 1 mg – 20 kg. This analysis will provide better insight into the methods of dissemination, and it will provide the basis for the development of different calibration schemes. The parameters of different calibration schemes such as robustness, effectiveness, or uncertainty will be studied. The new definition of the kilogram enables the primary calibration of different nominal masses such as 500 g or 100 g so the analysis of the dissemination process will include, the impact of different starting points on the uncertainties, and robustness.

Objective 2: Development and implementation of calibration methods to improve and maintain the mass scale (e.g., 1 mg – 20 kg with uncertainties of 0.001 mg – 3 mg or better)

The subdivision / multiplication methods for the dissemination of the mass unit are not implemented in many countries due to the fact that in the past there was mostly no need to perform the calibration at the class E1 level. Due to industrial developments the need for better calibration services has arisen. Based on stakeholder needs, the consortium will develop appropriate calibration methods for the dissemination of mass unit in the 1 mg – 20 kg range with uncertainties of 0.001 mg – 3 mg or better. The methods will be validated by interlaboratory comparison. Such methods will enable emerging NMIs to improve their calibration service for industry and to further expand their calibration and research capabilities. The methods will enable better control of the existing equipment such as the stability of the mass of the standard weights at the laboratory, which is not the case in less developed laboratories under current conditions.

Objective 3: Development of mathematical and statistical tools to calculate the results from mass measurement, and to evaluate uncertainties

The process of dissemination of the mass unit by subdivision / multiplication consists of many measurements (for the calibration of a typical weight set in the1 mg – 1 kg range, with 25 pieces and a 1 kg reference standard, usually more than 100 measurements are needed), which can be described by an overdetermined system of equations that can be solved by least square methods. With the original subdivision and multiplication methods

used, arrangements leading to orthogonal designs were proposed in the past [M. Grabe Note on the Application of the Method of Least Squares, Metrologia 14,4, 143, 1978], which had the advantage of reducing some of the uncertainty contributions such as covariances. The progress to be made focuses on computational models such as the method of Lagrange multipliers or how to incorporate buoyancy correction factors to the system of equations. The methods and tools developed in the project will be validated during interlaboratory comparisons and with simulated data. The project will produce reference data for future comparison of other algorithms.

Objective 4: To develop a EURAMET guideline for the realisation of the mass scale

To solve the problem of limited access to the proper methods of dissemination of the mass unit, a EURAMET guideline covering the realisation of the mass scale in the range 1 mg – 20 kg will be produced. The guideline will provide the means for less developed laboratories to further improve their calibration procedures. The project will submit a draft guideline to EURAMET for further approval.

Results

Objective1: Analysis of methods for the realisation and dissemination of the mass scale in the 1 mg – 20 kg range with uncertainties of 0.001 mg – 3 mg or better

The methods for further development have been selected. They cover different methods for determination of mass and related uncertainties. The final iteration of the methods includes influences from various sources like correction for buoyancy force or thermal expansion coefficient. All project partners are currently working on case studies to cover range 1 mg – 20 kg with the use of developed methods. Institutes such as CMI Czechia, IMBiH Bosnia and Herzegovina or ME-BoM North Macedonia use the selected methods for precise evaluation of the dissemination process and identification of the points where the laboratories should focus to achieve repeatability of the dissemination process. These points include better environmental control, development of dissemination schemes according to the mass comparators and mass standards or preparation of data for further evaluation. The strategy for future development of these institutes will include points which are not yet covered and which should help in achieving the goal of uncertainties in the required range of 0,001 mg – 3 mg or better. As example, laboratory of CMI Czechia will develop measurements of centre of gravity of mass standards.

Objective 2: Development and implementation of calibration methods to improve and maintain the mass scale (e.g., 1 mg – 20 kg with uncertainties of 0.001 mg – 3 mg or better)

The initial case study on the methods for dissemination of the unit of mass in the range 1 mg – 20 kg was carried after a first online training session. The emerging countries (SMD Belgium, BIM Bulgaria, BoM North Macedonia, DMDM Serbia and IMBiH Bosnia and Herzegovina) delivered the results for further analysis and preparation for the follow up case studies where all project partners will participate. The case study showed that a more precise mathematical analysis is needed.

The follow-up case study focusses on ranges 1 mg – 1 g and 1 kg – 20 kg. The range 1 g – 1 kg is covered within interlaboratory comparison which is registered as Euramet project 1556 “Pilot study comparison for the realisation of the mass scale”. The comparison is in progress. Both comparison and follow-up case study together cover whole range 1 mg – 20 kg. The laboratories will gather necessary information on the quality of their procedures from the results of the interlaboratory comparison which will provide additional input for further development of the laboratory.

Objective 3: Development of mathematical and statistical tools to calculate the results from mass measurement, and to evaluate uncertainties

INRIM prepared the software RealMass for evaluation of the results and uncertainties from mass measurements which was made available for the consortium for use in testing and feedback has been sought. The Gauss-Markoff and Lagrange multiplier methods with residual analysis were selected for the evaluation of the mass measurements together with influencing factors like thermal expansion or centre of gravity of the weight set. The RealMass software was validated by comparison with results from other software solutions such as spreadsheets calculations and Matlab scripts previously used by institutes BEV Austria or CMI Czechia or commercial software solutions such as ScalesNet which is used in ME-BoM North Macedonia. Laboratories used their own measurement results and compared their own calculations with the RealMass software. The examples from literature were also used for validation of the RealMass software.

The RealMass software is currently in development. The equations are complete, the new versions of the software change the user interface or add new information to the output files.

Objective 4: To develop a EURAMET guideline for the realisation of the mass scale

The first draft of the calibration guide has been prepared according to the basic structure of other EURAMET guides like EURAMET guide cg-18 – Guidelines on the Calibration of Non-Automatic Weighing Instruments.

Impact

The paper reviewing the need of the project was published in ACTA IMEKO journal. The project partners participated in the training activities focused on the principles of the dissemination of the mass unit. Thanks to the training the less developed laboratories were able to disseminate the unit of mass and to participate in the initial case study on dissemination of the mass unit in the range 1 mg – 20 kg which provided vital input for successful competition of all objectives of this project. Another paper was published in Measurement: Sensors and presented during IMEKO World Congress 2021 (online, Japan). This paper shows preliminary results from the initial case studies on dissemination of the mass unit in the range 1 mg – 20 kg and connections to the dissemination of the mass unit to the new definition of the kilogram. Another presentation was given during IMEKO TC3 Conference (October 2022, Croatia). A paper covering this presentation was accepted for publication. Other papers on the selected calibration methods, case study comparison of two laboratories and advances on the statistical software are being prepared for International Metrology Congress (March 2023, France) and International Conference of Weighing (April 2023, Germany).

Impact on industrial and other user communities

This project will establish an improved calibration service that will provide end users with access to calibrations in the range 1 mg – 20 kg with uncertainties of 0.001 mg – 3 mg or better. Such conditions will be beneficial, for example, for producers of weighing instruments.

The guidance for the dissemination of the mass unit will enable emerging countries to further develop their calibration services which will be used by other calibration laboratories and industrial customers such as the chemical, pharmaceutical or automotive industry. These customers will be able to improve their internal processes which will lead to the improvement of the competitiveness of European industries.

The outcomes will be disseminated to laboratories and industrial stakeholders by organising 1 general workshop for partners from Europe, 5 national workshops for local stakeholders and by presenting the project's results at 3 conferences and in 5 articles in peer reviewed scientific journals.

Impact on the metrological and scientific communities

Based on the project's results, the draft EURAMET guideline for the dissemination of the mass unit focusing on the 1 mg – 20 kg range with uncertainties of 0.001 mg – 3 mg or better will be developed. This will create a large impact on calibration laboratories and it will be presented to regional metrology organisations such as COOMET TC 1.6, accreditation organisations as well as to end users and manufacturers of weighing instruments.

The knowledge transfer from experienced NMIs to those less experienced in the process of dissemination of the mass unit will be very beneficial. The project will strengthen collaboration of the European mass laboratories and it will increase their competitiveness.

The EURAMET calibration guideline will describe 3 recommended procedures for selecting right combination of weighing cycles based on stability, robustness and statistical tools, methods for the calculation of the calibration results and uncertainty evaluation. The EURAMET guideline, covering all of these topics, will be beneficial for all Regional Metrology Organisations and for all NMIs worldwide. The draft EURAMET guideline will be submitted to EURAMET and it will be made available to users together with the developed software tools.

Impact on relevant standards

The consortium will promote the results of the project within the standardisation community and will provide input into the standardisation process e.g., GULFMET, OIML TC9/SC3 "Weights" or CCM-WGM. The project will have impact on future revision of OIML R111. One of the planned deliverables, the EURAMET guide on the dissemination of the mass unit, will become an official guide once approved by EURAMET. This will have an impact on other similar guides that are issued by other regional metrology organisations (such as COOMET, AFRIMETS or APMP).

Longer-term economic, social and environmental impacts

By improving the dissemination of the mass unit at the NMI level in the 1 mg – 20 kg range with uncertainties of 0.001 mg – 3 mg or better, this project will provide a better measurement capability for laboratories which

are currently less developed in the field of mass. European calibration laboratories and industry should be able to engage with the new calibration services and to have their instruments calibrated within Europe as close as possible to the location of the respective laboratory. This will meet the demands of industry to obtain high accuracy calibration services in Europe. The expanded availability of the calibration service will reduce the time when the calibrated items are not available to the stakeholders and the travel distance of the equipment, which will reduce the risk of damage and travel costs.

The increased availability of the calibration of the weights with state-of-the-art uncertainties in the 1 mg – 20 kg range will reduce calibration service costs for the industry. This will result in better competitiveness as they will be able to invest this budget in further research and services.

List of publications

1.Zelenka, Z., Alisic, S., Stoilkovska, B., Hanrahan, R., Kolozinsky, I., Popa, G., Pantic, D., Dikov, V., Zůda, J., Coenegrachts, M. and Malengo, A, Improvement of the realisation of the mass scale, DOI 10.21014/acta_imeko.v9i5.928

2. Z. Zelenka, S. Alisic, R. Hanrahan, I. Kolozinsky, G. Popa, J. Zůda, A. Malengo, Why and how to improve the subdivision technique in mass metrology, Measurement: Sensors, Volume 18, 2021, 100228, ISSN 2665-9174, https://doi.org/10.1016/j.measen.2021.100228

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

Project start date and duration:		1 September 2020, 36 months
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Internal Funded Partners: 1. CMI, Czechia 2. BEV-PTP, Austria 3. BIM, Bulgaria 4. BRML, Romania 5. DMDM, Serbia 6. IMBiH, Bosnia and Herzegovina 7. INRIM, Italy 8. NSAI, Ireland 9. SMD, Belgium	External Funded Partners: 10. ME-BoM, North Macedonia 11. NSC-IM, Ukraine	Unfunded Partners:
RMG: -		