APMP Key Comparison APMP.L-K5.2021

Calibration of Step Gauge

Technical protocol

National Institute of Metrology, China

Beijing, October, 2021

Contents

1 Document control

Version Draft A	Issued on 22 February 2021. Initial collection of data and outline of comparison
Version Final	Issued on 12th April 2021.
Version Update	Issued on 16th October 2021. Modification of schedule and participants.

2 Introduction

The metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organised by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs). Calibration and Measurement Capabilities (CMCs), which are traceable to national measurement standards, are supported by evidence primarily coming from the results of key and supplementary comparisons, together with the operation of approved and mutually accepted quality systems.

At its meeting in 2003, the APMP Technical Committee Length (TCL) decided that a new key comparison on step gauge measurements would be carried out and the resulting comparison, APMP.L-K5.2006 was undertaken, involving 13 NMIs; however several laboratories had anomalous results in that comparison. So at the 2013 APMP meeting, the APMP TCL decided to organize a follow-up comparison as a corrective action for NMIs reporting anomalous results in the 2006 comparison. This follow-up comparison is APMP.L-K5.2014. But this comparison was declared as Abandoned on 13 December 2018.

APMP TC-L decided to organize the next K5 comparison in 2021. NIM is the pilot laboratory.

The procedures outlined in this document cover the technical procedure to be followed during measurement of the step gauge. The procedure follows the guidelines established by the BIPM Participants.

3 Organization

3.1 Participants

APMP

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
Pilot	Hengzheng Wei National Institute of Metrology,China NO.18 Bei San Huan Dong Lu Chaoyang District Beijing 10029 China	Tel: +86 10 64524931 Email: weihz@nim.ac.cn
KRISS	Jong-Ahn Kim Korea Research Institute of Standards and Science 267 Gajeong-ro Yuseong-gu Daejeon 34113 Republic of Korea	Tel: +82 42 868 5683 Email: jakim@kriss.re.kr
NIMT	Wiroj SUDATHAM National Institute of Metrology (Thailand) 3/4-5 Moo 3 Klong 5 Klong Luang Pathumthani 12120 Thailand	Tel: +66 2 577 5100 Ext. 1109 Email: wiroj@nimt.or.th

NMIA	Peter Cox National Measurement Institute, Australia 1/153 Bertie Street Port Melbourne Victoria 3207 Australia	Tel: +61 3 9644 4906 Email: Peter.Cox@measurement.gov.au
NMC, A*STAR	Shihua Wang National Metrology Centre (NMC), A*STAR Fusionopolis Way #08-05 Innovis Singapore	Tel: +65 67149264 Email: wang_shihua@nmc.a-star.edu.sg
MSL	Eleanor Howick Measurement Standards Laboratory of New Zealand 69 Gracefield Road Lower Hutt New Zealand	Tel: +64 27 381 5594 Email: Eleanor.howick@measurement.govt.nz
NMIJ-AIST	Osamu Sato Research Institute of Engineering Measurement Dimensional Standards Group AIST Central 3, 1-1-1, Umezono, Tsukuba, Ibaraki 305-8563 Japan	Phone: +81-29-861-4041 Fax: +81-29-861-4080 e-mail: osm-satou@aist.go.jp

EURAMET

TUBITAK-UME	İlker MERAL TUBİTAK Gebze Yerleşkesi Barış Mah. Dr.Zeki Acar Cad. No:1 41470 Gebze / KOCAELİ Turkey	Tel: +90 262 679 5000 / Ext: 5305 Email: ilker.meral@tubitak.gov.tr

3.2 Schedule

The participating laboratories were asked to specify a preferred timetable slot for their own measurements of step gauge – the timetable given in table 2 has been drawn up taking these preferences into account.

Each laboratory has seven 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 1. Schedule of the comparison.

RMO	Laboratory	Starting date of measurement
APMP	NIM	08/06/2021
APMP	KRISS	27/07/2021
APMP	NIMT	15/09/2021
APMP	NMIA	04/11/2021
EURAMET	TUBITAK-UME	24/12/2021
APMP	MSL	12/02/2022
APMP	NMC, A*STAR	02/04/2022
APMP	NMIJ	22/05/2022
APMP	NIM	11/07/2022

3.3 Reception, transportation, insurance, costs

The artefact shall be examined immediately after receipt. The condition of the artefact shall be noted (a photograph or a drawing should be made if the artefact is damaged) and all discrepancies shall communicated to the pilot laboratory. The form in Appendix A should be used for this purpose.

The artefact should only be handled by authorized persons and stored in a proper way in order to prevent damage.

The artefact shall be examined before dispatch and any change in condition during the measurement shall be communicated to the pilot laboratory.

Please inform the pilot laboratory and the next laboratory via fax or e-mail when the artefact is about to be sent to the next recipient.

The artefact shall be packed according to the instructions in the package. Ensure that the content of the package is complete before shipment. Always use the original packaging.

Packaging for the artefact is suitably robust to protect the artefact from being deformed or damaged during transit. The step gauge is packed in a Pelican hardened plastic flight case. Notices in the boxes will state handling instructions in case the boxes have to be opened at customs. Please indicate with a notice to the airport personnel that the cases shall be towed on a palette in order to minimize the risk of damage.

The artefact should be sent via courier or delivery company, or be hand carried by the participants. The package shall be marked as ‘Fragile’.

Each artefact should be sent with enough time in advance as to have the following laboratory receive them at the nearest port or airport on the date that their period starts.

Fig. 1: Step gauge containers

The artefact will be accompanied by a suitable customs carnet (where appropriate) and documentation identifying the contents. The ATA 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! Every time the carnet is used, it is stamped TWICE – on exit from one country and on entry into the next. Please examine the carnet and assure that the transportation company used has arranged for correct stamping of the carnet. Failure to ensure both stamps (exit, entry) subjects the carnet holder to a penalty.

Transportation and insurance is each laboratory's responsibility and cost. Each participating laboratory covers the costs for its own measurements, transportation and any customs charges. Each laboratory is responsible for any damage of the artefact from the point of receipt at their site until the artefact is signed for on receipt at the next laboratory. The insurance value of the artefact is $6,000. The overall costs for the organization, initial measurements and the processing of results are covered by the pilot laboratory however any damage to or loss of artefact must be paid for by the responsible participant. By their confirmation of participation, each laboratory agrees to be bound by these requirements.

4 Artefact

4.1 Description of artefact

Artefact is a 700 mm nominal length step gauge produced by ITS GmbH. The artefact is shown in Fig. 2.

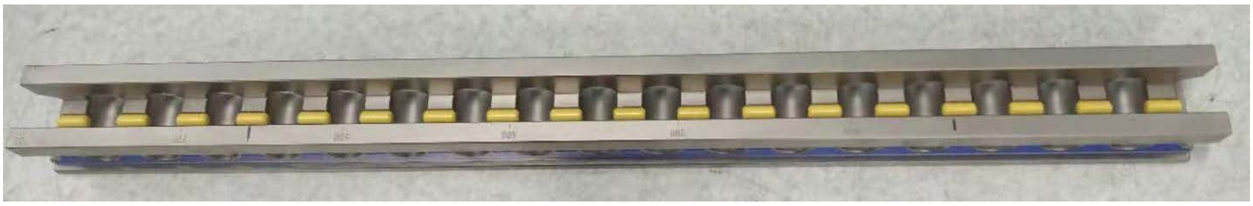

Fig. 2 Step gauge

Table 3. Details of the artefact

Manufacturer	ITS GmbH
Model	700mm
Serial Number	SE0700284
Material	Steel frame, Ceramic gauge
Weight	9.25 kg
Thermal expansion coefficient	11.5×10^{-6} K^{-1}

The main gauge represents a total length of 700 mm with 20 mm steps and consists of 36 measurement faces.
Dimensions of the artefact and reference for measurement are presented in figure 3. Note that on this gauge only the external faces may be used as alignment features. The top surface is used for Z axis alignment. The side surface is used for the X axis alignment. The target points for alignment on top and side surface are near the bessel point of step gauge.

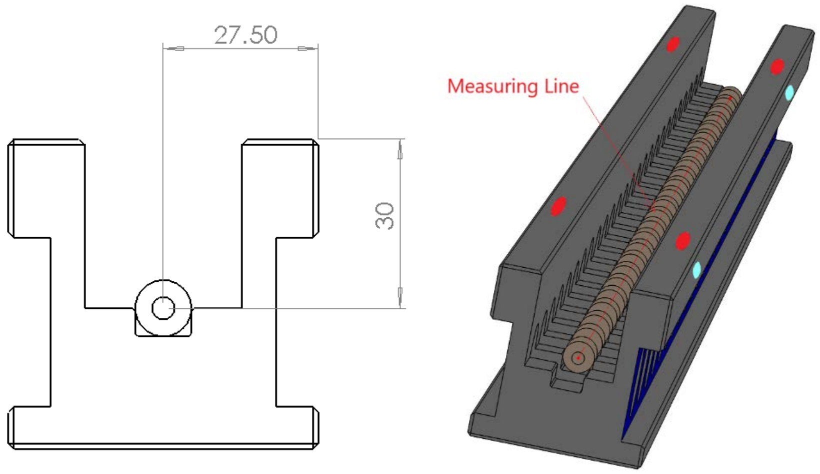

Fig. 3 Dimensions and reference position for measurement of the artefact

5 Measuring instructions

5.1 Mounting the artefact

The artefact in each circulation loop will be shipped without any special mounting fixtures (see section 3.3 for details on transport packaging). Within APMP.L-K5.2021 it is recommended to support the artefact at the Bessel points. For this, the positions of the Bessel points are indicated at the sides of the gauge. **Please do not clamp the step gauge from both sides.**

5.2 Handling the artefact

5.2.1 General handling

Open the transport container carefully. Use gloves to handle the step gauge and **never** touch the measuring faces of step gauge with bare fingers. Before shipping for transportation put several packs of silica-gel in wooden box.

5.2.2 Cleaning

The gauge should be cleaned of dust particles using dry, clean air or other clean gases. The measurement surfaces should be cleaned using alcohol with soft tissues. No other cleaning techniques are permitted.

5.2.3 Temperature measurement of the artefact

The measurement results have to be appropriately corrected to the reference temperature of 20 °C using the values of the thermal expansion coefficient provided (See section 4.1).

5.2.4 Storage

Use original transportation container to avoid dust deposits. Always try to keep the artefact under good measuring room conditions, i.e. within the room, where they get calibrated.

5.3 Traceability

The goal of this APMP comparison is to demonstrate the equivalence of routine calibration service for step gauge measurements offered by NMIs to clients, as listed by them (or soon to be listed) in Appendix C of the BIPM Mutual Recognition Agreement (MRA). To this end, participants in this comparison agree to use the same apparatus and methods as routinely applied when calibrating artefacts for clients. Participants are free to tune and operate their systems to best-measurement performance and to take any extra measurements needed to produce a best measurement result, provided that these extra efforts would also be available to a client if requested.

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).

5.4 Measurands

The measurands of the step gauge are the distances of the centres of the front and back faces of the individual gauges of the step-gauge with respect to the centre of the front face of the first gauge. The measurements should be carried out using the measurement lines laid out in section 4.1.

The thermal expansion coefficient indicated for the artefact should be used by laboratories when measuring the artefact. Laboratories should report the temperatures at which the length measurements were made. Laboratories should only measure the artefact at a temperature close to 20 °C.

5.5 Measurement instructions

The participants are free to choose their own method of measurement. However, under the assumption that the value of the measurand is a true property of the material measure of length, only one result for a measurand shall be given irrespective of the number of different measurement methods used. For each method applied, a complete description of the method has to be given. The measurements have to be reported for measuring conditions, given in 5.6.

Before calibration, the step gauge must be inspected for damage. Any scratches, dirty spots or other damages have to be documented.

The measurement results (appropriately corrected to the reference conditions) have to be reported using the table in Appendix B.1.

The artefact should not be used for any purpose other than described in this document. The artefact may not be given to any party other than the participants in the comparison.

5.6 Measurement conditions

The measured values have to be referred to the following reference conditions:

- Temperature of 20 °C (ITS-90)

If necessary, corrections have to be applied based upon the following parameters:

- Artefact thermal expansion coefficient $\alpha = (11.5 \pm 0.5)\cdot 10^{-6}\ \mathrm{K}^{-1}$

5.7 Measurement uncertainty

The uncertainty of measurement shall be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement* [2008 Edition]. In order to achieve a better comparability some possible influence parameters and notations are given in the following. The participants are encouraged to use all known and significant influence parameters for their applied methods.

Because for this key comparison the measurement equipment and procedure is not completely fixed, it is not possible to develop a full mathematical model for the measurement uncertainty for all participants. There are broad categories that uncertainties can be grouped into, in order to produce a comparative table. Table 4 does this for a measurement setup involving an interferometric - probe setup. The participants can append a more detailed analysis, but for the final report, summarize your uncertainties into the broad categories listed in Table 4. Leave blank those components that don't apply and add additional components if necessary. List or highlight any influence factors which prevent you from achieving your best Calibration Measurement Capability. For example your CMC may be achieved with an artefact made from a different material (perhaps with a lower temperature coefficient). Highlight this component and provide a note, as this will make it easier for an assessor to compare your results with your claimed CMC.

Please note that the individual gauges of each artefact may not be aligned to the measurement axis of the artefact as a whole and that additionally, the faces of the gauges may be non-orthogonal to the axes. These effects are contributions to the overall uncertainty budget.

The uncertainty should be reduced to the form provided in your laboratory's CMC claim for this service. This is normally given as a quadratic sum, expressed in short form as Q[*A*, *B*.*L*] where *A* is the fixed part and *B* the proportional part (see CCL/WGDM/00-51c.doc "CCL-WGDM Supplement to the JCRB Instructions for Appendix C" or WG-MRA guidance document GD-5 which is currently being finalised).

If the step gauge is measured by comparison, another mathematical model for the measurement uncertainty may be provided.

Table 4: Example of measurement uncertainty budget

Description	Quantity x_i	Standard uncertainty $u(x_i)$	Sensitivity coefficient $c_i = \partial l/\partial x_i$	Standard uncertainty (Fixed component µm)	Standard uncertainty (proportional component µm *L* in m)
Gauge temperature error (measured - actual)					
Gauge expansion coefficient (uncert.* temperature error from 20 °C)					
Gauge alignment to measurement axis (includes face)					
Gauge alignment errors due to the gauge reference surfaces					
Laser interferometer wavelength (traceability)					
Optical refractive index (air monitoring)					
Optical dead path					
Probe(system) repeatability(resolution)					
Probe diameter – or bidirectional uncertainty					
Abbe error					
Others					

6 Reporting of results

6.1 Results and standard uncertainties as reported by participants

As soon as possible after measurements have been completed, and within six weeks at the latest, the measurement results, detailed evaluation uncertainty of measurement and instrument description should be communicated to the pilot laboratory.

The measurement report forms in appendices B & 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. Alternatively, results may be submitted in an Excel spreadsheet. 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. Please observe the correct units to be used when reporting results.

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.

7 Analysis of results

7.1 Calculation of the KCRV

The key comparison reference value (KCRV) is calculated 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 interval 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.

7.2 Artefact instability

The stability of the artefacts being used in this comparison was tested by the pilot. But during the transportation and measurement artefact may be deformed due to temperature change or shock, thus the instability of the artefact must be determined in course of the comparison. For this check the measurements of the pilot laboratory are used exclusively, not those of the other participants. Using these data a linear regression line is fitted and the slope together with its uncertainty is determined.

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 artefact 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 artefact. 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. APMP TC-L has to determine the further approach.

7.3 Correlation between laboratories

Since the topic of this project is the comparisons 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. A correlation will become relevant only when the step gauge is 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.

Appendix A – Reception of Standards

To:	Hengzheng Wei National Institute of Metrology, NO.18 Bei San Huan Dong Lu, Chaoyang District, Beijing 10029, China. Phone: +86 10 64524931 Email: weihz@nim.ac.cn
From:	NMI: Name: Signature: ……………………………… Date: ………………………………

We confirm having received artefact for the APMP.L-K5.2021 comparison on the date given above.

After a visual inspection:

☐ There is no apparent damage.

☐ There are scratches or rust on the gauge surface. Please indicate the location and, if possible, include photos.

☐ There are indications that the step gauge has suffered a big shock or has been dropped. Please indicate the location and, if possible, include photos.

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

Appendix B – Results Report Form

To:	Hengzheng Wei National Institute of Metrology, NO.18 Bei San Huan Dong Lu, Chaoyang District, Beijing 10029, China. Phone: +86 10 64524931 Email: weihz@nim.ac.cn
From:	NMI: Name: Signature: ……………………………… Date:

Ⅰ. Measurement results

Face interval	Central length /mm	Standard uncertainty /µm	Effective degrees of freedom
0 - 1			
0 - 2			
0 - 3			
0 - 4			
0 - 5			
0 - 6			
0 - 7			
0 - 8			
0 - 9			
0 - 10			
0 - 11			
0 - 12			
0 - 13			
0 - 14			
0 - 15			
0 - 16			
0 - 17			
0 - 18			
0 - 19			

0 - 20			
0 - 21			
0 - 22			
0 - 23			
0 - 24			
0 - 25			
0 - 26			
0 - 27			
0 - 28			
0 - 29			
0 - 30			
0 - 31			
0 - 32			
0 - 33			
0 - 34			
0 - 35			

Ⅱ. Functional form of standard uncertainty

Uncertainty of measurement

Description	Quantity x_i	Standard uncertainty $u(x_i)$	Sensitivity coefficient $c_i =$ □L/□x_i	Standard uncertainty (Fixed component μm)	Standard uncertainty (proportional component μm L in m) ($\times 10^{-6} L$)	Effective degrees of freedom υ
Optical refractive index & Laser interferometer wavelength (traceability)						
Probe (system) repeatability						
Probe diameter – or bidirectional uncertainty						
Gauge temperature error (measured - actual)						
Gauge expansion coeff. & temperature error from 20ºC						

Abbe error						
Gauge alignment errors due to the gauge reference surfaces						
Laser alignment to measurement axis (includes face)						
Optical dead path						

The combined standard uncertainty is Q[*A*μm,*BL*], *L* in m. Take into other unpredictable factors in this comparison we claimed the following uncertainty:

Combined standard uncertainty:

Expanded uncertainty:

Please state your CMC uncertainty for your corresponding measurement service(s) (if you have such a CMC) and the identifier of the service (in MRA Appendix C).

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If the uncertainty of the CMC is different to the uncertainty claimed for this comparison, please explain why this is the case.

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Appendix C – Description of the measurement instrument

To:	Hengzheng Wei National Institute of Metrology, NO.18 Bei San Huan Dong Lu, Chaoyang District, Beijing 10029, China. Phone: +86 10 64524931 Email: weihz@nim.ac.cn
From:	NMI: Name: Signature: ……………………………… Date:

(Use more sheets if necessary, enclose photo(s) and/or sketch(es) of the instrument)

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