CCL Key Comparison CCL-K4.2015

Calibration of Diameter Standards

Technical protocol

(Final)

National Institute of Standards and Technology

Gaithersburg, Maryland

USA

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Contents

1 Document control

Version Draft A.1 Issued on 26 August 2015.
Version Draft A.2 Issued on 18 September 2015.
Version FINAL Issued on 30 September 2015.

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 organ9zed by the Consultative Committees of the CIPM or by the regional metrology organizations in collaboration with the Consultative Committees.

At its meeting in November 2013 , the Working Group on the MRA of the Consultative Committee for Length, CCL, decided upon a key comparison of diameter standards with NIST as the pilot laboratory. The artefact circulation is planned to start in 2015.

The procedures outlined in this document cover the technical procedure to be followed during the measurements. 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). To this end, participants in this comparison agree to use the same apparatus and methods as routinely applied to client artefacts.

By their declared intention to participate in this key comparison, laboratories accept the general instructions and agree 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 Participants

Participants are listed in Table 1.

Table 1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
NIST (pilot)	John Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Bldg 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 john.stoup@nist.gov
METAS	Rudolf Thalmann Federal Institute of Metrology METAS Sector Length, Optics and Time Lindenweg 50, 3003 Bern-Wabern, Switzerland	Tel. +41 58 387 03 85 Fax +41 58 387 02 10 rudolf.thalmann@metas.ch
INRIM	Gian Bartolo Picotto Istituto Nazionale di Ricerca Metrologica Strada delle Cacce 73 10135 Torino, Italy	Tel. +39 011 3919969 Fax +39 011 3919959 g.picotto@inrim.it

CEM	Emilio Prieto Centro Espanol de Metrologia (CEM) Alfar, 2-28760 Tres Cantos Madrid, Spain	Tel. +34 91 8074716 Fax +34 91 8074807 eprieto@cem.minetur.es
CENAM	Guillermo Navarrete Herrera / Miguel Viliesid Alonso CENAM-Centro Nacional de Metrología Km 4.5 carretera a Los Cués, 76246 El Marqués, Qro. Mexico	++ 52 442 211 05 00 – 04 gnavarre@cenam.mx mviliesi@cenam.mx
INMETRO	Wellington Santos Barros Inmetro - National Institute of Metrology, Quality and Technology Dimensional Metrology Laboratory Av. N. S. das Graças, 50 - Xerém Duque de Caxias – Rio de Janeiro – Brazil 25250-020	wsbarros@inmetro.gov.br
VNIIM	Natalia Kononova / Andrew Moskalev D.I. Mendeleyev Institute For Metrology (VNIIM), 190005, Russian Federation, St. Petersburg, Moskovsky pr. 19. Russia	+7 812 323 96 69 N.A.Kononova@vniim.ru +7 812 323 96 69 A.A.Moskalev@vniim.ru
CMS/ITRI	Jui-Hsi CHIN CMS/ITRI Industrial Technology Research Institute Rm. 213, Bldg. 8, No. 321, Sec. 2, Kuang Fu Rd., Hsinchu, 30011, Taiwan	Tel. +886 3 5732219 Fax +886 3 5726445 JuiHsiCHIN@itri.org.tw
NIM	Huang Yang / Kang Yanhui National Institute of Metrology, P.R. China (NIM) No.18, Bei San Huan Dong Lu, Chaoyang Dist, Beijing, P.R.China 100029	huangy@nim.ac.cn kangyh@nim.ac.cn
NIMT	Anusorn Tonmueanwai National Institute of Metrology Thailand (NIMT) 3/ 4-5 Moo 3, Klong 5, Klong Luang Pathumthani 12120 Thailand	Tel. + 6625775100 Fax + 6625775088 anusorn@nimt.or.th
MMISA	Oelof Kruger National Metrology Institute of South Africa (NMISA) Meiring Naude Road Pretoria 0001 South Africa	Tel. + 27 12 841 3005 Fax. + 27 12 841 4458 oakruger@nmisa.org

3.2 Schedule

The timetable shown in table 2 is being presented as a first draft option to the participating laboratories. The standard gauges will be measured by the pilot laboratory at the beginning of the circulation, then after completion of each regional circulation. This intercomparison will require an ambitious combination of gauge types, measurement methods, and instrumentation. **The roundness and straightness measurements are valuable and are requested so as to make maximum use of laboratory time, effort in circulation, and the data analysis.** Therefore each laboratory has six weeks to complete the full complement of measurements. The six week period also includes customs clearance and transportation to the following participant. With its confirmation to participate, each laboratory is obliged to perform the measurements in the allocated period and to allow enough time in advance for transportation so that the following participant receives them in time. If a laboratory has technical problems to perform the measurements or customs clearance takes too long, the laboratory has to contact the pilot laboratory as soon as possible and, according to whatever it decides, it might eventually be obliged to send the standards directly to the next participant before completing the measurements or even without doing any measurements.

Table 2. Preliminary schedule of the comparison.

RMO	Laboratory	Starting date of measurement
	NIST	24 August 2015 (Pilot)
EURAMET	METAS	9 October 2015
	INRIM	20 November 2015
	CEM	15 January 2016
	NIST	26 February 2016
APMP	CMS/ITRI	25 March 2016
	NIM	6 May 2016
	NIMT	1 July 2016
SIM	NIST	12 August 2016
	INMETRO	9 September 2016
	CENAM	21 October 2016
COOMET	VNIIM	2 December 2016
AFRIMETS	MMISA	13 January 2017
	NIST	24 February 2017

3.3 Reception, transportation, insurance, costs

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 from pilot to the next laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during the circulation.

Figure 1. Artefacts

Figure 2. Transport Case.

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

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

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! Every time the carnet is used, it is stamped TWICE – on exit from one country and on entry into the next. In this regard, the EU member states are considered as being one. country. 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**

4 The Standard Gauges

4.1 Description of gauges

Type	Identification Markings	Dimensions (mm)	Material
RING #1	VTG	5.25 diameter 10 total height	Tungsten Carbide
RING #2	L97	25.32 diameter 29 total height	Tungsten Carbide
RING #3	81218-1	25.4 diameter 29 total height	Steel
RING #4	368750-2-1	90 diameter 38.5 total height	Steel
CYLINDER #1	--	5.0 diameter 10 total height	Tungsten Carbide
CYLINDER #2	1C24	23.81 diameter 53 total height	Steel
PLUG #3	1P50	50 diameter 48 total height	Steel
SPHERE #1	--	7.94 diameter	Steel
SPHERE #2	--	20 diameter	Steel
SPHERE #3	Etched Locations	25.4 diameter	Tungsten Carbide

Ring gauge inscriptions:

The ring gauges are all marked on their top upper surface with their identification and lines indicating the diameter 'D' measurement direction. **The 25.32mm tungsten carbide ring and the 90mm steel ring have an additional line etched to indicate the position of the straightness trace location. These lines are marked with a 'G' (geometry) designation. This line also represents the location of the starting point or the zero degree position for the roundness trace measurements. Additional photos will be included to clarify the markings.**

Plug gauge inscriptions:

The two smallest cylinders will have the measurement direction and serial numbers marked on the ends. The 50mm plug gauge will have a line marked on the top surface with two etched 'D' designations indicating the diameter measurement direction**. An additional line marked 'G' (geometry) is the designated location of the straightness trace and the starting point or the zero degree position for the required roundness trace measurements**. A long handle will also be provided and can be used for ease of fixturing or positioning if required. **Additional photos will be included to clarify the markings.**

Sphere inscriptions:

The spheres do not have etched identification numbers. The 25.4mm diameter tungsten carbide sphere is etched with a wide circle and a single protruding line. **The center of the circle represents the point location of the marked two-point diameter measurement**. The line represents the starting point or zero degree position of the roundness trace to be measured at the equatorial plane of the sphere when the etched circle is facing upwards. The roundness trace will be orthogonal to the diameter location and **will not** trace through the diameter measurement points.

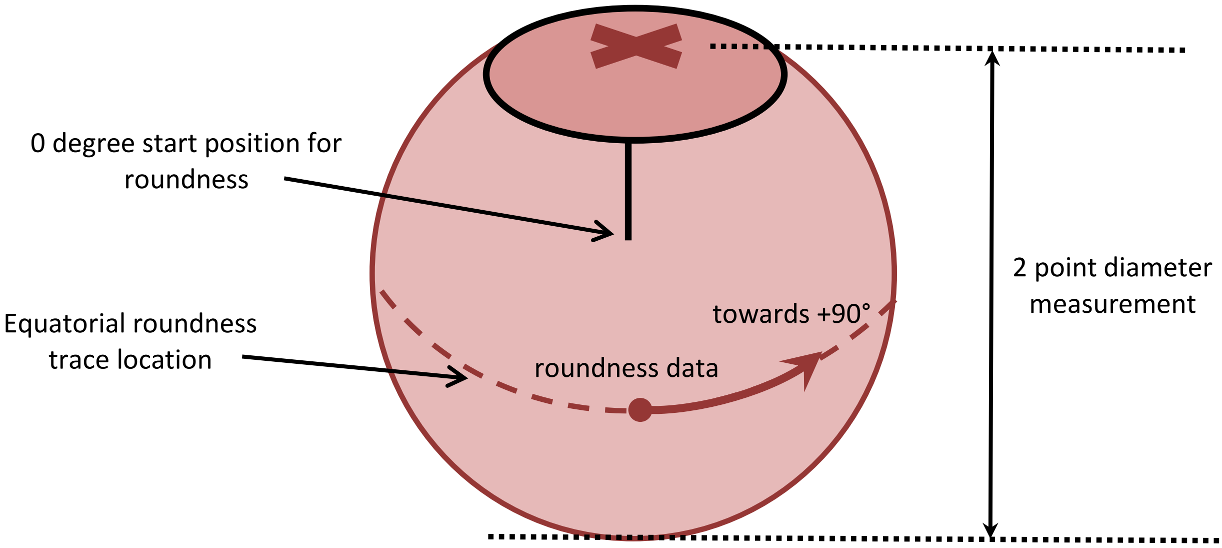

Figure 3. The 25.4mm tungsten carbide sphere etched markings and measurements.

The coefficients of thermal expansion given in the following table are obtained from the manufacturers and should be used for corrections to 20.0 degrees C.

Identification	Nominal diameter (mm)	Expansion coefficient $/10^{-6}\ K^{-1}$	Manufacturer
Ring #1 SN: VTG	5.25	4.6 ± 0.5	Vermont Gage
Ring #2 SN: L97	25.32	4.6 ± 0.5	Glastonbury Gage
Ring #3 SN: 81218-1	25.4	11.5 ± 0.5	Hemco
Ring #4 SN: 368750-2-1	90.0	11.5 ± 0.5	Edmunds
Cylinder #1	5.0	4.6 ± 0.5	R.L. Schmitt
Cylinder #2 SN: 1C24	23.81	11.5 ± 0.5	Glastonbury Gage
Plug #3 SN: 1P50	50.0	11.5 ± 0.5	Edmunds
Sphere #1	7.94	11.5 ± 0.5	Bal-tec
Sphere #2	20.0	11.5 ± 0.5	Bal-tec
Sphere #3	25.4	4.6 ± 0.5	Bal-tec

Table 3. List of gauge manufacturer details.

5 Measuring instructions

5.1 Handling the artefacts

The gauges should only be handled by authorized persons and stored in such a way as to prevent damage. Before making the measurements, the gauges 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 gauges before measurement should be registered in the form provided in appendix B. Laboratories should attempt to measure all gauges and all required features unless doing so would damage their equipment. No participant shall try to re-finish the gauges. 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 gauges should not be used for any purpose other than described in this document. The gauges may not be given to any party other than the participants in the comparison.

The gauges 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 gauges must be cleaned and greased, and put into a rust preventing paper for transportation. Ensure that the content of the package is complete before shipment. Always use the original packaging. Please inform the pilot laboratory and the next laboratory via fax or e-mail when the gauges are about to be sent to the next recipient.

5.2 Fixturing the artefacts

The ring, plug, and sphere standards shall be fixtured by each laboratory's own usual methods which are to be described on the measurement process description form in Appendix C.

For the purposes of roundness and straightness, the artifacts should be fixture as necessary to achieve the measurements required.

5.3 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).

5.4 Measurands

This intercomparison consists of an ambitious effort to quantify several measurands for many of the artefacts.

The diameter measurand is the diameter of each gauge at 20°C and corrected to zero force. The diameter of the ring and plug gauges should be measured at the marked lines midway between the ends. **The diameter of the 25.4mm tungsten carbide sphere should be measured at the marked position shown in figure 3**. The two smaller spheres should be measured for **average diameter using a minimum of ten randomly selected diameters**. Please note that for the cylindrical artefacts the lines defining the diameter measurement direction do not always cross precisely the centre of the cylinder/ring. The measurement direction shall therefore always be parallel to this line, but not necessarily coincident.

"x mm↑" and "x mm↓" refer to the required roundness measurement locations x mm above and below the mid height of the rings and plugs. The upper side of the rings and plugs are defined by the inscriptions. The roundness trace positions are chose specifically to **not intersect** with the diameter measurement locations. The roundness trace location for the 25.4mm sphere is also shown in figure 3 and is orthogonal to the diameter measurement. The roundness data should be collected using a **least squares fit (LSC-protocol)**. Roundness data should be reported using the part configuration in the enclosed figures.

The surface straightness measurement is to be collected on the 50mm plug gauge, the 25.32mm tungsten carbide ring and the 90.0mm ring. These lines are designated by the 'G' designation on the top surface of the artefacts. The straightness measurement location will intersect with the roundness traces, but **will not** intersect with the diameter measurement locations.

Whenever possible, the participants are invited to report the roundness and straightness deviations at the given cut-off frequencies (in UPR) of the long-pass filter, in order to achieve a better comparability of the results. If available, a **Gaussian-50%** filter should be used, but in any case the participants are asked to specify which type of filter is used.

By assuming that many participants use a roundness measuring system with 2000 sample points or less and spherical tips not smaller than 1 mm diameter, the preferred conditions are given below:

Artefact	**Serial Number**	**Recommended Roundness filter**	**Recommended Probe Diameter (mm)**	**Roundness Positions** **(referenced to midway of the gauging surface)**
25.32 mm TC RING	L97	50 UPR	3.0	+ 10 mm - 10 mm
90.0 mm Steel RING	368750-2-1	50 UPR	3.0	+ 10 mm -10 mm
50.0 mm Steel PLUG	1P50	50 UPR	3.0	+ 20 mm -20 mm
25.4 mm TC SPHERE	—	50 UPR	3.0	Equator (using the etched line as 0 degree radial reference)

Table 4. The measurement details for the roundness measurements

Artefact	**Serial Number**	**Recommended Straightness filter cut-off values**	**Recommended Probe Diameter (mm)**	**Straightness Positions**
25.32 mm TC RING	L97	0.8 mm	3.0	" G " line Central 20 mm of the gauge
90.0 mm Steel RING	368750-2-1	2.5 mm	3.0	" G " line Central 20 mm of the gauge
50.0 mm Steel PLUG	1P50	2.5 mm	3.0	" G " line Central 40 mm of the gauge

Table 5. The measurement details for the straightness measurements

For the 25.4 mm sphere, the participants are required to report the deviation from roundness at 50 UPR. Additional reporting at 300 UPR and 150 UPR can also be submitted if desired. These measurements should be performed using the roundness measuring service for which the CMC claims are to be tested.

5.5 Measurement uncertainty

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

All measurement uncertainties shall be stated as standard uncertainties, and the individual components of uncertainty itemized on separate sheets (Appendix E1) for each artefact or artefact type for submission. The corresponding effective degree of freedom for each component 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 a functional form is preferred. This is typically either $u = Q[a, b \cdot l] = \sqrt{a^2 + (b \cdot l)^2}$ or $u = a + b \cdot l$ where a and b are constants and *l* is the measured dimension (See Appendix E2 for further discussion).

Additionally, in the report of the measurement technique (Appendix C) the participant should list any relevant CMC claims for the service(s) related to the comparison.

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. W**ithin six weeks** at the latest.

The diameter measurement results (appropriately corrected to the reference temperature of 20 °C and the measuring force of zero) have to be reported using the table in Appendix D1.

The roundness and straightness measurement results will be characterized using the form in Appendix D4. Please indicate the filtering or cut-off value used for each roundness and straightness result. Unless unable to do so, please report the roundness and straightness results using a least squares (LS) fit analysis.

The measurement report forms in appendix D of this document will be sent by e-mail (Word document) to all participating laboratories. 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.

Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare within 2 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 Diameter KCRV

The key comparison reference value (KCRV) for the diameter measurements is calculated on a gauge-per-gauge basis as the weighted mean of the participant results, excluding results that are inconsistent with the claimed uncertainty. 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 artefact 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.

The key comparison reference value (KCRV) for the roundness and straightness measurements is calculated on a gauge by gauge basis as the weighted means of the participant results.

7.2 Artefact diameter instability

Steel gauges 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 gauges 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). Several of the gauges have twin examples from the same manufacturer and production time that are also being monitored by the pilot laboratory as an additional measure of material instability. These data will support conclusions determined for the circulated artefacts as necessary.

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 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. The data from the supplemental twin gauges being measured in controlled conditions by the pilot laboratory support the drift decisions for the circulated artefacts.
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. 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 diameters. The data from the supplemental twin gauges being measured in controlled conditions by the pilot laboratory support the drift decisions for the circulated artefacts.
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. The data from the supplemental twin gauges being measured in controlled conditions by the pilot laboratory **do not** support the drift evidence for the circulated artefacts.

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 (from table 3). A correlation will become relevant only when the gauges 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.

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 any other key comparison within CCL for the same measurement quantity.

Appendix A – Reception of Standards

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

We confirm having received the diameter standards for the CCL-K4 comparison on the date given above.

After a visual inspection:

☐ There is no apparent damage. Their precise state will be reported in the forms provided in Appendix B 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. Please use additional sheets if it is necessary to describe the damages.

Appendix B – Conditions of Measuring Surfaces

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

After detailed inspection of the measuring surfaces of the gauges, we report these findings. Please describe in words, diagrams, and photographs the nature and location of significant surface imperfections (scratches, indentations, corrosion, etc.). Please use additional sheets if necessary to describe the damages.

Appendix C1 – Description of the INTERNAL DIAMETER measurement process

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

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

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Traceability path: ....

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Description of measuring technique (including filter and cut off values, reversal, fixturing, etc.) ....

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Range of gauge 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) ....

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(use additional pages as needed)

Appendix C2 – Description of the EXTERNAL DIAMETER measurement process

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

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

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Traceability path: ....

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Description of measuring technique (including filter and cut off values, reversal, fixturing, etc.) ....

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Range of gauge 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) ....

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(use additional pages as needed)

Appendix C3 – Description of the SPHERE DIAMETER measurement process

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

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

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Traceability path: ....

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Description of measuring technique (including filter and cut off values, reversal, fixturing, etc.) ....

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Range of gauge 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) ....

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(use additional pages as needed)

Appendix C4 – Description of the ROUNDNESS/STRAIGHTNESS process

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

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

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Traceability path: ....

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Description of measuring technique (including filter and cut off values, reversal, fixturing, etc.) ....

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Range of gauge 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) ....

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(use additional pages as needed)

Appendix D1 – Results Report Form

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

Internal Diameter Ring Measurements

∅ 5.25 mm ring gauge, Tungsten Carbide, identification number: VTG

Location	Meas. diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Probe config.& size (mm) Meas. force used (mN)
Midway 0 deg.				

∅ 25.32 mm ring gauge, Tungsten Carbide, identification number: L97

Location	Meas. diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Probe config.& size (mm) Meas. force used (mN)
Midway 0 deg.				

□ 25.40 mm (1.0 inch) ring gauge, Steel, identification number: 81218-1

Location	Meas. diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Probe config.& size (mm) Meas. force used (mN)
Midway 0 deg.				

∅ 90.00 mm ring gauge, Steel, identification number: 368750-2-1

Location	Meas. diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Probe config.& size (mm) Meas. force used (mN)
Midway 0 deg.				

Appendix D2 – Results Report Form

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

External Diameter Cylinder/Plug Measurements

∅ 5.00 mm cylinder, Tungsten Carbide, identification number: none

Location	Meas. diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Probe config.& size (mm) Meas. force used (mN)
Midway 0 deg.				

∅ 23.81 mm cylinder, Steel, identification number: 1C24

Location	Meas. diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Probe config.& size (mm) Meas. force used (mN)
Midway 0 deg.				

∅ 50.00 mm plug gauge, Steel, identification number: 1P50

Location	Meas. diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Probe config.& size (mm) Meas. force used (mN)
Midway 0 deg.				

Appendix D3 – Results Report Form

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

Sphere Diameter Measurements

∅ 7.94 mm sphere, Steel, identification number: none

Location	Average diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Contact Geometry & Meas. Force Used (mN)
Average minimum of 10 random diameters				
# of meas		Range of results		

∅ 20.00 mm sphere, Steel, identification number: none

Location	Average diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Contact Geometry & Meas. Force Used (mN)
Average minimum of 10 random diameters				
# of meas		Range of results		

∅ 25.40 mm sphere, Tungsten Carbide, identification number: none

Location	Meas. diameter (mm)	std. uncert. k=1 (µm)	mat. temp. (°C)	Contact Geometry & Meas. Force Used (mN)
Single MARKED				
# of meas		Range of results		

Appendix D4 – Results Report Form

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

Roundness and straightness measurements

(strongly recommended to complete)

Ring and Plug Gauge roundness measurement locations listed below are referenced to the gauge midway position.

Gauge	Out-of-Roundness (µm)	u_{round} k=1 (µm)	Peak to Valley Straightness	u_{str} k=1 (µm)
∅ 25.32 mm tungsten carbide ring gauge	+10 mm↑ -10 mm↓		Line "G" Central 20 mm	
∅ 90 mm ring gauge	+10 mm↑ -10 mm↓		Line "G" Central 20 mm	
∅ 50 mm plug gauge	+20 mm↑ -20 mm↓		Line "G" Central 40 mm	
∅ 25.4 mm Tungsten Carbide Sphere	equator			

Please email to the pilot laboratory the roundness and straightness raw or filtered data sets as a text or data file. Please include all collected points, whether the data is raw or filtered, and list the number of points for each measurement.

Appendix E1 – Uncertainty Component Reporting Form

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

Uncertainty Components (use a separate form for each artifact measurand as required)

Gauge Size & ID or Gauge type:

Measurement (identify one): Diameter Roundness Straightness

Uncertainty Component Description x_i	Standard Uncertainty $u(x_i)$	Sensitivity Coefficient $\|c_i\| \equiv \partial l / \partial x_i$	Combined Standard Uncertainty $u_i \equiv \|c_i\|\ u(x_i)$
COMBINED STANDARD UNCERTAINTY (k = 1)			

Appendix E2 – Functional Uncertainty Report Form

To:	John R. Stoup National Institute of Standards and Technology 100 Bureau Drive Room A109, Building 220 Gaithersburg, MD 20899-0001 USA	Tel. +1 301 975 3471 Fax +1 301 975 8291 e-mail: John.Stoup@nist.gov
From:	Date: NMI:	Name: Signature:

Functional form of standard uncertainty for diameter measurements

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

(Note: the formula can serve as an approximate estimate, but the actual uncertainty of a measurement may deviate from this value for a variety of reasons, such as the quality of the artifact. The uncertainties associated with each measurement should be evaluated on a case-by-case basis.)

	a / nm	b / 1	Comment
Internal Diameter - Rings			
External Diameter – Plug/Cylinders			
Spheres – averaged diameter			
Sphere – marked diameter			

Notes: