Key Comparison EURAMET.L-K1.2019

(EURAMET Project 1487)

Measurement of short gauge blocks by interferometry

Technical protocol

Final

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Contents

1 Document control

Draft A.1 Issued on 15 July 2019.
Draft A.2 Issued on 15 September 2019
Draft A.3 Issued on 30 October 2019
Draft A.4 Issued on 13 November 2019
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2 Introduction

The metrological equivalence of national measurement standards and of calibration certificates issued by national metrology institutes is established by a set of key and supplementary comparisons chosen and organized by the Consultative Committees of the CIPM or by the regional metrology organizations in collaboration with the Consultative Committees.

Key comparison EURAMET.L-K1.2011 run since 2011 to 2014 in parallel to the CIPM key comparison CCL-K1.2011 which was piloted by CENAM and NRC, acting BEV (AT) as pilot laboratory. The sets of gauge blocks used in both the CCL and EURAMET key comparisons had almost the same composition, i.e. steel and ceramic gauges ranging from 0,5 mm to 500 mm in length.

CEM participated in such comparison only until 100 mm obtaining 7 inconsistent results out of 16, mainly for longer gauges. So, as corrective action and in order to offer a consistent CMC in line with their results, CEM decided to enlarge temporarily its published CMC from $U = Q[17, 0.30\ L]$ to $U = Q[34, 0.70\ L]$ while investigating the cause of their wrong values and until participating in a new comparison. After such decision, no further corrective actions were required.

After a careful investigation, it was not found a clear reason for such bad results. During that time, bilateral measurements on different sets of gauges of participants in the EURAMET comparison were done, resulting in good agreement.

Because the urgency for CEM to recover its previous CMC and be again able to offer to accredited laboratories the uncertainty they are demanding, CEM have just decided to organize this new small comparison at EURAMET level, after agreement with some participants, most of them also acting in the previous comparison.

CEM has prepared this technical protocol, in line with the previous existing ones in this field. Gauges to be circulated are **two sets, in steel and ceramic, with lengths of 1.5 mm, 3 mm, 5 mm, 6 mm, 15 mm, 24.5 mm (25 mm in ceramic), 80 mm and 100 mm**.

1 Organization

1.1 Participants

The following table includes the list of participants and the contact persons.

Table 1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
CEM	Joaquín Rodríguez CEM C/del Alfar 2	Phone: +34 91 807 48 01 jrgonzalez@cem.es

	ES-28760 Tres Cantos (Madrid) Spain	
PTB	Guido Bartl PTB WG 5.43 "Interferometry on Gauge Blocks" Bundesallee 100 D-38116 Braunschweig Germany	Phone: +49 (0531) 592-5430 guido.bartl@ptb.de
SMD	Hugo Pirée Service Métrologie Scientifique SMD Koning Albert II Laan 16, 1000 Brussel Belgium	Phone: +32 2277 7610 hugo.piree@economie.fgov.be
RISE	Marianne Äremann, Agneta Jakobsson RISE Box 857, 501 15 Borås, Sweden	Phone: +46 10-516 50 00 marianne.aremann@ri.se agneta.jakobsson@ri.se
METAS	Rudolf Thalmann, Felix Meli METAS Lindenweg 50, CH-3003, Bern-Wabern, Switzerland	Phone: +41 31 32 33 385 rudolf.thalmann@metas.ch felix.meli@metas.ch
INRIM	Marco Pisani INRIM Strada delle Cacce 91, IT-10135 Torino, Italy	Phone: +39 011 3919 970 m.pisani@inrim.it

1.2 Schedule

The participating laboratories were asked to specify a preferred timetable slot for their own measurements of the gauge blocks – the timetable given in table 2 has been drawn up taking these preferences into account. Each laboratory has **four weeks** that include customs clearance, calibration and transportation to the following participant. With its confirmation to participate, each laboratory is obliged to perform the measurements in the allocated period and to allow enough time in advance for transportation so that the following participant receives them in time. If a laboratory has technical problems to perform the measurements or customs clearance takes too long, the laboratory has to contact the pilot laboratory as soon as possible and, according to whatever it decides, it might eventually be obliged to send the standards directly to the next participant before completing the measurements or even without doing any measurements.

Table 2. Schedule of the comparison.

Laboratory	Starting date of measurement
CEM	November 2019
PTB	December 2019/January 2020
SMD	February 2020
METAS	March 2020
INRIM	April 2020
RISE	May 2020
CEM	June 2020

1.3 Reception, transportation, insurance, costs

Two cases containing the short gauge blocks are used for the transportation of the artefacts. Upon reception of the package, each laboratory has to check that the content is complete and that there is no apparent damage on the box or any of the standards. The reception has to be confirmed immediately to the pilot with a copy to the former participant (sender), preferably using the form of Appendix A.

The organization costs will be covered by the pilot laboratory, which include the standards themselves, the cases and packaging, and the shipping costs to the next laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during the circulation.

Once the measurements have been completed, the package shall be sent to the following participant. The steel gauge blocks need to be protected against corrosion when not being measured by means of protective oil. Please cover them with this product before packing them for transportation or when stocked for more than three days.

Each participating laboratory shall cover the costs of shipping and transport insurance against loss or damage. The package should be shipped with a reliable parcel service of its choice. Once the measurements have been completed, please inform the pilot laboratory and the following participant when the package leaves your installations indicating all pertinent information. If, at any point during circulation, the package is damaged, it shall be repaired by the laboratory before shipping it again.

2 Artefacts

2.1 Description of artefacts

The package contains 2 sets of 8 gauge blocks each, one in steel and the other in ceramic, of nominal lengths 1.5 mm, 3 mm, 5 mm, 6 mm, 15 mm, 24.5 mm (25 mm in ceramic), 80 mm and 100 mm. The gauge blocks are of rectangular cross section and comply with the calibration grade K of the standard ISO 3650.
Note: the gauge blocks were selected for good quality of the faces and small variation in length, the limit deviation t_e from nominal length may not be met by some of the artefacts.

The coefficients of thermal expansion given in the following table are obtained by the manufactures and should be used as such. Following a decision by the WGDM a pre-determination of this important artefact parameter is not to be communicated to the participants.

Table 3. List of artefacts.

Steel Set

Identification	Nominal length /mm	Expansion coefficient /10^{-6} K^{-1}	Manufacturer
830577	1.5	11.5	C.E. Johansson
	3		
	5		
	6		
	15		
	24.5		
900555	80		
	100		

Ceramic Set

Identification	Nominal length /mm	Expansion coefficient /10^{-6} K^{-1}	Manufacturer
G28900	1.5	9.7	TESA
K25630	3		
J86140	5		
J86168	6		
L75840	15		
J90964	25		
J14285	80		
H79370	100		

3 Measuring instructions

3.1 Handling the artefact

The gauge blocks should only be handled by authorized persons and stored in such a way as to prevent damage. Before making the measurements, the gauge blocks need to be checked to verify that their measuring surfaces are not damaged and do not present severe scratches and/or rust that may affect the measurement result. The condition of the blocks before measurement should be registered in the form provided in appendix B. Laboratories should attempt to measure all gauge blocks unless doing so would damage their equipment. If a gauge block will not wring readily, the participant shall inform the pilot about this problem, stating the respective gauge block and face. No participant shall try to re-finish measuring faces by burring, lapping, stoning, or whatsoever. The measurement of the face concerned or the complete gauge block shall be omitted.

No other measurements are to be attempted by the participants and the gauge blocks should not be used for any purpose other than described in this document. The gauge blocks may not be given to any party other than the participants in the comparison.

The gauge blocks should be examined before despatch and any change in condition during the measurement at each laboratory should be communicated to the pilot laboratory. After the measurements, the gauge blocks must be cleaned and greased. Ensure that the content of the package is complete before shipment. Always use the original packaging.

3.2 Traceability

Length measurements should be traceable to the latest realisation of the metre as set out in the current "*Mise en Pratique*". Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

3.3 Measurands

The gauge blocks shall be measured based on the standard procedure that the laboratory regularly uses for this calibration service for its customers. The "A" surface is the marked measuring face for gauge blocks with nominal length < 6 mm and the right hand measuring face for gauge blocks with a nominal length ≥ 6 mm, respectively (see Figure 2).

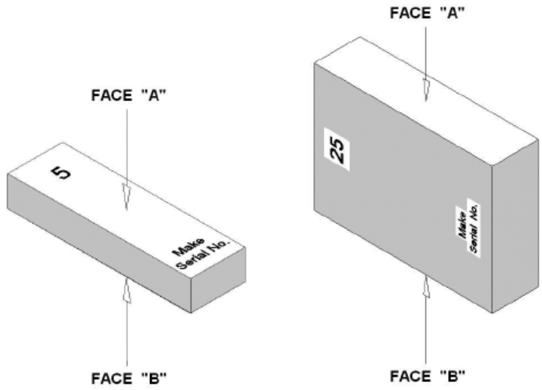

Figure 2 – Nomenclature of faces

The measurand to be reported is the deviation e_c of the central length l_c from the nominal length l_n of a gauge block. In this comparison the arithmetic mean of the two values for wringing on both faces is considered as representative for e_c (see equation (1), the superscripts label the face wrung to the platen). In cases where only one face could be wrung the corresponding value should be reported as the result.

$$e_c = \left(e_c^A + e_c^B\right)/2 \text{ with } e_c^A = l_c^A - l_n \text{ and } e_c^B = l_c^B - l_n \quad (1)$$

As an auxiliary measurand the difference of the found deviations d_c when the block is wrung to face A and face B, respectively, should be reported according to equation (2). Care has to be taken to use the correct sign.

$$d_c = e_c^A - e_c^B = l_c^A - l_c^B . \quad (2)$$

3.4 Measurement uncertainty

The uncertainty of measurement shall be evaluated according to the ISO Guide to the Expression of Uncertainty in Measurement. The participating laboratories are encouraged to use their usual model for the uncertainty calculation.

All measurement uncertainties shall be stated as standard uncertainties. If appropriate the corresponding effective degrees of freedom might be stated by the participants. If none is given, ∞ is assumed. For efficient evaluation and subsequent assessment of CMC claims an uncertainty statement in the functional form (3) is preferred:

$$u\left(e_c\right) = Q\left[a, b \cdot l_n\right] = \sqrt{a^2 + \left(b \cdot l_n\right)^2} . \quad (3)$$

3.5 Optical phase change and roughness correction

The position of the plane where light is reflected on a surface is depending mainly on the material and surface finish. As the free measuring face of the gauge block under measurement and the platen where it is wrung are in general different in both characteristics, this difference varies and a correction has to be applied. It shall be estimated or determined by each laboratory according to its calibration procedure as it usually does it for its customers.

Methods usually applied to determine this correction are the stack method, the total integrating sphere technique, the coupled interferometer method, etc. Participants should state their technique in appendix D.

3.6 Reference condition

Measurement results should be reported for the reference conditions as set down in the standard ISO 3650. Specifically the reference temperature of 20 °C, standard pressure of 101 325 Pa and the orientation are of importance. For corrections, the linear thermal expansion coefficient provided in this document (table 3) should be used.

4 Reporting of results

4.1 Results and standard uncertainties as reported by participants

As soon as possible after measurements have been completed, the results should be communicated to the pilot laboratory **within four weeks** at the latest.

The measurement report forms in appendix C of this document will be sent by e-mail (Word document) to all participating laboratories. It would be appreciated if the report forms (in particular the results sheet) could be completed by computer and sent back electronically to the pilot. In any case, the signed report must also be sent in paper form by mail or electronically as a scanned pdf document. In case of any differences, the signed forms are considered to be the definitive version.

Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare within 3 months a first draft A.1 report on the comparison. This will be circulated to the participants for comments, additions and corrections.

5 Analysis of results

5.1 Calculation of the KCRV

The key comparison reference value (KCRV) is calculated on a gauge-per-gauge basis as the weighted mean of the participant results. The check for consistency of the comparison results with their associated uncertainties will be made based on Birge ratio, the degrees of equivalence for each laboratory and each gauge block with respect to the KCRV will be evaluated using E_n values, along the lines of the *WG-MRA-KC-report-template*. If necessary, artefact instability, correlations between institutes, and the necessity for linking to another comparison will be taken into account.

5.2 Artefact instability

Steel gauge blocks occasionally show a growing or a shrinkage the rate of which is approximately linear with time. Since the artefacts used here are of unknown history, the instability of the blocks must be determined in course of the comparison. For this check the measurements of the pilot laboratory are used exclusively, not that of the other participants. Using these data a linear regression line is fitted and the slope together with its uncertainty is determined (per gauge block).

Three cases can be foreseen:

a) The linear regression line is an acceptable drift model and the absolute drift is smaller than its uncertainty. The gauge block is considered stable and no modification to the standard evaluation procedure will be applied. In fact the results of the pilot's stability measurements will not influence the numerical results in any way.

b) The linear regression line is an acceptable drift model and the absolute drift is larger than its uncertainty, i.e. there is a significant drift for the gauge block. In this case an analysis similar to [Nien F Z et al. 2004, Statistical analysis of key comparisons with linear trends, *Metrologia* **41,** 231] will be followed. The pilot influences the KCRV by the slope of the drift only, not by the measured absolute lengths.

c) The data are not compatible at all with a linear drift, regarding the uncertainties of the pilot's measurements. In this case the artefact is unpredictably unstable or the pilot has problems with its measurements. TC-L has to determine the further approach.

5.3 Correlation between laboratories

Since the topic here is the comparison of primary measurements, correlations between the results of different NMIs are unlikely. A possible exception is the common use of the recommended thermal expansion coefficients (from table 3). A correlation will become relevant only when the gauge blocks are calibrated far away from 20 °C which should not be the case. Thus correlations are normally not considered in the analysis of this comparison. However if a significant drift exist, correlations between institutes are introduced by the analysis proposed in section 7.2.

5.4 Linking of result to other comparisons

The CCL task group on linking CCL TG-L has set guidelines for linking this comparison to any other key comparison within CCL for the same measurement quantity. So, such guidelines will be applied.

Appendix A – Reception of Standards

To:	Pilot name, pilot institute Pilot address Fax: xxx e-mail: xxx@yy			
From:	NMI:	………………………………	Name:	………………………………
	Signature:	………………………………	Date:	………………………………

We confirm having received the gauge blocks for the EURAMET.L-K1.2019 comparison on the date given above.

After a visual inspection:

☐ There are no apparent damages; their precise state will be reported in the form provided in Annex B/C once inspected in the laboratory along with the measurement results.

☐ We have detected severe damages putting the measurement results at risk. Please indicate the damages, specifying every detail and, if possible, include photos. If it is necessary use additional sheets to report it.

Appendix B – Conditions of Measuring Faces

To:	Pilot name, pilot institute Pilot address Fax: xxx	e-mail: xxx@yy		
From:	NMI:	………………………………	Name:	………………………………
	Signature:	………………………………	Date:	………………………………

After detailed inspection of the measuring faces of the gauge blocks these are the results. Please mark significant surface faults (scratches, indentations, corrosion, etc.).

Short gauge blocks – steel									
	face	A	B	A	B	A	B	A	B
	l_n	1.5 mm		3 mm		5 mm		6 mm	
	face	A	B	A	B	A	B		
	l_n	15 mm		24.5 mm		80 mm		100 mm	

Short gauge blocks – ceramic									
	face	A	B	A	B	A	B	A	B
	l_n	1.5 mm		3 mm		5 mm		6 mm	
	face	A	B	A	B	A	B		
	l_n	15 mm		25 mm		80 mm		100 mm	

Appendix C – Results Report Form

To:	Pilot name, pilot institute Pilot address Fax: xxx e-mail: xxx@yy
From:	NMI: ……………………………… Name: ……………………………… Signature: ……………………………… Date: ………………………………

Short gauge blocks, steel							
l_n / mm	Ident. number	e_c / nm	$u(e_c)$ / nm	ν_{eff}	d_c / nm	$u(d_c)$ / nm	ν_{eff}
1.5	830577						
3							
5							
6							
15							
24.5							
80	900555						
100							

Functional form of standard uncertainty

$$u(e_c) = Q[a, b \cdot l_n] = \sqrt{a^2 + (b \cdot l_n)^2}$$

Gauge block set	a / nm	b / 1	Comment
Short, steel			

Short gauge blocks, ceramic							
l_n / mm	Ident. number	e_c / nm	$u(e_c)$ / nm	ν_{eff}	d_c / nm	$u(d_c)$ / nm	ν_{eff}
1.5	G28900						
3	K25630						
5	J86140						
6	J86168						
15	L75840						
25	J90964						
80	J14285						
100	H79370						

Functional form of standard uncertainty

$$u(e_c) = Q[a, b \cdot l_n] = \sqrt{a^2 + (b \cdot l_n)^2}$$

Gauge block set	a / nm	b / 1	Comment
Short, ceramic			

Appendix D – Description of the measurement instrument

To:	Pilot name, pilot institute Pilot address Fax: xxx e-mail: xxx@yy
From:	NMI: ……………………………… Name: ……………………………… Signature: ……………………………… Date: ………………………………

Make and type of instrument(s) ....

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....

....

Light sources / wavelengths used or traceability path:...

....

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Description of measuring technique (including any corrections such as phase correction & platen material, vertical to horizontal corrections etc):..

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Range of gauge block temperature during measurements & description of temperature measurement method: ....

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(use additional pages as needed)