NPL◉
National Physical Laboratory

CIPM Key Comparison

CCL-K2

Calibration of long gauge blocks

Technical protocol (Issue 1)

Contents

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1. Introduction

1.1   The metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs).

1.2   At its meeting in September 1997, the Consultative Committee for Length, CCL, identified several key comparisons in the field of dimensional metrology. In particular, it decided that a key comparison on length bar measurements shall be carried out, starting in autumn 1999 and lasting 18 months, with the National Physical Laboratory (NPL) acting as the pilot laboratory.

1.3   This technical protocol has been drawn up by a small working group comprising the National Physical Laboratory, UK (NPL), the National Research Council, Canada (NRC) and the National Measurement Laboratory, Australia (NML).

1.4   The procedures outlined in this document cover the technical procedure to be followed during measurement of the gauge blocks. The procedure, which follows the guidelines established by the BIPM[1], is based on the existing technical protocol document for the key comparison on gauge blocks[2]. It also takes account of the experience gained in a EUROMET comparison of long gauge blocks[3] carried out between 1993 and 1995.

1.5   A goal of the CCL key comparisons for topics in dimensional metrology is to demonstrate the equivalence of routine calibration services offered by NMIs to clients, as listed in Appendix C of the Mutual Recognition Agreement (MRA) [BIPM, 1999]. To this end, participants in this comparison agree to use the same apparatus and methods as routinely applied to client artefacts.

1.6   The title for the comparison has been changed *to 'CIPM Key comparison on calibration of long gauge blocks'* because the artefacts are rectangular-section long gauge blocks as specified in ISO 3650 (1998) and not length bars (which are of circular cross-section).

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[1] T.J. Quinn, *Guidelines for CIPM key comparisons*, 1 March 1999, BIPM, Paris

[2] R. Thalmann, J Decker, N Brown, *CCL Key Comparison: Calibration of Gauge Blocks by Interferometry*, April 1998, OFMET, Wabern

[3] H. Darnedde, J. Helmcke, European comparison of long gauge blocks, *Metrologia* **33** 485-491 (1996)

2. Organization

2.1 Participants

2.1.1   The list of participants which was submitted to the CCL for approval, was drafted by the pilot laboratory working closely with the RMOs.

2.1.2   The accuracy requirement of the participants is an ability to measure the central length of gauge blocks covering the range 175 mm to 900 mm to an uncertainty of less than approximately 200 nm at k = 1.

2.1.3   All participants must be able to demonstrate independent traceability to the realization of the metre.

2.1.4   There is an additional requirement to measure the gauge blocks at a temperature sufficiently close to 20 °C that the uncertainty in the measured expansion coefficient does not dominate the overall measurement uncertainty. This temperature range has been fixed as 19.9 °C - 20.1 °C.

2.1.5   By their declared intention to participate in this key comparison, the laboratories accept the general instructions and the technical protocols written down in this document and commit themselves to follow the procedures strictly.

2.1.6   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.

2.1.7   It has been necessary to limit the total number of participants for technical reasons, as recognized by paragraph 4 of the BIPM *'Guidelines for CIPM key comparisons'*.

2.2 Participants' details

EUROMET		
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SIM		
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2.3 Form of comparison

2.3.1   The comparison will be in a mixed form, both 'circular' and 'star-shaped'. The gauge blocks will be circulated within a region then returned to the pilot laboratory before

circulation in the next region. Because of time constraints, it will not be possible to arrange for a 'star-shaped' circulation within each region.

2.3.2   NPL will act as the pilot laboratory. All results are to be communicated directly to the pilot laboratory as soon as possible and certainly within 6 weeks of the completion of the measurements by a laboratory.

2.3.3   The participating laboratories were asked to specify a preferred timetable slot for their own measurements of the gauge blocks - the timetable given below has been drawn up taking these preferences into account.

2.3.4   Timetable

Region	Laboratory	Country	Date
EUROMET	IMGC	IT	September 1999
	PTB	DE	November 1999
	NPL	GB	December 1999
Pilot Lab	NPL	GB	January 2000
SIM	NIST	US	March 2000
	INMETRO	BR	April 2000
	NRC	CA	May 2000
Pilot Lab	NPL	GB	June 2000
APMP	NRLM	JP	July 2000
	NIM	CN	August 2000
	CSIRO	AU	September 2000
SADCMET	CSIR	SA	October 2000
Pilot Lab	NPL	GB	November 2000
COOMET	VNIIM	RU	January 2001
	SMU	SK	February 2001
Pilot Lab	NPL	GB	March 2001

2.3.5   The stability of the gauge blocks was assessed by measurement prior to the start of the circulation of the gauge blocks.

2.3.6   Each laboratory will receive the artefacts in turn, according to the pre-agreed timetable. In some cases there is a one month gap in the schedule because of unavailability of participants or other scheduling reasons. A final set of measurements will be made at the end of the comparison by the pilot laboratory.

2.3.7   Each laboratory has one month for calibration and transportation. With its confirmation to participate, each laboratory has confirmed that it is capable to perform the measurements in the time allocated to it. It guarantees that the standards arrive in the country of the next participant at the beginning of the next month.

2.3.8   If for some reason, the measurement facility is not ready or customs clearance takes too much time in a country, the laboratory has to contact the pilot laboratory immediately and – according to the arrangement made - eventually to send the

standards directly to the next participant before finishing the measurements or even without doing any measurements. If possible the laboratory will be sent the gauge blocks at the end of the comparison.

2.4 Handling of artefacts

2.4.1   The gauge blocks should be examined immediately upon receipt. The condition of the gauge blocks should be noted and communicated to the pilot laboratory. Please use the fax form in appendix A.5.

2.4.2   The gauge blocks should only be handled by authorized persons and stored in such a way as to prevent damage.

2.4.3   No re-lapping or re-finishing of the gauge blocks should be attempted. If a gauge block becomes un-measurable it will be removed from the remainder of the comparison. Laboratories should attempt to measure all gauge blocks unless doing so would damage their equipment.

2.4.4   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.

2.4.5   Please inform the pilot laboratory and the next laboratory via fax or e-mail when the gauge blocks are about to be sent to the next recipient.

2.4.6   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.

2.5 Transport of artefacts

2.5.1   It is of utmost importance that the artefacts be transported in a manner in which they will not be lost, damaged or handled by un-authorised persons.

2.5.2   Packaging for the artefacts has been made which will be suitably robust to protect the artefacts from being deformed or damaged during transit.

2.5.3   Artefacts should be carried by hand between participating laboratories, either by personal road transport, sea, or in an aircraft cabin. They should not be sent via courier or delivery company. They should be marked as 'Fragile'. It is suggested that each laboratory contacts the airline or carrier concerned to make suitable arrangements.

2.5.4   The artefacts should be accompanied by a suitable customs carnet (where appropriate) or documentation identifying the items uniquely. The packaging is lockable e.g. by clasp, but is easy to open with minimum delay to allow customs inspections to take place.

2.5.5   Transportation is each laboratory's responsibility and cost. Each participating laboratory covers the costs for its own measurements, transportation and any customs charges as well as for any damages that may have occurred within its country. The overall costs for the organisation, initial and interim measurements and

the processing of results are covered by the organising pilot. The pilot laboratory has no insurance for any loss or damage of the standards during transportation.

3. Description of the standards

3.1 Artefacts

3.1.1   The measurement artefacts are steel gauge blocks of rectangular cross-section as specified in ISO 3650 (1998).

3.1.2   A selection of lengths covering the range 175 mm to 900 mm has been chosen. Four gauge blocks have been selected: 1 x 175 mm, 2 x 500 mm and 1 x 900 mm. The rationale behind this selection is as follows. The 175 mm gauge block was chosen as it is considerably longer than the 100 mm gauge blocks circulated under the CCL Key Comparison on gauge block measurements by interferometry, but is still reasonably short. The 900 mm gauge block was chosen as it is close to the maximum length for a gauge block conforming to the specification standard (no suitable 1000 mm gauge block was available). The 500 mm gauge blocks were selected as they are too long to be measured in certain types of commercial Gauge Block Interferometer, thus requiring the laboratories to use different instruments. The size of 500 mm is the maximum size measured by many laboratories.

3.1.3   Thermal expansion coefficient of the artefacts

The linear coefficient of thermal expansion at 20 °C of the gauge blocks has been measured by the pilot laboratory and PTB. The values stated below and are the weighted means of the pilot laboratory and PTB results and should be used by the participants to correct the length measurements to the standard temperature of 20 °C. The uncertainties are given at k = 2 (95%).

Serial number	Nominal length (mm)	α (x 10^{-6} K^{-1})	uncertainty (x 10^{-6} K^{-1})
6071	175	10.968	0.016
6071	500	10.851	0.012
3701	500	10.624	0.012
3701	900	10.824	0.011

4. Measurement instructions

4.1 Traceability

4.1.1   Length measurements should be independently traceable to the latest realisation of the metre as set out in the current "*Mise en Pratique*".

4.1.2   Temperature measurements should be made using the International Temperature Scale of 1990 (ITS-90).

4.2 Measurand

4.2.1   The measurand is the central length of each gauge block at 20 °C, as defined in ISO 3650 (1998). If measurements are made by conventional gauge block interferometry then the measurements should be made with each face wrung in turn. Alternatively, two measurements should be made with the gauge blocks turned end-for-end between the measurements. The two results should be communicated to the pilot laboratory.

4.2.2   The individual thermal expansion coefficients of the gauge blocks have been determined before the start of the comparison. Laboratories must use these measured expansion coefficients when measuring the gauge blocks. Laboratories should report the temperatures at which the length measurements were made. Laboratories should only measure the gauge blocks within the temperature range of 19.9 °C - 20.1 °C.

4.2.3   If measurements are made by techniques other than those detailed in ISO 3650 (1998), then the results must be corrected to the standard conditions and definition of central length as stated in ISO 3650 (1998).

4.3 Measurement instructions

4.3.0   A goal of this CCL key comparison is to demonstrate the equivalence of routine calibration services for long gauge blocks offered by NMIs to clients, as listed by them in Appendix C of the Mutual Recognition Agreement (MRA) [BIPM, 1999]. To this end, participants in this comparison agree to use the same apparatus and methods as routinely applied to client artefacts. Participants are free to tune and operate their systems to best-measurement performance, and to take extra measurements needed to produce a best-measurement result, provided that these extra efforts would also be available to a client if requested.

4.3.1   Before calibration, the gauge blocks must be inspected for damage to the measurement surfaces and side faces. Any scratches, rusty spots or other damages have to be documented by a drawing using the appropriate form in appendix A.2.

4.3.2   The measurement result to be reported is the deviation of central length from nominal length, $\Delta L = L - L_{nom}$. The results of the measurements on both sides (ΔL_{left} and ΔL_{right}) obtained, in the case of interferometry, by wringing each measurement face in turn upon the reference flat and the average of the two wringings have to be reported using the table in appendix A.1. Here, "left" refers to the measurement obtained when the surface to the left of the marking on the side face of the gauge blocks is wrung to the platen. For non wrung measurements, laboratories should

interpret the terms "left" and "right" accordingly, and report the exact measurement conditions.

4.3.3   The measurement results have to be appropriately corrected to the reference temperature of 20 °C using the values of the thermal expansion coefficient provided by the pilot laboratory in section 3.1.3 of this document.

4.3.4   Length measurements have to be corrected to the state where the gauge block is lying in a horizontal plane, free from constraint.

4.3.5   If the gauge blocks are measured in the horizontal position and an auxiliary body is wrung to one measuring face, the mass of the auxiliary body must be compensated for. The results of a measurement of length by interferometry should be corrected for possible departures from standard conditions of measurement, for example:

- effects of temperature, barometric pressure and humidity upon wavelengths in air;
- effects of temperature on gauge block length (thermal expansion);
- effects of barometric pressure on gauge block length (compressibility);
- effects of optical phase shift on gauge block length.

4.3.6   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.

5. Measurement uncertainty

5.1   The uncertainty of measurement shall be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement*. In order to achieve optimum comparability, a mathematical model[4] containing the principal influence parameters for gauge block calibration by interferometry is given below. The participating laboratories are encouraged to follow this model as closely as possible, and adapt it to their instruments and procedures.

5.2   The length of a gauge block measured by interferometry and fringe fraction determination is described by

$$l = \frac{1}{q}\sum_{i=1}^{q}\left(\kappa_i + F_i\right)\frac{\lambda_i}{2n} + \Delta t_g \cdot \alpha \cdot L + \delta l_{\Omega} + \Delta l_s + \delta l_A + \delta l_G + \delta l_W + \Delta l_{\Phi} \qquad (1)$$

where:

l length of the gauge block at the reference temperature of 20 °C;

L nominal length of the gauge block;

q number of wavelengths used for the determination of the length based on the method of exact fractions ($i = 1, .., q$);

κ_i integer part of number of half wavelengths within gauge block length (fringe order);

F_i fractional part of fringe order;

λ_i vacuum wavelengths of the different light sources used;

n index of refraction of the air;

Δt_g = (20 - t_g) is the departure (in °C) of the gauge block temperature t_g from the reference temperature of 20 °C during the measurement ;

α linear coefficient of thermal expansion of the gauge block;

δl_{Ω} obliquity correction for the shift in phase resulting from the angular alignment errors of the collimating assembly, with zero expectation value $\left\langle \delta l_{\Omega} \right\rangle = 0$;

Δl_s aperture correction accounting for the shift in phase resulting from the finite aperture diameter s of the light source:

$$\Delta l_s = \frac{s^2}{16f^2}L \qquad (2)$$

   f is the focal length of the collimating lens;

δl_A correction for wave front errors as a result of imperfect interferometer optics, with zero expectation value $\left\langle \delta l_A \right\rangle = 0$;

δl_G correction accounting for flatness deviation and variation in length of the gauge block, with zero expectation value $\left\langle \delta l_G \right\rangle = 0$;

δl_w length attributed to the wringing film, with zero expectation value $\left\langle \delta l_W \right\rangle = 0$, since the length of the gauge block is defined to include the wringing film;

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[4] J.E. Decker, J.R. Pekelsky, Uncertainty evaluation for the measurement of gauge blocks by optical interferometry, *Metrologia* **34** 479-493 (1997)

Δl_Φ phase change accounting for the difference in the apparent optical length to the mechanical length.

5.3   With the length l of the gauge block expressed as a function of input quantities x_i

$$l = f(x_i) \tag{3}$$

the combined standard uncertainty $u_c(l)$ is the quadratic sum of the standard uncertainties of the input quantities $u(x_i)$ each weighted by a sensitivity coefficient c_i

$$u_c^2(l) = \sum_i c_i^2 u^2(x_i), \text{with } c_i = \frac{\partial l}{\partial x_i}. \tag{4}$$

5.4   In some cases, higher order terms of Eq.(4) might have to be taken into account as well.

5.5   The participants are required to report their measurement uncertainty budget in the table of appendix A.4. Some indicated standard uncertainties, in particular $u(n)$, $u(\delta l_\Omega)$ or $u(\Delta l_\Phi)$, might be based on a separate calculation, which can be added to the report. v_i is the number of degrees of freedom of $u(x_i)$, v_{eff} is the effective number of degrees of freedom of $u_c(l)$.

6. Reporting of results

6.1   Transmission of results

6.1.1   As soon as possible after measurements have been made, the results should be communicated to the pilot laboratory and at the latest within six weeks.

6.1.2   The measurement report forms in appendix A.1 of this document will be sent by e-mail (Word95 (V7.0) 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 co-ordinator. **In any case, the signed report must also be sent in paper form by mail.** In case of any differences, the paper forms are considered to be the definitive version.

6.1.3   Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare a first draft report on the comparison. This will be circulated to the participants for comments, additions and corrections. The procedure outlined in the BIPM '*Guidelines for CIPM key comparisons*' will be followed.

6.2   Calculation of the reference value

The method of calculating the key comparison reference value has yet to be decided.

Paragraph 9 of Appendix F of the document, '*Mutual Recognition of National Measurement Standards and of Measurement Certificates Issued by National Metrology Institutes*' states that the pilot laboratory will produce an appendix to Draft B of the report of the comparison which will contain '*proposals for a reference value and degrees of equivalence*'.

[At present, there is much discussion and assessment of the various possible approaches including, for example, the use of mean, weighted mean or median values. The small group (see §1.3, p2 of this document) headed by the pilot laboratory has therefore decided to defer making any recommendation at this stage. Participants will be kept fully informed as the discussion develops.]

A.1 Measurement results

S/N	nominal length L (mm)	central length deviation (**deviation** from nominal length)			uncertainty (1σ) u_c (µm)	eff. deg. of freedom ν_{eff}
		ΔL left (µm)	ΔL right (µm)	ΔL_{mean} (µm)		
6071	175					
6071	500					
3701	500					
3701	900					
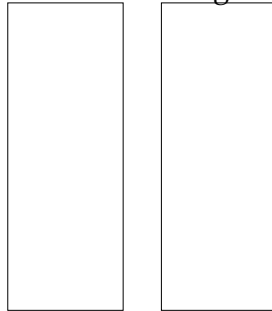
Laboratory: ....

Date:.. Signature:...

A.2 Inspection of the measurement surfaces
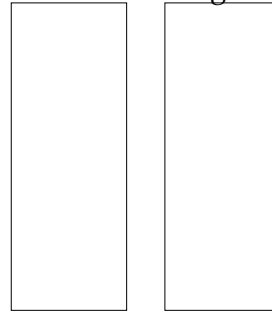
175 mm
S/N 6071
left   right
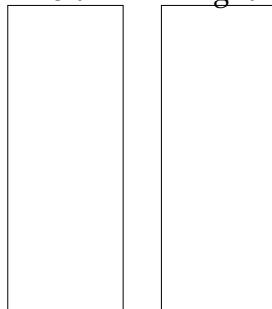
900 mm
S/N 3701
left   right
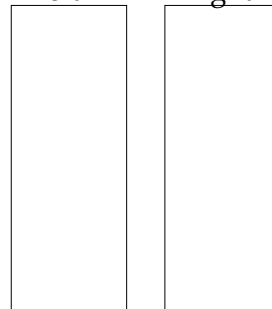
500 mm
S/N 6071
left   right

500 mm
S/N 3701
left   right

Additional notes:

Laboratory: ....

Date:... Signature:...

A.3 Description of the measurement instrument

Make and type of instrument..

....

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

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Description of measuring technique: ....

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

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....

Laboratory: ....

Date:.. Signature:...

A.4 Uncertainty of measurement

x_i	$u(x_i)$	ν_i	$c_i = \partial l / \partial x_i$	$u_i(l)$ / nm

Combined standard uncertainty: $u_c(l) =$

Laboratory: ....

Date:.. Signature:..

A.5 Receipt confirmation

FAX

To: **Dr Andrew Lewis**
National Physical Laboratory
Queens Road
Teddington
Midlesex
United Kingdom
TW11 0LW
Fax: +44 20 8943 2945
e-mail: andrew.lewis@npl.co.uk

From: (participating laboratory)

We confirm having received the standards of the *BIPM key comparison on long gauge block measurement* on ....(date).

After visual inspection

o   no damage has been noticed;

o   the following damage must be reported:

....
....
....
....

Laboratory: ....

Date:.. Signature:..