Korea Research Institute of Standards and Science

APMP Key Comparison APMP.L-K1.2018
Calibration of gauge blocks

Technical protocol

Chu-Shik Kang (KRISS)

Daejeon, October 2019

Contents

1 Document control

Version 1.0 Issued on 31 October 2019.

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.

Recent CIPM Key Comparison (KC) on gauge blocks by optical interferometry, CCL-K1.2011 was run during 2011 to 2012. In the annual meeting of Technical Committee for Length (TCL) of the Asia Pacific Metrology Programme (APMP) held in November 2015, it was agreed that the corresponding APMP KC will be run after the report of CCL-K1.2011 is released. At the TCL meeting in 2016, it was agreed that APMP will plan to run a regional KC on gauge block measurement by optical interferometry with KRISS as the pilot laboratory. In 2017, the artefacts were purchased and the comparison was registered in the key comparison database (KCDB) in June 2018 as APMP.L-K1.2018. The artefact circulation is planned to start in 2019 after the stability of the artefacts is checked.

The procedures outlined in this document cover the technical procedure to be followed during the measurements. A goal of this key comparison is to demonstrate the equivalence of routine gauge block calibration services offered by NMIs to clients, as listed in Appendix C of the CIPM Mutual Recognition Arrangement (MRA).

Usually, only measurement by optical interferometry is allowed for the key comparison on gauge block calibration. However, considering the fact that there are only few NMIs equipped with a long gauge block interferometer within the Asia Pacific region, it was discussed and decided within the Discussion Group 1 of the Consultative Committee for Length (CCL) that other measurement methods could also be used for the long gauge block calibration. However, it should be noted that if an NMI has several measurement methods for long gauge blocks, the method having the smallest measurement uncertainty shall be used for this KC.

By their declared intention to participate in this key comparison, laboratories accept the general instructions and to strictly follow the technical protocol of this document. Due to the large number of participants, it is very important that participating NMIs perform their measurements during assigned dates. Participants should keep in mind that the allocated time period is not only for measurements, but transportation and customs clearance as well. Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants.

3 Organization

3.1 Pilot laboratory

This key comparison will be coordinated by Dr. Chu-Shik Kang of the Korea Research Institute of Standards and Science (KRISS), which is the pilot laboratory of this key comparison.

3.2 Participants

The list of participant laboratories and their contact persons are shown in Table 1.

Table 1. List of participant laboratories and their contacts.

Lab. Code	Contact person, Laboratory address	Phone, Fax, Email address
KRISS	Chu-Shik Kang	Phone: +82 42 868 5103 Fax +82 42 868 5012 Email: cskang@kriss.re.kr

	Korea Research Institute of Standards and Science (KRISS), Building 201, 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113 Republic of Korea	
NMIJ/AIST	Akiko Hirai National Metrology Institute of Japan (NMIJ) /AIST, Central 3, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8563, JAPAN	Phone: +81-29-861-4283 Fax: +81-29-861-4080 E-mail: a-hirai@aist.go.jp
NMIA	Peter Cox National Measurement Institute, Australia (NMIA), 1/153 Bertie Street, Port Melbourne VIC 3207 Australia	Phone: +61 3 9644 4906 Fax: +61 3 9644 4900 email: Peter.Cox@measurement.gov.au
MSL	Eleanor Howick Measurement Standards Laboratory of New Zealand (MSL-NZ), 69 Gracefield Road, Gracefield, Lower Hutt 5040, New Zealand	Phone: +64 4 9313530 Fax: +64 4 566 600 Email: eleanor.howick@measurement.govt.nz
NIMT	Samana Peingbangyang National Institute of Metrology (Thailand), 3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani, 12120 THAILAND	Phone: +66-2577-5100. ext 1215 (O), 1110 (L) Fax: +66 (0) 2-577-5095 Email: samana@nimt.or.th
NMIM	Razman Mohd Halim National Metrology Institute of Malaysia (NMIM), Lot PT 4803, Bandar Baru Salak Tinggi, 43900, Sepang, Selangor Darul Ehsan, Malaysia	Phone: (603) 8778 1600 Fax: (603) 8778 1616 Email: razmanmh@sirim.my
MUSSD	A.D.D. Naminda Measurement Units, Standards and Services Department (MUSSD), Mahenawatta, Pitipana, Homagama, Colombo 1O2OO, Sri Lanka	Phone: +94-11-2182267 Fax: +94-11-2182269 Email: addimension@measurementsdept.gov.lk / addnaminda@yahoo.com
SCL	George Tang / Henry Chiu The Standards and Calibration Laboratory (SCL), 35/F Immigration Tower, 7 Gloucester Road, Wan Chai, Hong Kong	Phone.: +852 -2829 4805 / +852 -2829 4839 Fax: +852 - 2824 1302 Email: george.tang@itc.gov.hk / hklchiu@itc.gov.hk
NIM	Xudong Zhang National Institute of Metrology (NIM), No.18, Bei San Huan Dong Lu, Chaoyang Dist., Beijing, P. R. of China 100029	Phone: +86-10-64524924 Fax: +86-10-64524902 Email: zhxd@nim.ac.cn
SNSU-BSN	Ocka Hedrony / Nurul Alfiyati SNSU-BSN, Kompleks Puspiptek Ged. 420, Setu, Tangerang Selatan, Banten 15314, Indonesia	Phone: 62 818 08258759 / 62 856 1024377 Fax: 62 21 7560568 Email: ocka@bsn.go.id / nurul@bsn.go.id
CMS/ITRI	Ming-Wei Chang Center for Measurement Standards (CMS)/ITRI, Bldg. 16, No.321, Sec. 2, Guangfu Rd., East Dist., Hsinchu City 300, Taiwan	Phone: +886-3-573-2150 Fax: +886 3 572 4952 Email: MWChang@itri.org.tw
NMC, A*STAR	Siew Leng Tan / Shengkai Yu NMC, A*STAR 1 Science Park Drive, Singapore 118221	Phone: 65 62791938 / 65 62791907 Fax: 62791992 Email: tan_siew_leng@nmc.a-star.edu.sg / yu_shengkai@nmc.a-star.edu.sg

3.3 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 calibrating long gauge blocks only is given 4 weeks that include customs clearance, calibration and transportation to the following participant, and each laboratory calibrating both short and long gauge blocks is given six weeks. Extra 1 week is given to MUSSD and CMS/ITRI whose time slot includes the New Year’s Day and the Chinese New Year’s Day, respectively.

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. Tentative schedule of the comparison

RMO	Laboratory	Economy	Starting date of measurement	Given no. of weeks
APMP	KRISS (Pilot lab)	Republic of Korea	6 January 2020	6 weeks
APMP	NIM	China	17 February 2020	6 weeks
APMP	NIMT	Thailand	30 March 2020	6 weeks
APMP	MSL	New Zealand	11 May 2020	6 weeks
APMP	NMIJ/AIST	Japan	22 June 2020	6 weeks
APMP	NMIA	Australia	3 August 2020	4 weeks
APMP	NMIM	Malaysia	31 August 2020	6 weeks
APMP	SNSU-BSN	Indonesia	12 October 2020	4 weeks
APMP	SCL	Hong Kong China	9 November 2020	4 weeks
APMP	MUSSD	Sri Lanka	7 December 2020	5 weeks
APMP	CMS/ITRI	Chinese Taipei	11 January 2021	7 weeks
APMP	NMC, A*STAR	Singapore	1 March 2021	6 weeks
APMP	KRISS (Pilot lab)	Republic of Korea	12 April 2021	6 weeks

3.4 Reception, transportation, insurance, costs

A plastic case containing 2 long gauge blocks and two wooden cases for the short gauge blocks, is used for the transportation of the artefacts (Figure 1). 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 gauge blocks need to be protected against corrosion by means of protective oil when not being measured. 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. In the case that a laboratory or its shipping agent damages one or more artefacts, they may be required by the pilot to replace the artefacts at their own cost (or from the insurance).

Figure 1 – Transporting case

For shipment, the package is accompanied by an ATA carnet. The carnet shall always be shipped with the package, never inside the box, but apart. **Please be certain, that when receiving the package, you also receive the carnet!**

4 Artefacts

4.1 Description of artefacts

The package contains short gauge blocks - 9 steel and 9 tungsten carbide blocks - and 2 long gauge blocks. The gauge blocks are of rectangular cross section and comply with the calibration grade K of the standard ISO 3650.

The coefficients of thermal expansion given in Table 3 are obtained by the manufactures and should be used as such.

Table 3. List of artefacts.

Identification	Nominal length /mm	Expansion coefficient /10^{-6} K^{-1}	Manufacturer
09199X	0.5	4.5 ± 1.0	KOBA
09609X	2	4.5 ± 1.0	KOBA
08538X	2.5	4.5 ± 1.0	KOBA
10019X	3	4.5 ± 1.0	KOBA
09391X	5	4.5 ± 1.0	KOBA
10603X	10	4.5 ± 1.0	KOBA
08201X	20	4.5 ± 1.0	KOBA
07583X	75	4.5 ± 1.0	KOBA
10636X	100	4.5 ± 1.0	KOBA

174202	0.5	10.8 ± 0.5	Mitutoyo
174732	2	10.8 ± 0.5	Mitutoyo
174429	2.5	10.8 ± 0.5	Mitutoyo
130226	3	10.8 ± 0.5	Mitutoyo
160971	5	10.8 ± 0.5	Mitutoyo
136906	10	10.8 ± 0.5	Mitutoyo
173764	20	10.8 ± 0.5	Mitutoyo
171057	75	10.8 ± 0.5	Mitutoyo
172859	100	10.8 ± 0.5	Mitutoyo
160259	400	10.8 ± 0.5	Mitutoyo
160115	500	10.8 ± 0.5	Mitutoyo

5 Measuring instructions

5.1 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 Appendices B1-B3. 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.

Measurements of short gauge blocks shall be performed only by using optical interferometry, but long gauge blocks are allowed to be measured with the measurement method having smallest uncertainty in the NMI/DI. Thus, mechanical comparison method, interferometric comparison method, or other similar methods could be used for the long gauge block measurements.

Measurements may only be performed using equipment normally used to offer the relevant CMC service. In case of multiple CMC services in this area, only the service/equipment with the smallest uncertainty should be used, unless the pilot and other participants agree to allow additional instruments to be used; in which case, only the results of the instrument/service with the smallest uncertainty may contribute to the KCRV. 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.

5.2 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).

5.3 Measurand

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).

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 project 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.

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

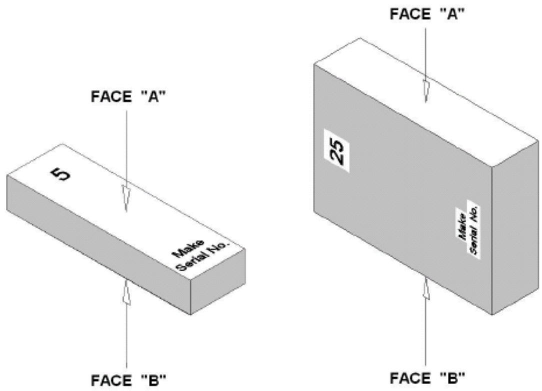


Figure 2 - Nomenclature of faces

5.4 Measurement uncertainty

The uncertainty of measurement shall be evaluated according to the ISO *Guide to the Expression of Uncertainty in Measurement* (ISO/IEC Guide 98-3 or JCGM 100). The participating laboratories are encouraged to use their usual model for the uncertainty evaluation.

All measurement uncertainties shall be stated as standard uncertainties. The corresponding effective degree of freedom should 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:

$$u(e_c) = Q[a, b \cdot l_n] = \sqrt{a^2 + (b \cdot l_n)^2} \quad \text{with } \nu_{\text{eff}} = ?? \qquad (3)$$

The measurement function and the uncertainty budget are to be reported using the form given in Appendices D1-D3. Additionally, in the report of the measurement technique (Appendices E1-E3) the participant should list any relevant CMC claims for the service(s) related to the comparison.

5.5 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 Appendices E1-E3.

5.6 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.

6 Reporting of results

6.1 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 six weeks** at the latest.

The measurement report forms in Appendices C1-C3, D1-D3 and E1-E3 of this document will be sent by e-mail (Word document) to all participating laboratories by the pilot. Appendices C1-C3 are to be used for reporting the measurement results, and Appendices D1-D3 are to be used for reporting the measurement functions and the uncertainty budgets. It would be appreciated if the report forms 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.

When reporting the results of the comparison, each participant should also report the range and uncertainty of any existing CMC related to the comparison. This will be used by the pilot when checking whether or not CMC claims are supported by the comparison results.

In the case that the measurement uncertainty reported by a participant in a comparison is significantly bigger than the relevant CMC claim, this should be explained at the time of submitting the results (e.g. air conditioning failure at time of measurements, damage on artefacts affecting measurements).

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

7 Analysis of results

7.1 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 *CCL 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.

7.2 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. Technical Committee for Length (TCL) has to determine the further approach.

7.3 Correlation between laboratories

For comparison of gauge block lengths measured by optical interferometry, correlations between the results of different NMIs are unlikely since this is a comparison of primary measurements. 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 exists, correlations between institutes are introduced by the analysis proposed in section 7.2. For comparison of gauge block lengths measured by mechanical comparison, correlation between results of different NMIs may exist, for example when the reference long gauge blocks were calibrated from another participant of this comparison. In such a case, the effect of correlation will be taken into account during the analysis.

7.4 Linking of result to other comparisons

The CCL task group on linking CCL TG-L will set guidelines for linking this comparison to other key comparison within CCL for the same measurement quantity (e.g. CCL-K1.2011).

Appendix A – Reception of Standards

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: ……………………………………………………… Name: ……………………………………………… Signature: ……………………………………………… Date: ………………………………………………

We confirm having received the gauge blocks for the APMP.L-K1.2018 comparison on the date given above.

After a visual inspection:

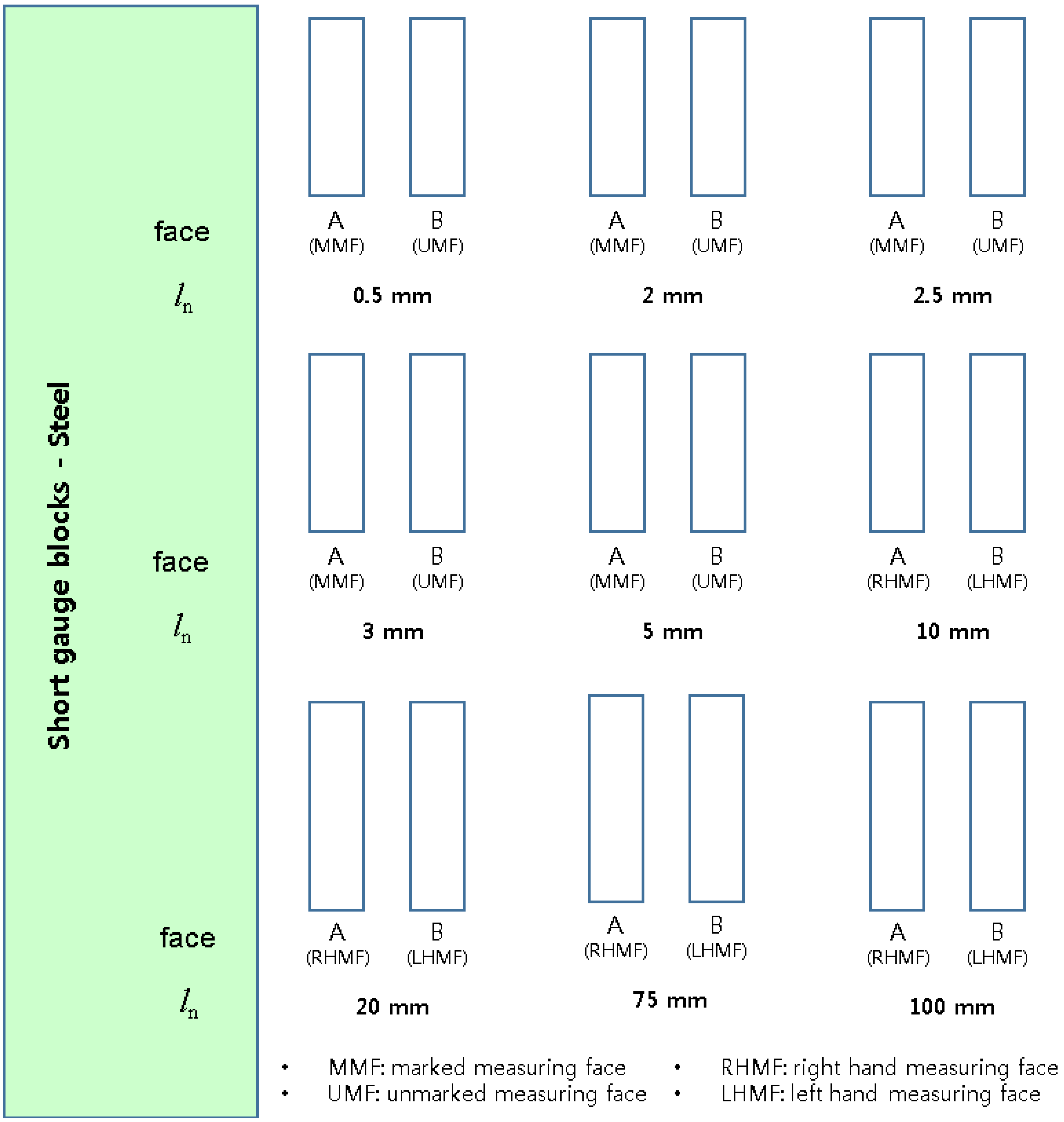
☐ There are no apparent damages; their precise state will be reported in the form provided in Annex B/C once inspected in the laboratory along with the measurement results.

☐ 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 B1 – Conditions of Measuring Faces (Short gauge blocks, steel)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: .... Name: .... Signature: .... Date: ....

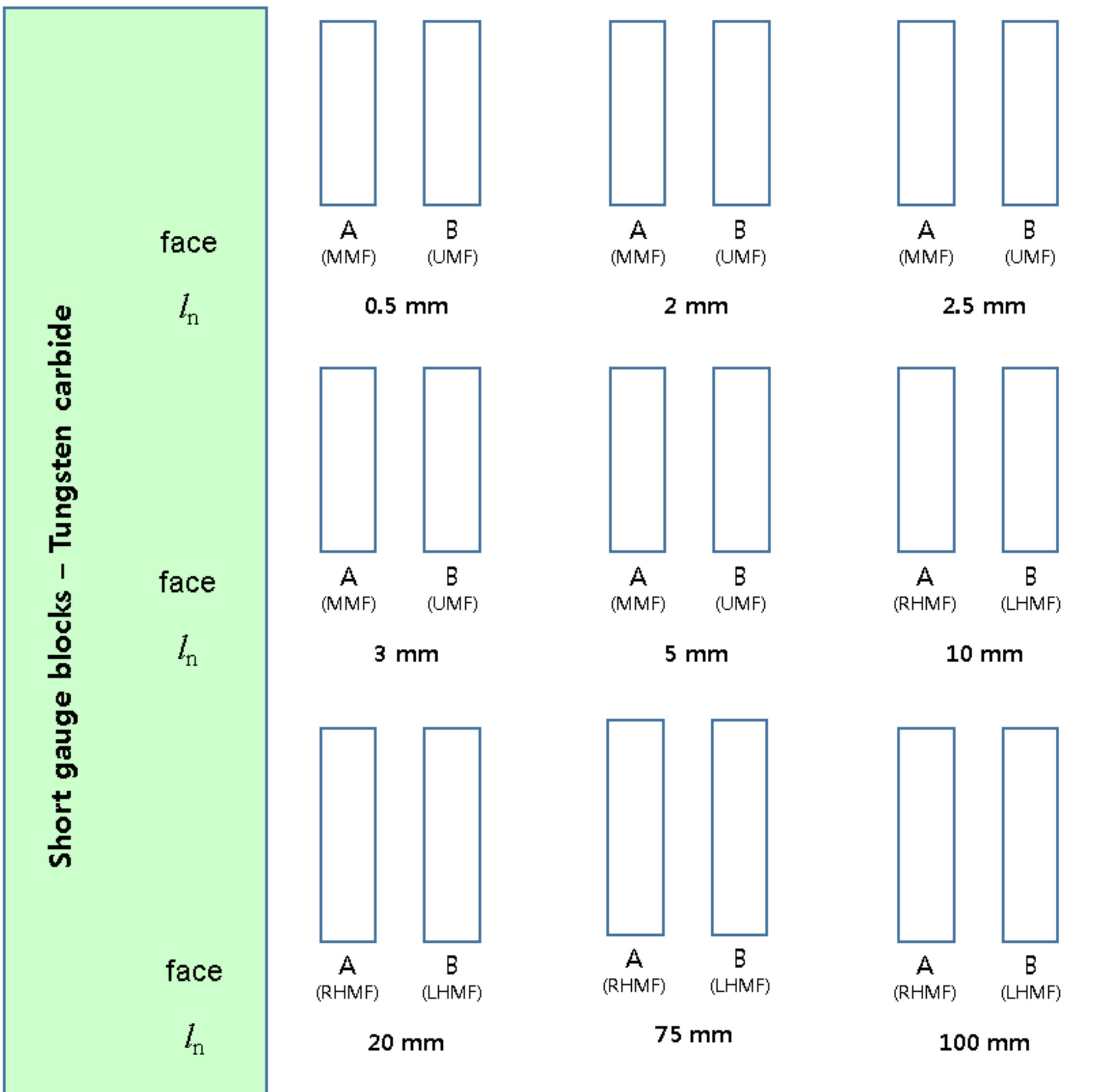
After detailed inspection of the measuring faces of the gauge blocks these are the results. Please mark significant surface faults (scratches, indentations, corrosion, etc.).



Appendix B2 – Conditions of Measuring Faces (Short gauge blocks, tungsten carbide)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
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.).

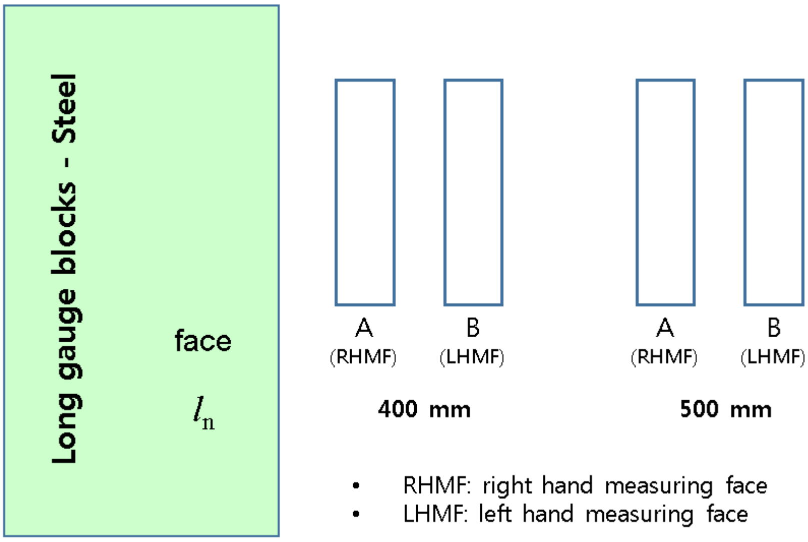


- MMF: marked measuring face
- UMF: unmarked measuring face
- RHMF: right hand measuring face
- LHMF: left hand measuring face

Appendix B3 – Conditions of Measuring Faces (Long gauge blocks)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012	e-mail: cskang@kriss.re.kr
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.).



Appendix C1 – Results Report Form (Short gauge blocks, steel)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: …………………………………………………… Name: ……………………………………………… Signature: ……………………………………………… Date: ………………………………………………

Short gauge blocks, steel								
l_n / mm	Serial number	Deviation of central length from nominal length			Material of platen	Phase change correction in nm	$u(e_c)$ / nm (k = 1)	ν_{eff}
		e_c^A / nm	e_c^B / nm	e_c / nm				
0.5								
2								
2.5								
3								
5								
10								
20								
75								
100								

Functional form of standard uncertainty

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

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

Appendix C2 – Results Report Form (Short gauge blocks, tungsten carbide)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: ………………………………………………… Name: ……………………………………………… Signature: ……………………………………………… Date: ………………………………………………

Short gauge blocks, tungsten carbide								
l_n / mm	Serial number	Deviation of central length from nominal length			Material of platen	Phase change correction in nm	$u(e_c)$ / nm (k = 1)	ν_{eff}
		e_c^A / nm	e_c^B / nm	e_c / nm				
0.5								
2								
2.5								
3								
5								
10								
20								
75								
100								

Functional form of standard uncertainty

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

Gauge block set	a / nm	b / 1	Comment
Short, tungsten carbide			

Appendix C3 – Results Report Form (Long gauge blocks)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: ………………………………………………… Name: ……………………………………………… Signature: ……………………………………………… Date: ………………………………………………

Long gauge blocks, steel								
l_n / mm	Serial number	Deviation of central length from nominal length			Material of platen	Phase change correction in nm	$u(e_c)$ / nm (k = 1)	ν_{eff}
		e_c^A / nm	e_c^B / nm	e_c / nm				
400								
500								

Functional form of standard uncertainty

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

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

Appendix D1 – Measurement function and the uncertainty budget: Short gauge blocks, steel (1/2)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr	
From:	NMI: ………………………………………………………	Name: ………………………………………………
	Signature: ………………………………………………	Date: ………………………………………………

Measurement Function (mathematical model of measurement):

Definition of variables in the measurement function:

Page 1/2

Appendix D1 – Measurement function and the uncertainty budget: Short gauge blocks, steel (2/2)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: …………………………………………………… Name: ……………………………………………… Signature: ……………………………………………… Date: ………………………………………………

Uncertainty budget

source of uncertainty x_i	standard uncertainty $u(x_i)$	sensitive coefficient c_i	probability distribution	uncertainty contribution u_i	degrees of freedom ν_i
combined standard uncertainty (k = 1) u_c					

Appendix D2 – Measurement function and the uncertainty budget: Short gauge blocks, tungsten carbide (1/2)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: ……………………………………………………… Name: ……………………………………………… Signature: ……………………………………………… Date: ………………………………………………

Measurement Function (mathematical model of measurement):

Definition of variables in the measurement function:

Appendix D2 – Measurement function and the uncertainty budget: Short gauge blocks, tungsten carbide (2/2)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: ……………………………………………………… Name: ……………………………………………… Signature: ……………………………………………… Date: ………………………………………………

Uncertainty budget

source of uncertainty x_i	standard uncertainty $u(x_i)$	sensitive coefficient c_i	probability distribution	uncertainty contribution u_i	degrees of freedom ν_i
combined standard uncertainty (k = 1) u_c					

Appendix D3 – Measurement function and the uncertainty budget: Long gauge blocks, steel (1/2)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: …………………………………………………… Name: …………………………………………… Signature: …………………………………………… Date: ……………………………………………

Measurement Function (mathematical model of measurement):

Definition of variables in the measurement function:

Appendix D3 – Measurement function and the uncertainty budget: Long gauge blocks, steel (2/2)

To: Dr. Chu-Shik Kang, KRISS

267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea

Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr

From: NMI: …………………………………………………… Name: ……………………………………………

Signature: …………………………………………… Date: ……………………………………………

Uncertainty budget

source of uncertainty x_i	standard uncertainty $u(x_i)$	sensitive coefficient c_i	probability distribution	uncertainty contribution u_i	degrees of freedom ν_i
combined standard uncertainty (k = 1) u_c					

Appendix E1 – Description of the measurement instrument for <u>short gauge blocks</u> (1/2)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
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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Relevant 95 % CMC uncertainty claim for the service(s) related to this comparison topic (if existing) and identifier of the CMC……

……

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Appendix E1 – Description of the measurement instrument for <u>short gauge blocks</u> (2/2)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: ………………………………………………… Name: …………………………………………… Signature: …………………………………………… Date: ……………………………………………

If the reported uncertainty is significantly bigger than that of the related CMC, explanation for the increased uncertainty ....

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....

(use additional pages as needed)

Appendix E2 – Description of the measurement instrument for long gauge blocks (1/2)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: ………………………………………………… Name: …………………………………………… Signature: …………………………………………… Date: ……………………………………………

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

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Light sources / wavelengths used or traceability path (if applicable): ....

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

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

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Relevant 95 % CMC uncertainty claim for the service(s) related to this comparison topic (if existing) and identifier of the CMC...

....

....

Appendix E2 – Description of the measurement instrument for long gauge blocks (2/2)

To:	Dr. Chu-Shik Kang, KRISS 267 Gajeong-ro, Yuseong-gu, Daejeon, 34113, Republic of Korea Fax: +82 42 868 5012 e-mail: cskang@kriss.re.kr
From:	NMI: ………………………………………………… Name: …………………………………………… Signature: …………………………………………… Date: ……………………………………………

If the reported uncertainty is significantly higher than that of the related CMC, explanation for the increased uncertainty ....

....

....

(use additional pages as needed)