BIPM Capacity Building & Knowledge Transfer Programme

2024 BIPM - TÜBİTAK UME Project Placement

REPORT

Project Name	Method of subdivision calibration of a set of weights
Description	Study of the method of subdivision/multiplication calibration of a set of weights, creation of a standard and development of standards
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Motivation & Introduction

The aim of my project is to gain the necessary knowledge and expertise to develop the mass laboratory of the Uzbek National Metrology Institute (UzNIM), a sub-decadal method for calibrating weights, which requires the highest accuracy.

As a result of the project, the Large and Small Weights Laboratory of the Uzbek National Institute of Metrology (UzNIM) will expand its mass capabilities and provide high accuracy and reliable metrological traceability from the national standard to testing and calibration laboratories and other institutions.

The project results in improving existing knowledge, learning new methods of calibration of mass measuring instruments and learning new methods of control and analysis of reference and working measuring instruments in the field of mass metrology. As a result of the project implementation, the Uzbek National Institute of Metrology (UzNIM) mass laboratory will expand its capacity to provide reliable metrological traceability from the national mass unit standard to accredited laboratories and other accredited laboratories and other institutions involved in mass measurements, self-calibration of its own reference weights of accuracy class E1 and creation of a new primary mass standard will be carried out. Other expected results include improved measurement accuracy by independently determining the density and volume of the weights of our own and user mass standards.

Research

Training programme for the implementation of Mass Scales:

- 4-Phases of Dissemination;
- Calibration of Reference Standards (E1 Class Weights);
- Introduction to Linear Algebra;
- Realization of a Mass Scale (E0 Class Weights);

- Mass Comparison Measurments between 100 mg – 1 g;

- EURAMET TC-M Meeting (Online) Introduction to Matlab;

- Analysis measurements with Matlab;

- Analysis measurements with RealMass_Cal_V1_1 Software;

- Review and Discussion Presentation by Ms. Natalya Farkhodova.

The need to adopt a consensus value for the realization of the unit of mass after the redefinition of the kilogram arose due to the divergence of the values of Planck constant (hour). The use of a consensus value will facilitate a smooth transition from traceability based on the International Prototype Kilogram (IPK) to a point where individual realization experiments can be used for sovereign realization and dissemination of the unit of mass.

The dissemination of the kilogram after 20 May 2019 will take place in four successive phases:

- Implementation of the revised SI;

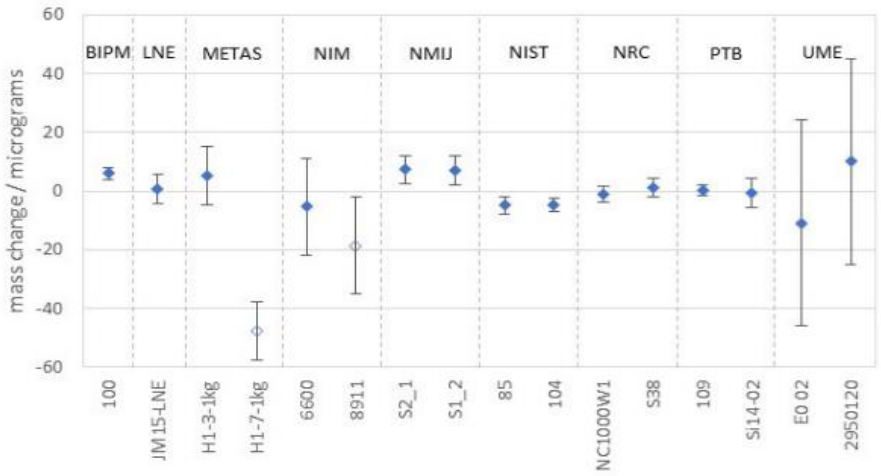
- Traceability (taking into account the additional uncertainty associated with the new definition);

- Dissemination of the consensus value;

- Dissemination of individual realizations.

Phase	Time scale	Description	Source of traceability	Uncertainty of BIPM mass calibrations	Role of realization experiments	Dissemination of mass from NMIs with realization experiments
0	Until 20 May 19[1]	Traceability to the IPK	$m_{\mathrm{IPK}} \equiv 1$ kg $u_{m_{\mathrm{IPK}}} \equiv 0$	$u_{\mathrm{stab}}(t)$	Measurement of h	Dissemination from national prototype traceable to IPK
1	20 May 19 - date 1[2]	Traceability to the IPK, taking into account the additional uncertainty coming from the (new) definition	$m_{\mathrm{IPK}} = 1$ kg $u_{m_{\mathrm{IPK}}} = 10\ \mu\mathrm{g}$	$\approx \sqrt{u^2_{m_{\mathrm{IPK}}} + u^2_{\mathrm{stab}}(t)}$	Contribute to Key Comparison (KC), improve to resolve discrepancies	Dissemination from national prototype traceable to IPK, with 10 µg added uncertainty
2	date 1 – date 2[3]	Dissemination via a consensus value[4] (CV)	Consensus value (CV)	$\approx \sqrt{u^2_{\mathrm{CV}} + u^2_{\mathrm{stab}}(t)}$	contribute to CV (via KC), improve experiments to resolve discrepancies	Dissemination from consensus value with uncertainty $\approx \sqrt{u^2_{\mathrm{CV}} + u^2_{\mathrm{stab,NMI}}(t)}$
3	from date 2	Dissemination by individual realizations	Fixed value of h $u(h) \equiv 0$	(Uncertainty of BIPM realization experiment)	Realization of the unit of mass, Participation in KCs to demonstrate equivalence	Dissemination from validated realization experiments with the uncertainty of the experiment. The terms of the CIPM MRA are applicable.

CCM.M-K8.2021: Key Comparison Results for KB and XRCD Experiments



BIPM: Kibble Balans

LNE: Kibble Balans

METAS: Kibble Balans

NIM: Joule Balans

NMIJ: X-Ray Crystal Intensity

NIST: Kibble Balans

NRC: Kibble Balans

PTB: X-Ray Crystal Intensity

We measured mass weights with nominal masses ranging from 1 mg to 100 mg with accuracy class E1 using the direct comparison method. For each comparison, the nominal masses of the reference and control weights should be the same. A set of weights of class E1 from 1 mg to 100 mg, a reference set of weights of class E0 from 1 mg to 100 mg, 6 series and 6 ABBA cycles were used as the object of calibration. The use of these cycles eliminates linear drift. During the project I improved my knowledge of calibrating E1 and E2 weights in accordance with IBSN: 3-527-9614-X (Comprehensive Mass Metrology) and also improved Excel software to calculate measurement results with expanded uncertainty. A comparison of the software was carried out.

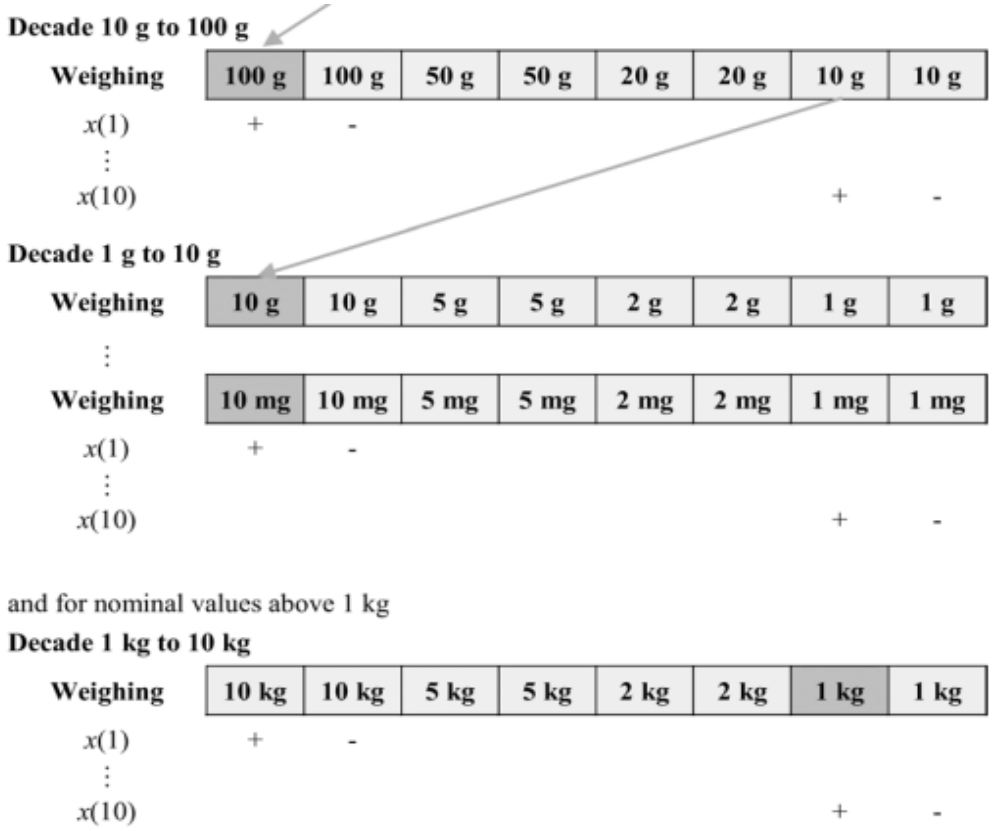
In order to perform self-calibration of weights of accuracy class E1 and to create a new primary mass standard, the method of sub-decade calibration in accordance with IBSN: 3-527-9614-X (Comprehensive Mass Metrology) was studied.

Decade 100 g to 1 kg

Weighing	1 kg	1 kg	500 g	500 g	200 g	200 g	100 g	100 g
$x(1)$	+	-						
$x(2)$	+		-	-				
$x(3)$		+	-	-				
$x(4)$			+	-				
$x(5)$			+		-	-	-	
$x(6)$				+	-	-		-
$x(7)$					+	-		
$x(8)$					+		-	-
$x(9)$						+	-	-
$x(10)$							+	-

Decade 10 g to 100 g

Weighing	100 g	100 g	50 g	50 g	20 g	20 g	10 g	10 g



This method involves several weightings in each decade of the set. In these weightings, different combinations of weights with the same total nominal mass are compared. This method is mainly used to calibrate sets of class E1 weights when maximum accuracy is required. However, these methods, especially the calculation of the correction, require more complex mathematics.

Weighting equantions

1	$m_{10g-2} - m_{10g-1} = y_1$
2	$m_{5g-1} + m_{5g-2} - m_{10g-1} = y_2$
3	$m_{5g-1} + m_{5g-2} - m_{10g-2} = y_3$
4	$m_{5g-2} - m_{5g-1} = y_4$
5	$m_{2g-1} + m_{2g-2} + m_{1g-1} - m_{5g-1} = y_5$
6	$m_{2g-1} + m_{2g-2} + m_{1g-2} - m_{5g-2} = y_6$
7	$m_{2g-2} - m_{2g-1} = y_7$
8	$m_{1g-1} + m_{1g-2} - m_{2g-1} = y_8$
9	$m_{1g-1} + m_{1g-2} - m_{2g-2} = y_9$
10	$m_{1g-2} - m_{1g-1} = y_{10}$

Mass weights are realized using a suitable weighing scheme, which mathematically is a redefined system of weighing equations; the weighing scheme describes the comparison of masses made with certain combinations of mass standards. The masses sought are obtained using the least squares

method. The least squares analysis also provides the standard uncertainties (or variance) of these values and the covariances for the mass combinations.

Also during the project I learnt:

- methods of calculation of instability and drift of measuring instruments, control of metrological characteristics of measuring instruments;

- calculation of intercalibration interval of measuring instruments;

- presentation of measurement results to the customer in calibration certificates;

- method of cleaning of weights;

- methods of verification of measurement results.

Conclusions and Future Work

As a result of the research, theoretical knowledge and practical experience were gained in the direction of the sub-decadal method for the set of weights.

Within three months, I will adapt the Large and Small Weights Laboratory of the Uzbek National Institute of Metrology (UzNIM) to implement the subdivision method to ensure high accuracy and reliable metrological traceability from the national standard to testing and calibration laboratories and other institutions. And we will also pass the accreditation for the extension of the new service. And in the near future we will organize an event to multiply to the knowledge gained at the Uzbek National Institute of Metrology (UzNIM) and in nearby Central Asian countries.

Acknowledgements

First of all, I would like to thank BIPM and UME TUBITAK for providing the training opportunity and for giving me the chance to learn and implement the project from one of the leading experts in the world.

I would also like to mention that I gained a lot of information during the two-day workshop conducted by the staff of Mr Anderson Maina and Mr Chingis Kuanbaev from the International Relations and Communications Department of BIPM and TUBITAK UME, which I will try to pass on to my colleagues.

I would also like to thank and express my deepest respect for the time spent on my training and project implementation and the continuous support of Ms Dr. Beste KORUTLU YILMAZ, Head of the TÜBİTAK UME Mass Laboratory, and the research assistants Ms Dr. Özlem PEHLİVAN YILDIRIM and Ms Lenara Kangi.