CCL Key Comparison

The Calibration of Internal and External Diameter Standards

Instructions and technical protocols

Contents

October 10, 2000

1. Introduction

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

At its meeting in September 1997, the Consultative Committee for the Definition of the Metre, CCDM, (today called the Consultative Committee for Length, CCL) identified key comparisons in the field of dimensional metrology and decided upon the general content and the proposed pilot laboratory and time-frames of each key comparison. In particular, it was decided that a key comparison on diameter standards shall be performed with the National Institute of Standards and Technology (NIST), as the pilot laboratory. Subsequent meetings of the CCL broadened the scope of this first key comparison to include internal diameter standards and external diameter standards. The CCL recommended the other measurement operations that may fall inside this general field, such as roundness, spherical diameter, spherical and cylindrical form be included in future activity.

The results of this international comparison will contribute and be included in the agreement for establishing the metrological equivalence. The interregional CCL key comparison will be combined, where necessary, with regional comparisons following the same protocol. Laboratories participating in both, the interregional and the regional comparisons establish the link between the comparisons and assure their equivalence.

The procedures outlined in this document follow the guidelines established by the BIPM[1] and are intended to allow for a clear and unequivocal comparison of the measurement results and to complete the comparison in the time frame provided. These general procedures are based on experiences from preceding CCDM and CCL comparisons carried out in other fields from 1993 to 1998[2, 3]. Due to the large number of laboratories participating, the time schedule is tight. Therefore particular attention must be made to the availability of the laboratory carrying out the calibrations, and to transportation and customs problems.

[1] T.J. Quinn, Guidelines for key comparisons carried out by Consultative Committees, BIPM, Paris
[2] B.G. Vaucher and R. Thalmann, CCDM Gauge Block Intercomparison , April 1993, OFMET, Wabern
[3] R. Thalmann, J. Decker, N. Brown, CCL Key Comparison: calibration of Gauge Blocks by Interferometry, April 1998, OFMET, Wabern

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

2. Organization

2.1 Participants

2.1.1 The preliminary list of participants was drafted by the pilot laboratory and was approved at the CCL meeting of 18 July 98.

2.1.2 The general requirement for the participating laboratories is the ability to measure, by any primary means, provided it is a measurement service to clients, the diameter of external diameter standards within the range 2 mm to 100 mm and the diameter of internal diameter standards within the range 5 mm to 100 mm. The uncertainty requirements for the diameter measurements is set at approximately 200 nm at k=1.

2.2 Participants details

Contact Person	**National Metrology Institute** **Address**	**Tel: / Fax:** **Email:**
A. Korolev	VNIIM 19, perspective de Moskovsky 198005 St. Petersburg, Russia	Tel. +7-812-251-8638 Fax +7-812-113-0114 e-mail: akorspb@mail.ru
Kostadin Doytchinov	NRC Montreal Rd. M-36 Ottawa K1A 0R6, Canada	Tel. +1-613-991-0265 Fax +1-613-952-1394 e-mail: kostadin.doytchinov@nrc.ca
Miguel Viliesid	CENAM A.P. 1-100, Centro Queretaro, Qro. 76900, Mexico	Tel. +(52-42) 11-05-74 Fax +(52-42) 11-05-77 e-mail: mviliesid@cenam.mx
Chu-Shik Kang	KRISS 1 Toryong-dong Yusong, Taejon 305-340 Korea	Tel. +82-42-868-5103 Fax +82-42-868-5012 e-mail: cskang@kriss.re.kr
Shen Shaoxi	NIM No. 18 Bei San Huan Dong Lu Beijing 100013, China	Tel. +86-1-64218627 Fax +86-1-64218703 e-mail: shenshaoxi@ihw.com.cn
John Miles	CSIRO Bradfield Road West Lindfield NSW 2070, Australia	Tel. +612-9413-7157 Fax +612-9413-7200 e-mail: john.miles@mst.csiro.au
Oelof Kruger	CSIR	Tel. + 27-12-841-3005

	Meiring Naude Road Brummeria, Pretoria 0001, Republic of South Africa	Fax + 27-12-841-4458 e-mail: oakruger@csir.co.za
Frank Luedicke	PTB Bundesallee 100 D-38114 Braunschweig, Germany	Tel. +49-531-592-5310 Fax +49-531-592-9292 e-mail: frank.luedicke@ptb.de
Rudolf Thalmann	OFMET Lindenweg 50 CH-3003 Bern – Wabern, Switzerland	Tel. +41-31-323-3385 Fax +41-31-323-3210 e-mail: rudolf.thalmann@eam.admin.ch
David Flack	NPL Centre for Length Metrology NPL, Queens Road, Teddington, Middlesex TW11 0LW	Tel. +44-208-943-6347 Fax +44-208-943-2945 e-mail: david.flack@npl.co.uk
Attilio Sacconi	IMGC Strada delle Cacce, 73, 10135- Torino, Italy	Tel. +39-11-3977-466 Fax +39-11-3977-7459 e-mail: A.Sacconi@imgc.to.cnr.it

Coordinator:

John Stoup	NIST Building 220, Rm B113 Gaithersburg, MD 20899 USA	Tel. +1-301-975-3476 Fax +1-301-975-8291 e-mail: john.stoup@nist.gov

2.3 Comparison form and details

2.3.1 The comparison will be carried out in mixed form, circulation and star type. The artifacts will be circulated within a region and then returned to the pilot laboratory for re-measurement before circulation in the next region.

2.3.2 NIST will act as the pilot laboratory. All results are to be communicated to the pilot laboratory as soon as possible. Six weeks from the completion of the measurements by a laboratory is a reasonable timeframe.

2.3.3 The material stability of the diameter artifacts will be assessed and characterized by measurement at the pilot laboratory prior to the start of the circulation. Only those gages exhibiting stability of better than 1 ppm/year will be used in the circulation.

2.3.4 Each laboratory has one month to complete the measurements and provide transportation to the next laboratory on the schedule. If for any reason, the measurement facility can not meet these requirements, the laboratory must contact the pilot laboratory immediately and, according on the arrangement made, send the artifacts directly to the next participant before finishing the measurements. If possible the laboratory will be sent the artifacts at the end of the comparison.

2.3.5 Timetable

Region	Laboratory	Country	Arrival Date
EUROMET	OFMET	Switzerland	Nov 1, 2000
	NPL	U.K.	Jan 1, 2001
	PTB	Germany	Feb 1, 2001
	IMGC	Italy	Mar 7, 2001
Pilot Lab	NIST	USA	Apr 7, 2001
SIM	NRC	Canada	Jun 1, 2001
	CENAM	Mexico	Jul 1, 2001
Pilot Lab	NIST	USA	Aug 1, 2001
APMP	NIM	China	Sept 1, 2001
	KRISS	Korea	Oct 1, 2001
	CSIRO	Australia	Nov 1, 2001
Pilot Lab	NIST	USA	Dec 1, 2001
SADCMET	CSIR	South Africa	Jan 1,2002
COOMET	VNIIM	Russia	Feb 1, 2002
Pilot Lab	NIST	USA	Mar 7, 2002

2.4 Handling and Transportation

2.4.1 The artifacts must be unpacked and handled by authorized persons to avoid damage.

2.4.2 The artifacts should be examined immediately upon receipt for rust or damage to the gaging surfaces. Give particular attention to the area around the gaging points. Examine these areas with the eyeloop provided in the packaging. The condition of
each artifact must be recorded on the form provided and mailed or faxed to the pilot laboratory. Please use the form in appendix B.

2.4.3 No refinishing of the artifacts should be attempted. If an artifact is deemed unmeasurable due to wear or damage, contact the pilot laboratory immediately. Laboratories should attempt to measure all artifacts unless the nominal sizes are not within the range for their standard measurement service.

2.4.4 After the measurements, the artifacts must be cleaned, greased if necessary, and carefully re-packaged in the original container. Ensure that the content of the package is complete and that the packing material will sufficiently isolate and protect the artifacts during shipping.

2.4.5 Transportation is at each laboratory's responsibility and cost. A pro-forma invoice showing a small value will be used. Each participating laboratory must cover the costs for its own measurements, as well as for any customs charges incurred during shipping. The pilot laboratory does not have insurance for any loss or damage of the artifacts during transportation.

3. Description of the artifacts

3.1 The package contains 4 ring gages made of steel and 5 cylinders made of steel. The thermal expansion coefficient of the diameter artifacts has been supplied by the manufacturer and is assumed to be $11.5 \pm 0.5\ 10^{-6}\ K^{-1}$. The artifacts are identified in the following tables.

Ring gages:

Identification	Nominal diameter (mm)	Expansion coeff. (10^{-6} K^{-1})	Manufacturer
R1	5.17	11.5 ± 0.5 (k=1)	Glastonbury Gage
R2	11.95	11.5 ± 0.5 (k=1)	Glastonbury Gage
R3	49.3	11.5 ± 0.5 (k=1)	Glastonbury Gage
NIST-7	100	11.5 ± 0.5 (k=1)	Glastonbury Gage

Cylinders:

Identification	Nominal diameter (mm)	Expansion coeff. (10^{-6} K^{-1})	Manufacturer
D1	2.0	11.5 ± 1.0	Glastonbury Gage
D2	3.465	11.5 ± 1.0	Glastonbury Gage
D3	24.0	11.5 ± 1.0	Glastonbury Gage
42198	50.0	11.5 ± 1.0	SIP
D5	98.5	11.5 ± 1.0	Glastonbury Gage

3.2 A description and photograph of the artifacts are included in Appendix E.

4. Measurement instructions

4.1 Diameter standards.

4.1.1 Before measurement, the artifacts have to be inspected for damage of the measurement surfaces, particularly at the gaging points. Any damage must be recorded using the appropriate forms in appendix B.

4.1.2 The measurement item of interest is the diametrical distance between the nominal gauge points, defined as mid-elevation along the gauge cylinder and in the diameter direction specified by the engraved marks on the gauge.

4.1.3 The measurement results must be appropriately corrected to the reference temperature of 20° C using the thermal expansion coefficients given in this document. Additional corrections have to be applied according to the equipment and procedures used by each laboratory.

4.1.4 If any artifacts are found to have a magnetic condition, the magnetism must be removed per individual laboratory practices before the diameter measurements are performed. Note this condition in the comments on the form in appendix B.

4.1.5 A laboratory may submit measurements from more than one measurement system as long as the timetable is adhered to and that each measurement system is available to general clients for measurement services.

5. Measurement uncertainty

The uncertainty of the measurements should be calculated according to the ISO Guide for the Expression of Uncertainty in Measurement. Because for this key comparison the measurement equipment and procedures of the participating laboratories may be widely variable, the measurement uncertainty will be discussed in a more general case. The form in appendix D should be used for presenting the uncertainty information for each of the following cases.

5.1 Ring Gages and External Diameter Standards.

5.1.1 The measured diameter of an artifact can be expressed as follows:

$$l = L_i - L(\alpha_a \Delta t_a - \alpha_m \Delta t_m) + \delta_m + E + \delta_p + \delta_{am} + \delta_{aa}$$

where:

l length of the artifact at the reference temperature of 20°C;
L_i diameter indication of the measuring instrument;
L nominal diameter of the artifact;
α_a linear coefficient of thermal expansion of the artifact;
α_m linear coefficient of thermal expansion of the measuring instrument scale;
Δt_a = (t_a - 20°C) departure of the artifact temperature t_a from the reference temperature of 20°C during the measurement;
Δt_m = (t_m - 20°C) departure of the measuring instrument scale temperature t_m from the reference temperature of 20°C during the measurement;
δ_m correction for the determination of the linear accuracy of the scale (ie. index of refraction and wavelength corrections for laser scales, interpolation and positional accuracy of holographic scales, etc.);
E correction for the combination of artifact and probe contact deformation to an undeformed condition for the artifact;
δ_p correction for the determination of the probe ball diameter where required;
δ_{am} correction accounting for scale alignment errors;
δ_{aa} correction accounting for alignment errors of the artifact;

This is only an example. Other terms may be added or omitted depending on the individual laboratory's measuring instrument, techniques, and procedures.

5.3 The participants are required to report the individual measurement uncertainty budgets for each of the measurements covered in this intercomparison using the form in the table of appendix D.

6. Reporting of results

6.1 As soon as possible after measurement have been made, the results should be sent to the pilot laboratory.

6.2 The measurement report form for the diameter measurements is in appendix A. If possible, the electronic version of this form should be completed and sent to the coordinator. The signed report must also be sent in paper via mail and must include a completed instrument and technique description form in appendix C. If external and internal diameter measurements are performed on different instruments, a form for each process should be completed. In case of differences, the paper forms are considered to be the definitive version.

6.3 Within 2 weeks following the receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyze the results and prepare first draft reports on each comparison. These will be circulated to the participants for comments and corrections. The procedure outlined in the BIPM Guidelines will be followed.

6.4 Due to the current discussions about what constitutes a reference value and the methods used for the calculations, the method for the calculation of the reference values for these key comparisons will be fixed after the completion of the measurements.

APPENDIX A

Ring Gage Measurement Results

Ring gage serial no.	Nominal size	Deviation from the nominal size midway between ends, corrected to 20 ° C 0°	Standard uncertainty (1σ)	Effective degrees of freedom ν_{eff}	Actual measurement temperature
	(mm)	(μm)	(μm)		° C

External Diameter Measurement Results

Plug gage serial no.	Nominal size	Deviation from the nominal size midway between ends, corrected to 20 ° C 0°	Standard uncertainty (1σ)	Effective degrees of freedom, ν_{eff}	Actual measurement temperature
	(mm)	(μm)	(μm)		° C

APPENDIX B

Damage Inspection

(Please note polar and z-axis locations of damage with drawings if necessary)

Inspection of the artifacts – Ring gages:

Inspection of the artifacts – External diameter standards:

APPENDIX C

Measurement Process Description

Internal or external diameter?

Description and type of the measurement instrument:
(Please add schematic drawings or descriptive papers if necessary)

Source of traceability and path:

Description of the measuring method and technique:
(Include the magnitudes of the applied forces and probe diameter size)

APPENDIX D

Uncertainty of the Measurement

Components of uncertainty for: External Diameter
(circle Ext. or Int)

Internal Diameter

x_i	$u(x_i)$	v_i	$c_i = \delta l / \delta x_i$	$u_i(l)$ / nm

Combined standard uncertainty: $u_c(l)$ =

APPENDIX E

Description of artifacts

Rings

100 mm:	gaging area / gage height	- 39 mm
	overall diameter	- 162 mm
	exterior surface description	- flanged design with knurled sides
49.3 mm:	gaging area / gage height	- 39 mm
	overall diameter	- 100 mm
	exterior surface description	- flanged design with knurled sides
11.95 mm:	gaging area / gage height	- 19 mm
	overall diameter	- 35 mm
	exterior surface description	- knurled sides
5.17 mm:	gaging area / gage height	- 9 mm
	overall diameter	- 23 mm
	exterior surface description	- knurled sides

External Diameter Standards

98.5 mm:	gaging area / gage height	: 53 mm
	center hole	: 23 mm thru hole
	center flange	
50.0 mm:	gaging area / gage height	: 25 mm
	handle	: 75 mm long
24.0 mm:	gage length	: 50 mm
	solid cylinder	
3.465 mm:	gage length	: 50 mm
	solid cylinder	
2.0 mm:	gage length	: 50 mm
	solid cylinder	