EUROMET.L-K4.2005

(EUROMET Project 812)

Calibration of diameter standards

Group 1

Final Report - Version B-Final

ISTITUTO NAZIONALE DI RICERCA METROLOGICA

G.B. Picotto, December 2009

Contents

1. *Introduction*

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

At its meeting in October 2003, the TC group for Length identified several EUROMET key comparisons in the field of dimensional metrology. In particular, it decided that a key comparison on diameter standards is to be carried out. This comparison follows the previous EUROMET 384 (EUROMET.L-K4) comparison.

Due to the large number of the participants, it has been decided to have 2 groups in the project. The participants for the 2 groups were separated according to the claimed uncertainties. Those whose uncertainties are less that or equal to 0.3 micrometer (for 50 mm gauge) belong to the group 1, the others to the group 2.
INRIM (formerly IMGC), Italy, acts as the pilot laboratory for the group 1; MKEH (formerly OMH), Hungary, acts as the pilot for the group 2.

A goal of the EURAMET 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.

Eleven laboratories from EURAMET and two laboratories from other RMO's participated in the group 1 of this EURAMET comparison. Laboratories participating in both the interregional and the regional comparisons establish the link between the comparisons and assure their equivalence. The comparison followed the guidelines established by the BIPM [1]. The measurement results given in this report are summarized using the layout principles of the documents for previous comparisons [2-4]. The allowance to use parts of this prior work wherever possible is gratefully acknowledged.

The report summarizes the results submitted by the participants in the Group 1 of the EUROMET.L-K4.2005 (EUROMET Project 812) comparison on internal and external diameter standards. This report is circulated as the first version of the draft B report.

2. *Organisation*

2.1 *Participants in the group 1*

Laboratory	Address	Contact person / e-mail
INMETRO	Instituto Nacional de Metrologia (INMETRO) Brazil	João Antônio Pires Alves jaalves@inmetro.gov.br
INPL (Euromet corresponding NMI)	The National Physical Laboratory of Israel Israel	Ilya Kuselman ilya.kuselman@moital.gov.il
INRIM (formerly IMGC)	Istituto Nazionale di Ricerca Metrologica Italy	Gian Bartolo Picotto g.picotto@inrim.it
LNE	Laboratoire National de Metrologie et d'Essais France	Georges Vailleau georges.vailleau@lne.fr
METAS	Swiss Federal Office of Metrology and Accreditation Switzerland	Rudolf Thalmann rudolf.thalmann@metas.ch
MIKES	Centre for Metrology and Accreditation (MIKES) Finland	Antti Lassila antti.lassila@mikes.fi
MKEH (formerly OMH)	Hungarian Trade Licensing Office Hungary	Edit Banreti banretie@mkeh.hu
NMISA (formerly CSIR-NML)	NMISA Mechanical Metrology South Africa	Oelof Kruger oakruger@nmisa.org
NPL	National Physical Laboratory United Kingdom	David Flack david.flack@npl.co.uk
PTB	Physikalisch-Technische Bundesanstallt Germany	Otto Jusko Otto.Jusko@ptb.de
SMD	Ministere des Affaires Economiques Belgium	Hugo Piree Hugo.Piree@economie.fgov.be
SP	Swedish National testing and Research Institute, Sweden	Mikael Frennberg mikael.frennberg@sp.se
VSL (formerly NMI-VSL)	Dutch Metrology Institute The Netherlands	Gerard Kotte gkotte@vsl.nl

2.2 *Circulation*

Laboratory	Country	Date
INRIM	Italy	June 2005
METAS	Switzerland	July 2005
-	-	August 2005
MKEH (OMH)	Hungary	September 2005
SMD	Belgium	October 2005
SP	Sweden	November 2005
PTB	Germany	December 2005
NMI-VSL	Netherlands	January 2006
NPL	United Kingdom	February 2006
MIKES	Finland	March 2006
LNE	France	April 2006
INPL	Israel	May 2006
INRIM	Italy	June- mid July 2006
NMISA (CSIR-NML)	South Africa	July - August 2006

INPL	Israel	Sept – Oct 2006
INMETRO	Brazil	Nov- Dec 2006
INRIM	Italy	January 2007
INRIM	Italy	Nov - Dec 2007

Some delay occurred in the circulation, partly at custom operations.
Measurements reports have been submitted by all the NMIs. Unfortunately, INPL (Israel) has withdrawn.

3. *Diameter standards*

The standard gauges to be calibrated by the participants in the Group 1 were chosen to be two rings with a diameter of about 40 mm and 3,5 mm, two plugs with a diameter of about 50 mm and 4 mm, and a sphere with a diameter of about 30 mm. An additional plug of nominal 7,5 mm diameter has been added for optional measurements.

Type	**Manufacturer identification**	**Dimensions (mm)**	**Material**
Ring	MG 04-437	Ø 3,5 height 10	Steel
Ring	MG IMGC 92/3	Ø 40 height 24	Steel
Plug	Microtool 2534	Ø 4 height 9 total height 45	Steel
Plug	Microtool 2535	Ø 50 height 25 total height 102	Steel
Ball	SWIP D4769	Ø 30	Ceramic (Al_2O_3)
Plug for optional measurements			
Plug	MG 04-253	Ø 7,5 height 10 total height 74	Steel

Inscriptions:
Ring gauges: the two ring gauges are all marked on their upper surface with their identification and two lines indicating the measurement direction.

Plug gauges: the two plug gauges (and the optional plug) are all marked on their handle with their identification and two lines indicating the measurement direction. The upper side shall be opposite to the handle.

Ball: the identification number and two lines indicating the measurement direction are marked on the ball support. The measurement direction is also given by three paint marks at the top of the ball.

Figure 1 Photographs of the diameter gauges.

4. *Measurement Instructions*

A goal of this EUROMET key comparison is to demonstrate the equivalence of routine calibration services for diameter standards 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.

Traceability

Length measurements traceable to the latest realisation of the metre as set out in the current "*Mise en Pratique*". Temperature measurements made using the International Temperature Scale of 1990 (ITS-90).

Measurand

The measurand is the diameter of each gauge at 20 °C and corrected to zero force. The diameter of the ring and plug gauges is measured at the marked lines in 3 different heights according to the table below given in the technical protocol. The diameter of the sphere is measured at the marked lines.

Note that the lines defining the measurement direction does unfortunately not always cross precisely the centre of the cylinder/sphere. The measurement direction is therefore always be parallel to this line, but not necessarily coincident.

„*x* mm↑“ and „*x* mm↓“ refer to the required measurement locations *x* mm above and below the mid height of the cylinder. The upper side of the rings is defined by the inscription; for the plugs the handle or the holding cylinder are assumed to be below.

Cylindrical gauges - Group 1

Gauge	Manufacturer identification	Diameter and roundness measurement locations
Ring Ø 3,5 mm	MG 04-437	2 mm↑ Middle 2 mm↓
Ring Ø 40 mm	MG IMGC 92/3	6 mm↑ Middle 6 mm↓
Plug Ø 4 mm	Microtool 2534	2 mm↑ Middle 2 mm↓
Plug Ø 50 mm	Microtool 2535	6 mm↑ Middle 6 mm↓
Plug for optional measurements		
Plug Ø 7,5 mm	MG 04-253	2 mm↑ Middle 2 mm↓

The roundness of the ring and plug gauges is measured at the same heights as the diameter measurements and one roundness measurement for the sphere on the equator. Also the straightness of the ring and plug gauges is measured in the marked lines (0 and 180 °).

The calibration should be carried out as for a normal customer. It means that there is no information about the form error of the artefacts. The measurements have to be reported for zero measuring force and at the reference temperature 20 °C, using a thermal expansion coefficient of $11{,}6 \cdot 10^{-6}$ K^{-1} for the cylindrical standard and of $8{,}1 \cdot 10^{-6}$ K^{-1} for the ceramic ball, which are both assumed values because they have not been measured.

The roundness and straightness measurements are required only if they are done normally for the customers as well.

Whenever possible, the participants are invited to report the deviation from roundness at 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 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 filters are given in the following table:

Ring/plug	Filter
3,5 mm ring 4 mm plug 5 mm plug/ring	15 UPR
7,5 mm plug	50 UPR
40 mm ring 50 mm plug	150 UPR

For the 30 mm sphere, the participants are invited to report the deviation from roundness at 500 UPR, 150 UPR and 50 UPR (Undulations per revolution).
In addition, the participants are invited to report the deviation from roundness of the sphere (at 500, 150 and 50 UPR) as obtained when the best measurement capability for roundness standards is applied.

Uncertainty
Estimated according to the ISO ‘Guide to the Expression of Uncertainty in Measurement’.

5. *Apparatus and measurement methods*

A short description of the measurement apparatus and probing systems used by the participants is given below. Probing conditions are given as well. Descriptions are taken and/or summarized from the partner's reports.

INRIM : Modified M3 Moore Measuring Machine, equipped with a laser interferometer and a LVDT probe with tip sphere diameters from 2 mm to 3 mm. The probe tip sphere is calibrated using a 10 mm gauge block. The probing force is 3 mN.
Roundness measurements were made with a rotating table instrument (RTH TR30, modified at IMGC), equipped with an indexing table (AA gauge Ultradex). The probe tip of the LVDT transducer used in roundness measurements were a Teflon sphere (3 mm dia.) and a steel sphere (1 mm dia.). The LVDT probe was calibrated with a precision displacement actuator, interferometrically calibrated in steps of λ/4.

METAS
Diameter of cylindrical gauges: Length-based measuring machine designed by SIP and METAS. Internal and external measurements performed through displacement measurements using a plane mirror interferometer, satisfying the Abbe principle. Spherical probe calibrated using gauge blocks. Applied measurement force extrapolated to zero.
Diameter of sphere: SIP 3002 length measurement machine (Abbe comparator) with laser interferometer and flat probes.
Roundness of cylindrical gauges: Form measurement instrument TR300 (Rank Taylor Hobson).
Roundness of sphere: Roundness instrument TR73 (Rank Taylor Hobson). Error separation with multistep procedure (10 steps).

MKEH (formerly OMH): Calibrations were performed using a length-measuring machine SIP 550M with comparison method. The standards used were ∅12 mm and ∅40 mm reference rings for internal measurements, and ∅5 mm and ∅50 mm reference plugs for external measurements The reference rings and plugs were calibrated at METAS. Corrections were applied for elastic compression due to measurement force, material and geometry of gauges. Probes with spherical, hooked and flat tips were used for internal and external diameter measurements. The probing force is 1 N.

SMD: Mahr 828 CiM – 1000 mm universal measuring machine with Tinsley 25 Ohm temperature measuring system (6 sensors). The rings, plugs and ball are calibrated by comparison with reference rings and plugs, which were calibrated at METAS. Both the reference and the calibrated object are mounted horizontally on the Mahr 828 CiM with 1 temperature sensors on each ring. Probes with sphere diameter of 3 mm and flat tips were used for internal and external diameter measurements. The probing force is 1 N.
Taylor Hobson TR300 for roundness, straightness and parallelism measurements.

SP: 1D measuring machine (SIP 305) using a laser interferometer as length scale. For the small ring, a cary test indicator with a small ball (2 mm, probing force 0,15 N) was used. For the 40 mm ring hooked feelers with small spherical tips (force 1,5 N) were used. The plugs and sphere were measured with flat feelers with 5 mm diameter (probing force 1,5-2 N). Gauge blocks were used as standards. For internal measurements shafts were wrung to the faces of the gauge blocks.

PTB: All diameter measurements except the 3,5 mm ring were made with a custom-built "KOMF" (Comparator for Length and Form). This is a comparator with two feeler systems and two laser-interferometers. It is set-up in a clean-room facility. Probing system with a 5 mm tip sphere and contact force of 1 mN.
The 3,5 mm ring diameter was measured with a Mahr MFU8 (PTB-special version). This form measuring machine is equipped with a single laser interferometer in the radial axis. Tip probe sphere of 1 mm and contact force of 10 mN.

Roundness measurements were performed with a RTH Talyrond 73.
Straightness measurements were performed with a Mahr MFU8.

NMI-VSL: The measurements on the diameter standards were made using a CMM (Zeiss UC550) equipped with a 1D Interferometer (double-pass flat mirror configuration). The artefacts are aligned to the machine coordinates. On each position the diameter is measured 5 times from which the average and standard deviation is calculated. Probing system with a 3 mm tip sphere and contact force of 200 mN. The probing constant is determined on a calibrated 10 mm gauge block.
The ball diameter is measured by probing 5 points on each opposite side of the ball. The ball diameter is the result of a ball fit through the 10 measurement points.

NPL :
External Diameter – NPL Modified Zeiss Metroscope. Probing system with flat tips (dia. 2 mm) operating under a contact force of 2.5 N.
Internal Diameter – NPL designed Internal Diameter measuring machine. Probing system with tip spheres of 2 mm and 5 mm and contact force of 60 mN.
Roundness (Plugs and Rings) - Taylor Hobson Talycenta.
Roundness (Sphere) - Taylor Hobson Talyrond 73.

MIKES : Diameter calibrations were made with SIP-550M 1D measuring machine with a laser interferometer as length scale. Plugs were calibrated between 7 mm spherical Rubin styluses with contact force of 1 N. The sphere was calibrated with flat ends and 1 N contact force. For all outer diameter calibrations gauge block with equal nominal length was used as reference. Applied correction of the elastic deformation to zero force.
The rings were calibrated with same set-up but using MAHR millitron sensor with tip probe sphere of 3 mm and contact force of ~0.2 mN. The probe diameter was calibrated against gauge blocks. No force correction were applied.
Roundness was measured by Taylor Hobson Talyrond 73 using hatchet stylus. Measurements were done using multi-step error separation.
Straightness was measured by Taylor Hobson Form Talysurf . The reported straightness are Pt-values (peak to peak) from lowpass (Gauss 0.8 mm) filtered profiles.
The 3.5 mm ring was too small for the instruments used for roundness and straightness.

LNE : Measurements are made on a SIP 214 machine, the x-table displacements are controlled by a laser interferometer in the ABBE plan. The contact probe is a CARY sensor equipped with ruby balls of 5 mm for the plug 50 mm, the ring 40 mm and the sphere, of 3 mm for the 4 and 7,5 mm plugs, and of 1,5 mm for the 3,5 mm ring. The probing force is of 4 mN. All measurement results are given at 20 °C and zero force.
For the plug and sphere the sensor is calibrated on a 15 mm gauge block and for the ring on a gauge bridge of 15 mm, both are measured on the TESA-NPL interferometer.

INMETRO :
Diameter - the gauges were calibrated in a system composed by a coordinate measuring machine and a laser interferometer. Gauge-blocks were used to determine the probing error. The measurements were performed in several days, using different probes with tip spheres from 1,5 mm up to 5 mm, and a probing force of 100 mN.
Five cycles of measurements per calibration were performed.
Form (roundness MZC) - the gauges were calibrated in a Talyrond 73 in HPR mode, using a 1-150 UPR, 2CR filter. At least ten cycles of measurements per calibration were performed. The roundness of the ∅ 3,5 mm ring was not measured due to equipment constraints. The plugs ∅ 50 and ∅ 7,5 mm in the position below the middle, were not measured due to scratches in these positions.

NMISA (formerly CSIR-NML) : For the 3,5 mm ring gauge a Federal comparator was used with direct comparison to gauges blocks. For the 4 mm and 7,5 mm plug gauges, a Wedge comparator was used with comparison to gauge blocks.

For the 30 mm sphere, 40 mm ring gauge and 50 mm plug gauge diameters, a Lab master universal measuring machine was used. The labmaster uses a laser interferometer to measure the difference between the standard gauge block and the unit under test. Probing systems with tip spheres of 1,5 mm and 3 mm or flat tips. Contact forces from 140 mN up to 3,3 N. Two sets of results are submitted for the diameter measurements of the 40 mm ring gauge as CSIR NML has two CMC entries using two different methods.
A Talyrond 252 roundness measuring machine was used for all roundness and straightness measurements, except a Talyrond 73 was used for the high accuracy measurements of the sphere. Two sets of results are submitted for the roundness measurements of the sphere as CSIR NML has two CMC entries (hemisphere and external cylinder).
CSIR NML is not accredited for ring gauges under 5 mm, and for straightness calibrations but agreed to participate.

6. *Stability of circulating gauges*

The pilot laboratory measured the artefacts at the beginning of the comparison, at the middle and at the end of the circulation. The artefacts were remeasured also in late 2007. No significant drifts of the artefacts were observed from these measurements. The overall results (variations of the measured diameters) are shown in the Figure 2.

Some scratches and minor damages not interfering with the diameter measuring sections were reported during the circulation. No significant damages were visually observed at the measuring sections of the gauges.
The contact areas of the plugs have been observed also with an optical microscope. The wear effects are more visible on one side (left) of the two plugs of 50 mm and 4 mm, probably more often used for centering.

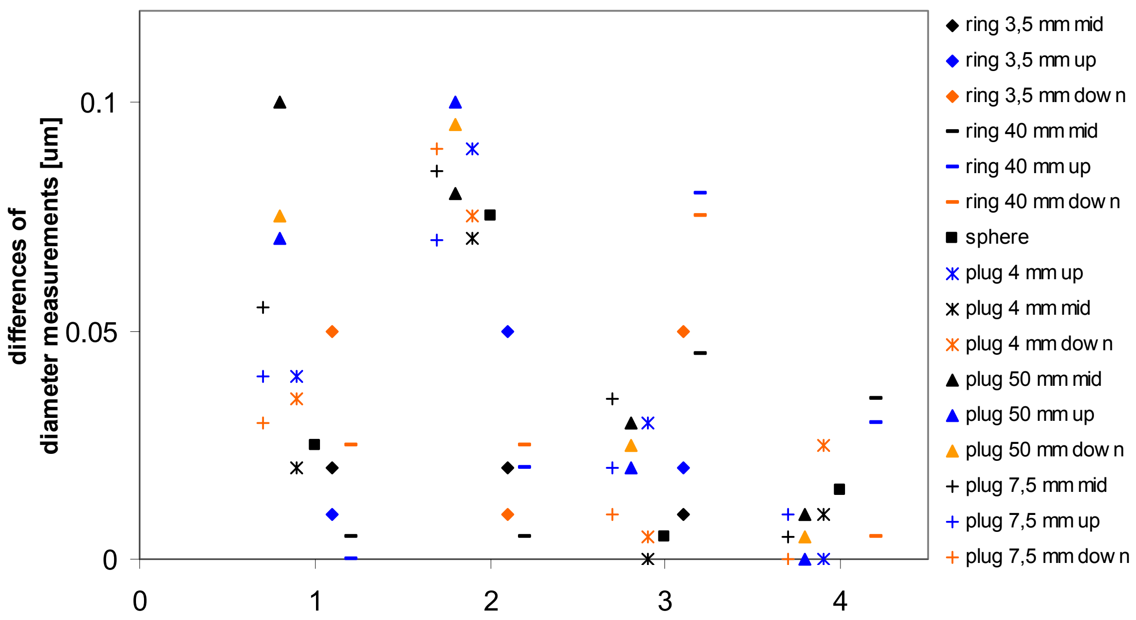


Figure 2 Differences of the diameters as measured by the pilot at the beginning, at the middle and at the end of the circulation (June 05, June 06, Jan 07, Dec 07).

7. *Preliminary analysis of results*

After an initial overview of the data, a calculation of reference values, uncertainties, *En* values, and Birge ratios has been made. The weighted mean has been chosen for the analysis.
There are some results with apparent anomaly, that is the *En* value (coverage factor *k*=2) calculated from the weighted mean is larger than one (>1.00). Then, the weighted mean is recomputed after zero weighting the result with the largest *En* values, then *En* values are recomputed and the process iterated until all remaining *En* values are less than 1.

Participants whose results have *En* values larger than 1 have been asked to check their results (as required under CIPM guidance rules on key comparisons). MKEH (OMH), INMETRO, NMI-VSL, NPL, PTB, SMD and SP were asked to check some of their results.

7.1 Revised measurement reports

Revised measurement reports have been submitted by SP and NMI-VSL. SP has revised the uncertainty of the sphere diameter measurement whereas NMI-VSL has revised uncertainties for external diameter measurements. Corrected values have been used for the calculation of W-mean and *En* values given in this report.
The other contacted participants did checks but no other apparent errors were found.

Just after seeing Draft A, SMD communicated a correction of their result for the ring 40 mm diameter, section down, due to a mistake in taking the data from the logbook (data from the section up were use instead of those from the section down). The corrected value is now used in the calculations of the weighted mean and *En* ; the former value is also given in the table.

The measurement reports are collected in the Appendix B.

7.2 Follow-up measurements

After the Draft A was circulated, the pilot was asked from 3 partners to have back some of the circulated standards to be measured using other apparatus or for internal checking of their measuring systems. The pilot informed the other participants.

- METAS has measured the ring 3,5 mm and the plug 4 mm diameter by using a microCMM, measurement period May 2008;
- NPL has re-measured the diameter at the middle section of the three plugs of 50mm, 7.5mm and 4 mm, measurement period August 2008 ;
- SMD has re-measured the small ring 3,5mm diameter by using a new probe, measurement period August 2008.

The follow-up measurement reports received from the partners are collected in the Appendix C.
METAS: the new results for the diameter of the ring 3,5 mm and of the plug 4 mm fully confirm their first ones, obtained on a completely different machine with somewhat larger uncertainty.
NPL: the new results for the diameter (middle section) of the plugs 4mm and 7.5mm differ from the previous ones and are now quite close to the reference values. It is believed that the original error in the measurement of plug 7,5mm (04-253) was due to the centres not being aligned properly. The difference in plug 4mm (2534) is more difficult to explain. The latest value is closer to the reference value but there is no obvious reason why. A possibility is that the anvil parallelism was not properly checked for the original measurements, however, there is no way of confirming this hypothesis.
The new result for the 50 mm plug gauge is close to the previous one. There seems to be a consistent offset between NPL's measurements and the reference value both in 2006 and 2008.

SMD: the new results for the diameter of the ring 3,5mm are quite close to the reference values. It is not fully understood what caused the problem. Perhaps a problem with the setup so that the conical shaft of the probe touched the ring instead of the ball at the end of the probe.

8. *Results*

The results submitted by the participants are collected in the following tables. Each table show the reported diameter (and roundness) at a given section of the ring/plug or at the equator of the sphere. Straightness values of cylindrical gauges are also given.

The graphs show the diameter results with their expanded (*k*=*2*) uncertainties. Together with the *W-mean* and *En* values (coverage factor *k*=2) are given the uncertainties $u_{int}(x_w)$, $u_{ext}(x_w)$, the normalising factor *C* and Birge ratio *Rb*.
It is worth noting that *En* values for a coverage factor *k=1* have been reported in the previous drafts (draftA and draftB issue1.1).

For a dataset of submitted results (diameter, roundness) corresponding to a measuring section of the diameter gauges, the weighted Mean, W-mean $\overline{X}w$, of the *n* submitted values Xi is :

$$\overline{X}w = \sum_{i=1}^{n} Wi \cdot Xi$$

where the weight *Wi* of each value is given by:

$$Wi = C \cdot \frac{1}{[u(Xi)]^2}$$

with the nomalising factor *C*:

$$C = \frac{1}{\sum_{i=1}^{n} (\frac{1}{u(Xi)})^2}$$

The uncertainty of the W-mean is given by the internal (submitted uncertainties) and external (spread of results) standard deviation:

$$u_{\text{int}}(\overline{X}w) = \sqrt{\frac{1}{\sum_{i=1}^{n} (\frac{1}{u(Xi)})^2}}$$

$$u_{ext}(\overline{X}w) = \sqrt{\frac{1}{(I-1)} \frac{\sum_{i=1}^{n} w_i (Xi - \overline{X}w)^2}{\sum_{i=1}^{n} Wi}}$$

The consistency of each result with the W-mean and their corresponding uncertainties is calculated by *En* :

$$En = \frac{Xi - Xw}{\sqrt{[u(Xi)]^2 - [u_{\text{int}}(\overline{X}w)]^2}}$$

When the result Xi is excluded from (not correlated with) the W-mean the *En* is calculated by:

$$En = \frac{Xi - Xw}{\sqrt{[u(Xi)]^2 + [u_{\text{int}}(\overline{X}w)]^2}}$$

En values less than one (<1.00) are expected for a coverage factor *k*=2.
With our datasets has never occurred that a value with *En* >1 has got a value *En* <1 when excluded and recalculated from the recomputed W-mean.

The consistency of a dataset is checked by using the so-called Birge ratio *Rb*, which is the ratio of external and internal standard deviations and compares the spread of the results with the spread of the reported uncertainties.

$$R_B = \frac{u_{ext}(\overline{X}w)}{u_{\text{int}}(\overline{X}w)}$$

For a coverage factor of k = 2, the ratio is expected to be

$$R_B < \sqrt{1 + \sqrt{8/(n-1)}}$$

With 12, 10 or 8 laboratories data are consistent provided that *Rb* < 1.36, 1.39, 1.43, respectively.

Reference is made to formulas and derivations as given in the EUROMET.L-K2 final report - Calibration of long gauge blocks [4], and/or the CCL-K4 final report - Calibration of internal and external diameter standards [3].

8.1 *Result tables*

In the tables there are results with *En* values (coverage factor *k*=2) calculated from the weighted mean, larger than one (>1.00). When the Birge ratio of the full dataset is not consistent the weighted mean is recomputed after zero weighting the result with the largest *En* value, then *En* values are recomputed and the process iterated until the Birge ratio value is consistent.
In the process iteration, we always excluded the result corresponding to the largest *En*. This method has been also used when two *En* values (>1) are nearly equal [4].

The data not included (zero weight) in the recomputed weighted mean are those written in *italic* in the column *En** of the tables of results.

Considering the full dataset of results (diameter) the (*)W-mean and *En** values have been obtained after zero weighting 26 submitted results, i.e., the SMD results corresponding to the three sections of the ring 3,5mm diameter; the PTB result corresponding to the section down of the ring 40mm; the NPL and NMI-VSL (all sections) and INMETRO (middle and up sections) results with the plug 4mm; the SMD, NMI-VSL and NPL results (all sections) and MKEH (middle section) for the plug 50mm; the SMD

result with the sphere; the NMI-VSL results (all sections) for the plug 7,5mm (optional measurements). For this last gauge the NPL results are not included in the calculations.
In order to achieve a consistent *Rb* value, the iterated process has required 3-steps with the plug 4mm and 4-steps with the plug 50mm, and a significant number of data (3 or 4 over 12) are therefore excluded from the reference values.

The results of the departure from roundness of the sphere have shown three consistent datasets at 500, 150 and 50 UPR, nevertheless, not all the laboratories have submitted data.

Multiple measurements taken using different equipments have been submitted by NMISA (formerly CSIR-NML) for the diameter of the ring 40 mm, and by NPL for the roundness of the sphere. Different submissions within each laboratory are treated as an independent measurement [3]. This allows to have more valid measurements using different equipments/techniques which may help for a better estimate of the reference value.

8.1.1 *Corrections made on roundness data with respect to draftA*

Due to some discrepancies between the roundness values given in the table III of the PTB report and the values from the roundness plots attached to the PTB report, corrections have been made to the PTB roundness values for the 3.5 mm diameter and for the plug 50 mm diameter.

As explained by PTB, in table III of the report the results of the 3.5 mm ring were calculated for 500 UPR filtering and not 15 UPR as in the corresponding plots. Furthermore upper and lower position were interchanged.
I.e. for 15 UPR it should read:
upper pos.: 0.029 µm
middle pos.: 0.021 µm
lower pos: 0.047 µm
For the 50 mm plug the table data were correctly taken from the 150 UPR data - but again the upper and lower position are interchanged and the number 0.57(4) was mistyped as 0.87 !
Such the table should read for 150 UPR filtering:
upper pos.: 0.574 µm
middle pos.: 0.113 µm
lower pos: 0.412 µm

In addition, it has pointed out that roundness plots of the 50mm plug submitted by PTB, namely of the up and low measuring sections, show a relatively high departure from roundness mainly due to single and large peaks visible in the two plots.

PTB commented that they tried to clean the artefacts carefully, nevertheless, some single particles might have been left on the surface. Current software allows for "killing" the single peak, but for the comparison they thought it would be best to report the true profile (also without neglecting profile points).

It has also noticed that roundness data at 150UPR have been submitted by INMETRO for the three measuring sections of the plugs 4 mm and 7.5 mm, whereas they were specified in the TP respectively at 15UPR and 50UPR.

8.1.2 Notes on straightness data

The *En* values corresponding to the three straightness results submitted for the ring 3.5mm, are not given in the present draft. In fact, the straightness plots of the ring 3.5mm taken at PTB over a length of 9 mm show a departure from straightness close to the ends of such evaluation length.

It has also mentioned that a few dominant peaks are visible in the PTB straightness plots of the ring 40mm taken @ 0.25mm filtering.

Ring 3,5 mm sn04-437 – middle section

Lab Name	*Lab Submitted Value /µm*	*Lab Submitted u(k=1) /µm*	*En (k=2)*	*En* (k=2)*	*Roundness /µm*	*u_{round} (k=1) /µm*	*Straightness (0°) /µm*	*Straightness (180°) /µm*	*u_{str} (k=1) /µm*	*Filter*	*meas length*
INRIM	3520.640	0.050	0.89	0.53	0.032	0.050	0.06	0.09	0.05		/ 6mm
METAS	3520.630	0.040	1.02	0.55	0.040	0.030	0.03	0.04	0.05	@ 0.25mm	
MKEH (OMH)	3520.600	0.130	0.17	0.04							
SMD	3519.930	0.071	-4.52	*-4.52*							
SP	3520.400	0.120	-0.65	-0.80							
PTB	3520.580	0.037	0.37	-0.15	0.021	0.020	0.30 (^)	0.25 (^)	0.04	@ 0.25mm	/ 9mm
NMI-VSL	3520.560	0.047	0.05	-0.34							
NPL	3520.550	0.039	-0.08	-0.57	0.070	0.041					
MIKES	3520.600	0.095	0.24	0.05							
LNE	3520.620	0.050	0.68	0.32							
NMISA (CSIR-NML)	3520.430	0.210	-0.30	-0.38	0.110	0.090					
INMETRO	3520.650	0.110	0.43	0.28							

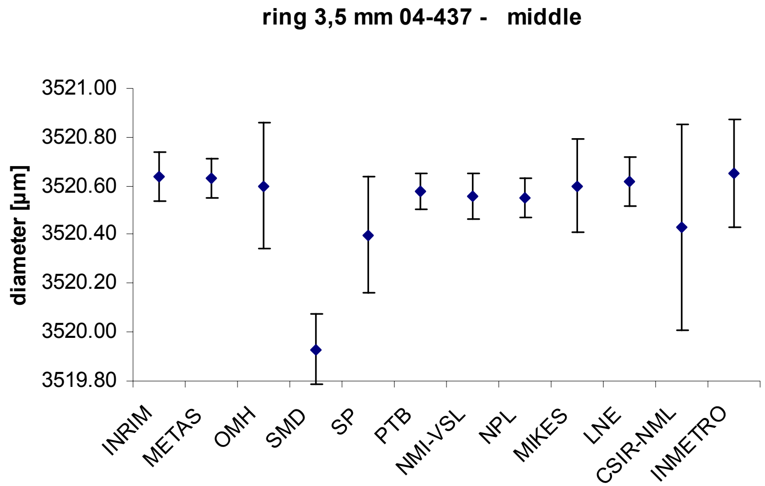
@ 15 UPR

(^) see par. 8.1.2

W-Mean /µm	3520.556
no. labs	12
C	2.63E-04
u int (Xw) /µm	0.0162
u ext (Xw) /µm	0.0461
Birge ratio Rb	2.85
Rb crit	1.36

(*) Larger consistent subset of results

(*) W-Mean /µm	3520.590
no. labs	11
C	2.77E-04
u int (Xw) /µm	0.0166
u ext (Xw) /µm	0.0142
Birge ratio Rb	0.85
Rb crit	1.38



Ring 3,5 mm sn04-437 – 2 mm↑

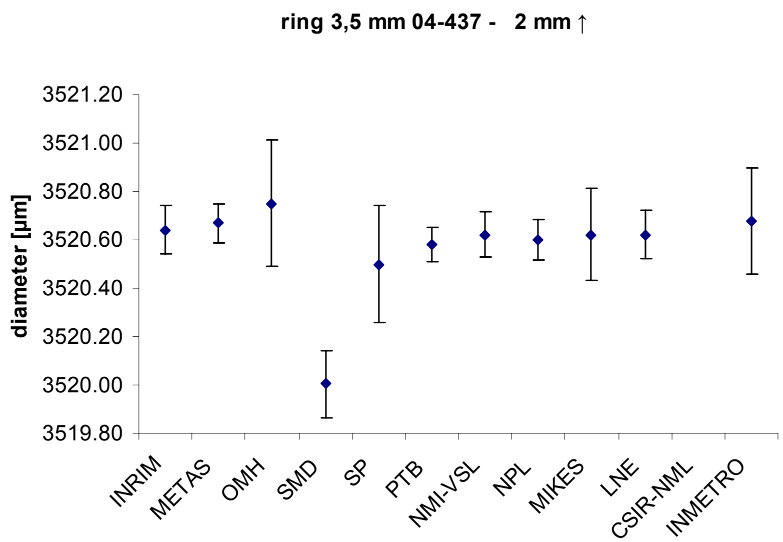
Lab Name	*Lab Submitted Value /µm*	*Lab Submitted u(k=1) /µm*		*En (k=2)*	*En* (k=2)*		*Roundness /µm*	*u round (k=1) /µm*	
INRIM	3520.640	0.050		0.56	0.21		0.040	0.050	
METAS	3520.670	0.040		1.14	0.69		0.040	0.030	
MKEH (OMH)	3520.750	0.130		0.63	0.51				
SMD	3520.004	0.070		-4.28	*-4.28*				
SP	3520.500	0.120		-0.36	-0.50				
PTB	3520.580	0.035		-0.11	-0.65		0.029	0.020	
NMI-VSL	3520.620	0.047		0.38	0.00				
NPL	3520.600	0.041		0.18	-0.26		0.080	0.041	
MIKES	3520.620	0.095		0.18	0.00				
LNE	3520.620	0.050		0.35	0.00				
NMISA (CSIR-NML)									
INMETRO	3520.680	0.110		0.43	0.28				

@ 15 UPR

W-Mean /µm	3520.587
no. labs	11
C	2.62E-04
u int (Xw) /µm	0.0162
u ext (Xw) /µm	0.0454
Birge ratio Rb	2.81
Rb crit	1.38

(*) Larger consistent subset of results

(*) W-Mean /µm	3520.620
no. labs	10
C	2.77E-04
u int (Xw) /µm	0.0166
u ext (Xw) /µm	0.0131
Birge ratio Rb	0.79
Rb crit	1.39



Ring 3,5 mm sn04-437 – 2 mm↓

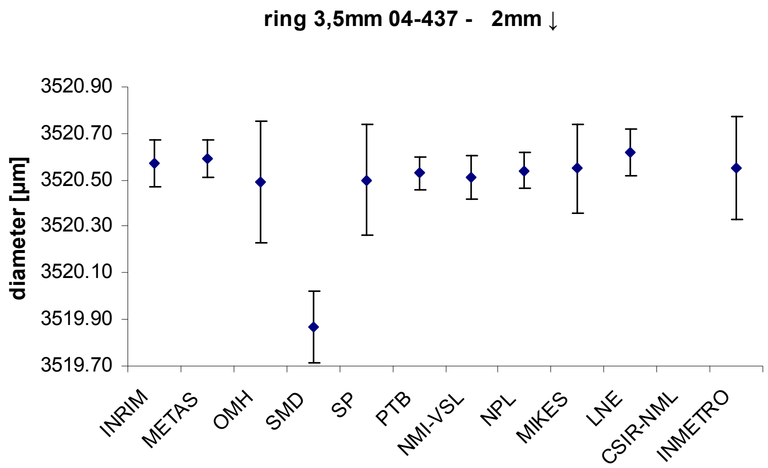
Lab Name	*Lab Submitted Value /µm*	*Lab Submitted u(k=1) /µm*		*En (k=2)*	*En* (k=2)*		*Roundness /µm*	*u_{round} (k=1) /µm*	
INRIM	3520.570	0.050		0.48	0.17		0.055	0.05	
METAS	3520.590	0.040		0.90	0.50		0.100	0.03	
MKEH (OMH)	3520.490	0.130		-0.13	-0.25				
SMD	3519.867	0.078		-4.31	*-4.31*				
SP	3520.500	0.120		-0.10	-0.23				
PTB	3520.530	0.035		0.09	-0.38		0.047	0.02	
NMI-VSL	3520.510	0.047		-0.16	-0.49				
NPL	3520.540	0.039		0.22	-0.19		0.120	0.040	
MIKES	3520.550	0.095		0.14	-0.02				
LNE	3520.620	0.050		1.01	0.70				
NMISA (CSIR-NML)									
INMETRO	3520.550	0.110		0.12	-0.02				

@ 15 UPR

W-Mean /µm	3520.524
no. labs	11
C	2.61E-04
u int (Xw) /µm	0.0161
u ext (Xw) /µm	0.0453
Birge ratio Rb	2.81
Rb crit	1.38

(*) Larger consistent subset of results

(*) W-Mean /µm	3520.554
no. labs	10
C	2.72E-04
u int (Xw) /µm	0.0165
u ext (Xw) /µm	0.0118
Birge ratio Rb	0.71
Rb crit	1.39



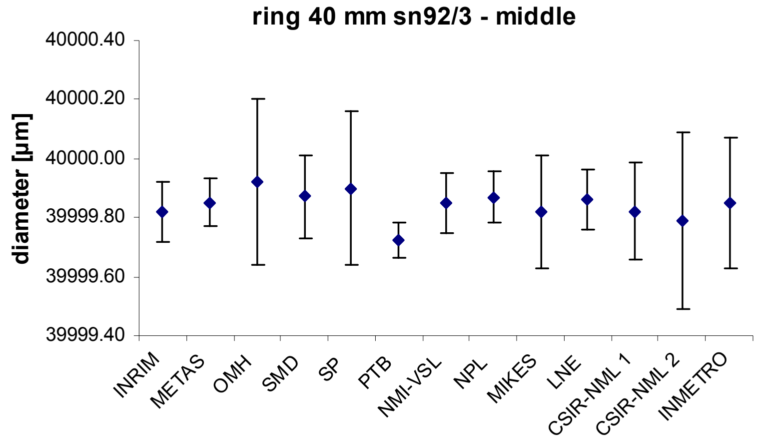
Ring 40 mm sn92/3 – middle section

Lab Name	*Lab Submitted Value /µm*	*Lab Submitted u(k=1) /µm*	*En (k=2)*	*Roundness /µm*	*u_{round} (k=1) /µm*	*Straightness (0°) /µm*	*Straightness (180°) /µm*	*u_{str} (k=1) /µm*	*Filter*	*meas length*
INRIM	39999.820	0.050	0.03	0.058	0.050	0.10	0.12	0.05		/ 18mm
METAS	39999.850	0.040	0.45	0.070	0.040	0.04	0.03	0.05	@0.8mm	
MKEH (OMH)	39999.920	0.140	0.37							
SMD	39999.871	0.070	0.40							
SP	39999.900	0.130	0.32	0.070	0.030					
PTB	39999.723	0.030	-1.83	0.065	0.020	0.19 (^)	0.24 (^)	0.04	@0.25mm	/ 21mm
NMI-VSL	39999.850	0.050	0.35							
NPL	39999.870	0.043	0.66	0.080	0.041					
MIKES	39999.820	0.095	0.02	0.064	0.050	0.115	0.019	0.05	@0.8mm	
LNE	39999.860	0.050	0.45							
NMISA (CSIR-NML) 1	39999.820	0.082	0.02	0.090	0.090	0.31	0.21	0.25	@0.8mm	/ 20mm
NMISA (CSIR-NML) 2	39999.790	0.150	-0.09							
INMETRO	39999.850	0.110	0.15	0.079	0.012					

@150 UPR

(^) see par. 8.1.2

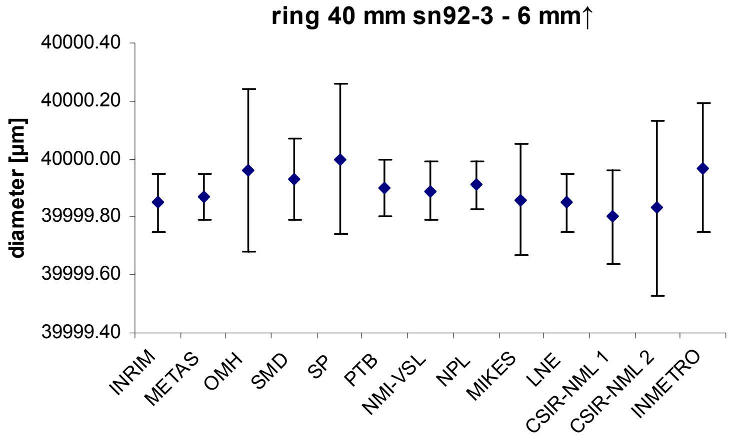
W-Mean /µm	39999.817
no. labs	13
C	2.39E-04
u int (Xw) /µm	0.0155
u ext (Xw) /µm	0.0172
Birge ratio Rb	1.11
Rb crit	1.35



Ring 40 mm sn 92/3 – 6 mm↑

Lab Name	Lab Submitted Value /µm	Lab Submitted u(k=1) /µm	En (k=2)	Roundness /µm	u_{round} (k=1) /µm
INRIM	39999.850	0.050	-0.35	0.052	0.050
METAS	39999.870	0.040	-0.18	0.110	0.040
MKEH (OMH)	39999.960	0.140	0.28		
SMD	39999.930	0.071	0.34		
SP	40000.000	0.130	0.45	0.070	0.030
PTB	39999.898	0.049	0.16	0.071	0.020
NMI-VSL	39999.890	0.050	0.07		
NPL	39999.910	0.042	0.35	0.080	0.041
MIKES	39999.860	0.095	-0.12	0.077	0.050
LNE	39999.850	0.050	-0.35		
NMISA (CSIR-NML) 1	39999.800	0.082	-0.52	0.110	0.090
NMISA (CSIR-NML) 2	39999.830	0.150	-0.18		
INMETRO	39999.970	0.110	0.40	0.078	0.012
				@150 UPR	

W-Mean /µm	39999.883
no. labs	13
C	2.85E-04
u int (Xw) /µm	0.0169
u ext (Xw) /µm	0.0108
Birge ratio Rb	0.64
Rb crit	1.35



Ring 40 mm sn 92/3 – 6 mm↓

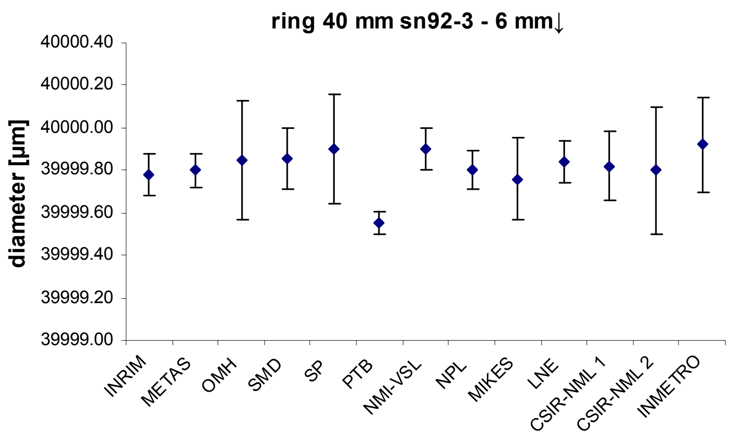
Lab Name	*Lab Submitted Value /µm*	*Lab Submitted u(k=1) /µm*	*Lab corrected Value /µm*	*En (k=2)*	*En* (k=2)*		*Roundness /µm*	u_{round} *(k=1) /µm*	
INRIM	39999.780	0.050		0.38	-0.49		0.088	0.050	
METAS	39999.800	0.040		0.76	-0.35		0.080	0.040	
MKEH (OMH)	39999.850	0.140		0.38	0.09				
SMD	39999.931	0.072	39999.856	0.80	0.22				
SP	39999.900	0.130		0.60	0.29		0.090	0.030	
PTB	39999.552	0.028		-4.09	*-4.09*		0.085	0.020	
NMI-VSL	39999.900	0.050		1.64	0.80				
NPL	39999.800	0.045		0.66	-0.31		0.120	0.041	
MIKES	39999.760	0.095		0.09	-0.35		0.105	0.050	
LNE	39999.840	0.050		1.01	0.16				
NMISA (CSIR-NML) 1	39999.820	0.082		0.47	-0.03		0.100	0.090	
NMISA (CSIR-NML) 2	39999.800	0.150		0.19	-0.08				
INMETRO	39999.920	0.110		0.81	0.44		0.096	0.012	

@150 UPR

W-Mean /µm	39999.744
no. labs	13
C	2.33E-04
u int (Xw) /µm	0.0153
u ext (Xw) /µm	0.0376
Birge ratio Rb	2.46
Rb crit	1.35

(*) Larger consistent subset of results

(*) W-Mean /µm	39999.825
no. labs	12
C	3.32E-04
u int (Xw) /µm	0.0182
u ext (Xw) /µm	0.0131
Birge ratio Rb	0.72
Rb crit	1.36



Plug 4 mm sn2534 – middle section

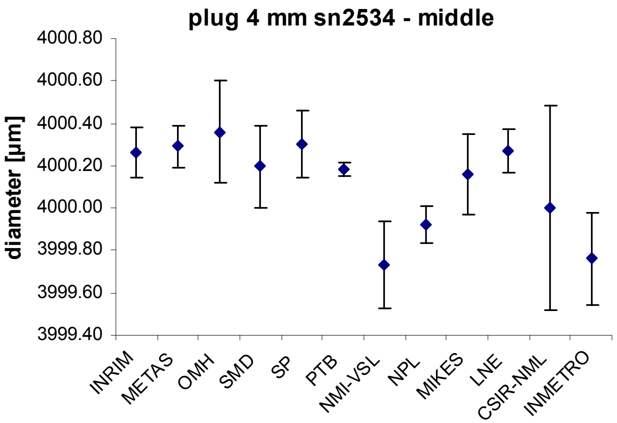
Lab Name	*Lab Submitted Value /µm*	*Lab submitted / (corrected) u(k=1) /µm*	*En (k=2)*	*En* (k=2)*	*Roundness /µm*	u_{round} *(k=1) /µm*	*Str (0°) /µm*	*Str (180°) /µm*	u_{str} *(k=1) /µm*	*Filter*	*meas length*
INRIM	4000.260	0.060	0.80	0.45	0.166	0.050	0.09	0.08	0.05		/ 7mm
METAS	4000.290	0.050	1.29	0.86	0.070	0.030	0.05	0.05	0.05	@0.25mm	
MKEH (OMH)	4000.360	0.120	0.81	0.64							
SMD	4000.197	0.096	0.16	-0.05							
SP	4000.300	0.080	0.85	0.59	0.220	0.030					
PTB	4000.182	0.017	0.75	-1.34	0.112	0.020	0.10	0.10	0.04	@0.25mm	/ 8mm
NMI-VSL	3999.730	0.045 (0.103)	-2.13	*-2.30*							
NPL	3999.920	0.043	-2.99	*-3.16*	0.100	0.049					
MIKES	4000.160	0.095	-0.03	-0.25	0.209	0.050	0.082	0.065	0.05	@0.8mm	
LNE	4000.270	0.050	1.08	0.65							
NMISA (CSIR-NML)	4000.000	0.240	-0.35	-0.43	0.120	0.090					
INMETRO	3999.760	0.110	-1.86	*-2.02*	0.728 (^)	0.010					

@15 UPR (^) @150 UPR

W-Mean /µm	4000.166
no. labs	12
C	1.75E-04
u int (Xw) /µm	0.0132
u ext (Xw) /µm	0.0365
Birge ratio *Rb*	2.76
Rb crit	1.36

(*) Larger consistent subset of results

(*) W-Mean /µm	4000.207
no. labs	9
C	2.00E-04
u int (Xw) /µm	0.0141
u ext (Xw) /µm	0.0168
Birge ratio *Rb*	1.19
Rb crit	1.41



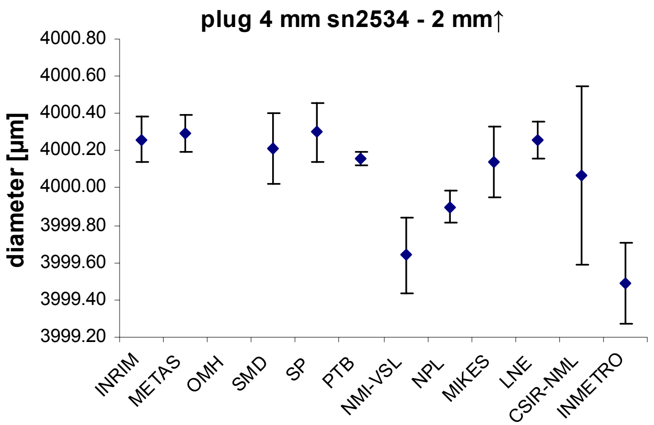
Plug 4 mm sn2534 – 2 mm↑

Lab Name	*Lab Submitted Value /µm*	*Lab submitted / (corrected) u(k=1) /µm*	*En (k=2)*	*En* (k=2)*		*Roundness /µm*	*u_{round} (k=1) /µm*	
INRIM	4000.260	0.060	1.05	0.58		0.143	0.050	
METAS	4000.290	0.050	1.59	1.02		0.080	0.030	
MKEH (OMH)								
SMD	4000.212	0.096	0.39	0.10				
SP	4000.300	0.080	1.03	0.68		0.220	0.030	
PTB	4000.159	0.019	0.86	-1.53		0.110	0.020	
NMI-VSL	3999.640	0.045 (0.103)	-2.44	*-2.66*				
NPL	3999.900	0.042	-3.03	*-3.31*		0.110	0.049	
MIKES	4000.140	0.095	0.01	-0.28		0.184	0.050	
LNE	4000.260	0.050	1.28	0.70				
NMISA (CSIR-NML)	4000.070	0.240	-0.14	-0.26		0.120	0.090	
INMETRO	3999.490	0.110	-2.97	*-3.17*		0.764 (^)	0.010	
						@15 UPR	(^) @150 UPR	

W-Mean /µm	4000.137
no. labs	11
C	2.00E-04
u int (Xw) /µm	0.0141
u ext (Xw) /µm	0.0482
Birge ratio Rb	3.41
Rb crit	1.38

(*) Larger consistent subset of results

(*) W-Mean /µm	4000.193
no. labs	8
C	2.36E-04
u int (Xw) /µm	0.0154
u ext (Xw) /µm	0.0204
Birge ratio *Rb*	1.33
Rb crit	1.44



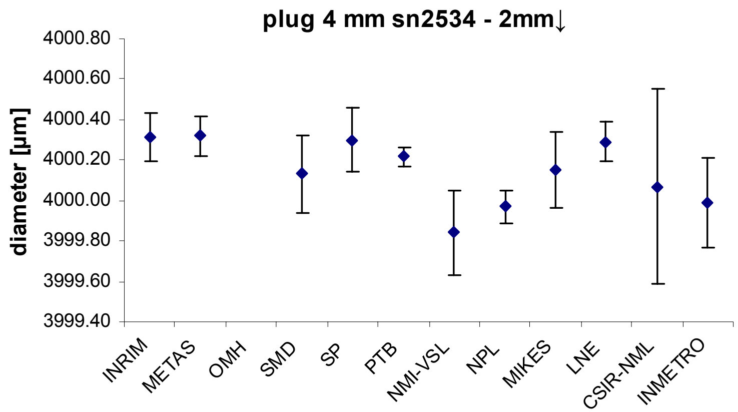
Plug 4 mm sn2534 – 2 mm↓

Lab Name	*Lab Submitted Value /µm*	*Lab submitted / (corrected) u(k=1) /µm*	*En (k=2)*	*En* (k=2)*		*Roundness /µm*	*u_{round} (k=1) /µm*	
INRIM	4000.310	0.060	1.03	0.63		0.180	0.050	
METAS	4000.320	0.050	1.36	0.88		0.080	0.030	
MKEH (OMH)								
SMD	4000.130	0.096	-0.32	-0.57				
SP	4000.300	0.080	0.70	0.40		0.230	0.030	
PTB	4000.217	0.023	0.77	-0.67		0.126	0.020	
NMI-VSL	3999.840	0.045 (0.103)	-1.72	*-1.90*				
NPL	3999.970	0.042	-2.87	*-2.98*		0.120	0.049	
MIKES	4000.150	0.095	-0.22	-0.47		0.182	0.050	
LNE	4000.290	0.050	1.04	0.56				
NMISA (CSIR-NML)	4000.070	0.240	-0.25	-0.35		0.150	0.090	
INMETRO	3999.990	0.110	-0.92	-1.14		0.610 (^)	0.010	
						@15 UPR	(^) @150 UPR	

W-Mean	/µm	4000.191
no. labs		11
C		2.43E-04
u int (Xw)	*/µm*	0.0156
u ext (Xw)	*/µm*	0.0387
Birge ratio Rb		2.49
Rb crit		1.38

(*) Larger consistent subset of results

(*) W-Mean	/µm	4000.238
no. labs		9
C		2.90E-04
u int (Xw)	/µm	0.0170
u ext (Xw)	/µm	0.0228
Birge ratio *Rb*		1.34
Rb crit		1.41



Plug 50 mm sn2535 – middle

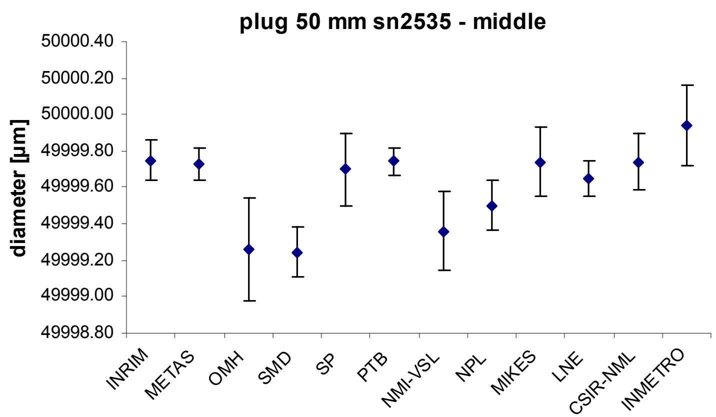
Lab Name	*Lab Submitted Value /µm*	*Lab submitted / (corrected) u(k=1) /µm*	*En (k=2)*	*En* (k=2)*		*Roundness /µm*	*u_{round} (k=1) /µm*		*Str (0°) /µm*	*Str (180°) /µm*	*u_{str} (k=1) /µm*	*Filter*	*meas length*
INRIM	49999.750	0.055	0.87	0.19		0.067	0.050		0.11	0.11	0.05		/ 15mm
METAS	49999.730	0.045	0.86	0.00		0.090	0.040		0.07	0.07	0.05	@0.8mm	
MKEH (OMH)	49999.260	0.140	-1.44	*-1.66*									
SMD	49999.244	0.068	-3.17	*-3.42*									
SP	49999.700	0.100	0.21	-0.15		0.060	0.030						
PTB	49999.742	0.037	1.28	0.19		0.113	0.020		0.11	0.08	0.04	@0.25mm	/ 21mm
NMI-VSL	49999.360	0.053 (0.107)	-1.42	*-1.70*									
NPL	49999.500	0.068	-1.21	*-1.61*		0.100	0.041						
MIKES	49999.740	0.095	0.43	0.05		0.143	0.050		0.109	0.10	0.05	@0.8mm	
LNE	49999.650	0.050	-0.10	-0.88									
NMISA (CSIR-NML)	49999.740	0.078	0.53	0.07		0.100	0.090		0.20	0.11	0.25	@0.8mm	/ 22mm
INMETRO	49999.940	0.110	1.29	0.97		0.045	0.010						

@150 UPR

W-Mean	/µm	49999.659
no. labs		12
C		3.35E-04
u int (Xw)	/µm	0.0183
u ext (Xw)	/µm	0.0486
Birge ratio Rb		2.65
Rb crit		1.36

(*) Larger consistent subset of results

(*) W-Mean	/µm	49999.730
no. labs		8
C		4.14E-04
u int (Xw)	/µm	0.0204
u ext (Xw)	/µm	0.0197
Birge ratio *Rb*		0.97
Rb crit		1.44



Plug 50 mm sn2535 – 6 mm ↑

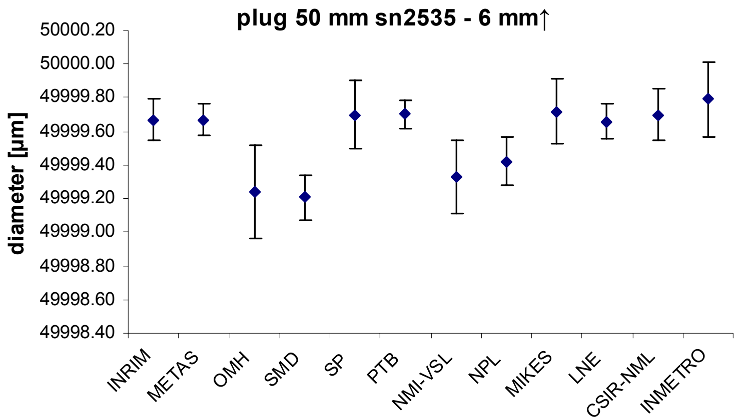
Lab Name	*Lab Submitted Value /µm*	*Lab submitted / (corrected) u(k=1) /µm*	*En (k=2)*	*En* (k=2)*		*Roundness /µm*	u_{round} *(k=1) /µm*	*En* (k=2)*	
INRIM	49999.670	0.060	0.52	-0.07		0.071	0.050	0.20	
METAS	49999.670	0.045	0.72	-0.09		0.090	0.040	0.50	
MKEH (OMH)	49999.240	0.140	-1.34	-1.58					
SMD	49999.209	0.067	-3.13	*-3.34*					
SP	49999.700	0.100	0.45	0.12		0.060	0.030	0.15	
PTB	49999.703	0.041	1.27	0.36		0.574 (^)	0.020		
NMI-VSL	49999.330	0.053 (0.107)	-1.33	*-1.59*					
NPL	49999.420	0.072	-1.38	*-1.73*		0.110	0.043	0.69	
MIKES	49999.720	0.095	0.59	0.23		0.134	0.050	0.84	
LNE	49999.660	0.050	0.53	-0.19					
NMISA (CSIR-NML)	49999.700	0.078	0.59	0.15		0.100	0.090	0.27	
INMETRO	49999.790	0.110	0.83	0.52		0.040	0.010	-1.14	

@150 UPR
(^) a dominant peak is visible in the roundness plot taken at PTB

W-Mean /µm		49999.611
no. labs		12
C		3.60E-04
u int (Xw)	/µm	0.0190
u ext (Xw)	/µm	0.0484
Birge ratio Rb		2.55
Rb crit		1.36

(*) Larger consistent subset of results

(*) W-Mean /µm		49999.678
no. labs		9
C		4.39E-04
u int (Xw)	/µm	0.0210
u ext (Xw)	/µm	0.0254
Birge ratio *Rb*		1.21
Rb crit		1.41



Plug 50 mm sn2535 – 6 mm↓

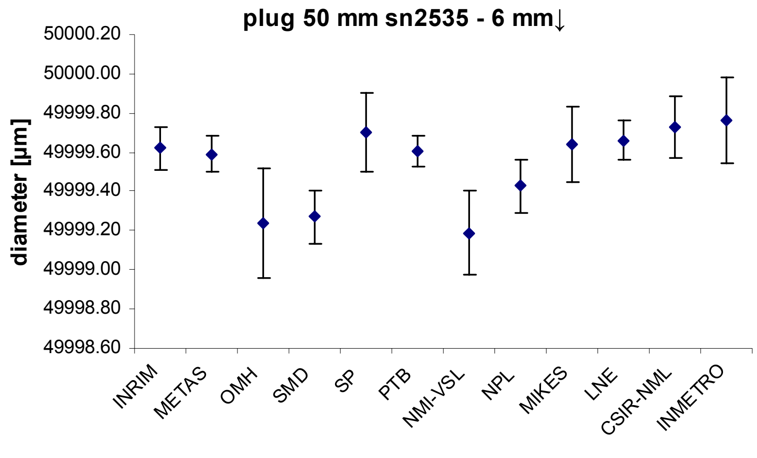
Lab Name	Lab Submitted Value /µm	Lab submitted / (corrected) u(k=1) /µm	En (k=2)	En* (k=2)		Roundness /µm	u_{round} (k=1) /µm	
INRIM	49999.620	0.055	0.49	-0.05		0.073	0.050	
METAS	49999.590	0.045	0.25	-0.44		0.090	0.040	
MKEH (OMH)	49999.240	0.140	-1.19	-1.39				
SMD	49999.271	0.067	-2.32	*-2.52*				
SP	49999.700	0.100	0.66	0.38		0.090	0.030	
PTB	49999.604	0.040	0.48	-0.31		0.412 (^)	0.020	
NMI-VSL	49999.190	0.053 (0.107)	-1.80	*-2.00*				
NPL	49999.430	0.068	-1.07	*-1.38*		0.120	0.046	
MIKES	49999.640	0.095	0.38	0.08		0.143	0.050	
LNE	49999.660	0.050	0.97	0.38				
NMISA (CSIR-NML)	49999.730	0.078	1.06	0.70		0.080	0.090	
INMETRO	49999.760	0.110	0.88	0.62				

@150 UPR
(^) a dominant peak is visible in the roundness plot taken at PTB

W-Mean	/µm	49999.570
no. labs		12
C		3.46E-04
u int (Xw)	/µm	0.0186
u ext (Xw)	/µm	0.0423
Birge ratio Rb		2.27
Rb crit		1.36

(*) Larger consistent subset of results

(*) W-Mean	/µm	49999.625
no. labs		9
C		4.24E-04
u int (Xw)	*/µm*	0.0206
u ext (Xw)	*/µm*	0.0261
Birge ratio Rb		1.27
Rb crit		1.41



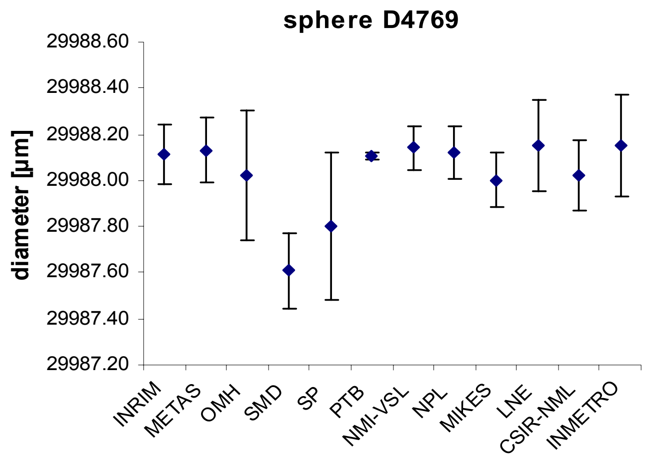
Sphere 30 mm sn D4769 – diameter

Lab Name	*Lab Submitted Value /µm*	*Lab submitted / (corrected) u(k=1) /µm*		*En (k=2)*	*En* (k=2)*
INRIM	29988.110	0.065		0.09	0.05
METAS	29988.130	0.070		0.22	0.19
MKEH (OMH)	29988.020	0.140		-0.28	-0.30
SMD	29987.609	0.081		-3.04	*-3.04*
SP	29987.800	0.070 (0.160)		-0.94	-0.95
PTB	29988.106	0.009		1.05	0.30
NMI-VSL	29988.140	0.047		0.45	0.39
NPL	29988.120	0.057		0.19	0.14
MIKES	29988.000	0.059		-0.85	-0.89
LNE	29988.150	0.100		0.26	0.23
NMISA (CSIR-NML)	29988.020	0.076		-0.52	-0.56
INMETRO	29988.150	0.110		0.23	0.21

W-Mean	/µm	29988.099
no. labs		12
C		6.93E-05
u int (Xw)	/µm	0.0083
u ext (Xw)	/µm	0.0171
Birge ratio Rb		2.06
Rb crit		1.36

(*) Larger consistent subset of results

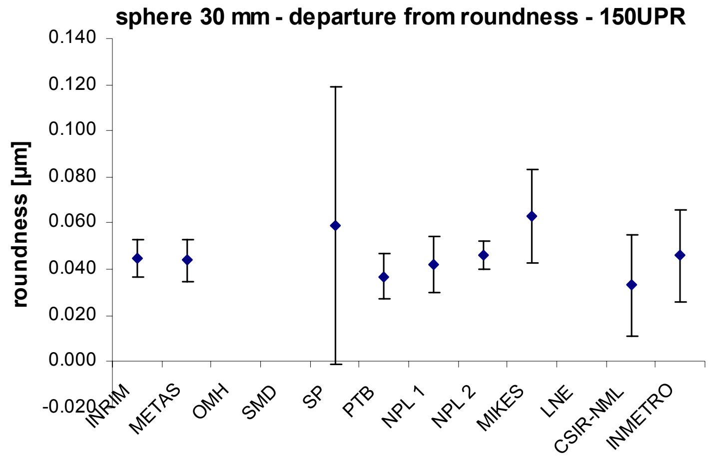
(*) W-Mean	/µm	29988.104
no. labs		11
C		7.00E-05
u int (Xw)	/µm	0.0084
u ext (Xw)	/µm	0.0082
Birge ratio Rb		0.98
Rb crit		1.38



Sphere 30 mm sn D4769 – departure from roundness

Lab Name	*Departure from roundness 500 UPR /µm*	u_{round} *(k=1) /µm*	*En (k=2)*	*Departure from roundness 150 UPR /µm*	u_{round} *(k=1) /µm*	*En (k=2)*	*Departure from roundness 50 UPR /µm*	u_{round} *(k=1) /µm*	*En (k=2)*
INRIM	0.047	0.004	0.25	0.045	0.004	0.11	0.044	0.004	0.74
METAS	0.046	0.0045	0.07	0.044	0.0045	-0.03	0.040	0.0045	0.16
MKEH (OMH)									
SMD									
SP	0.067	0.030	0.36	0.059	0.030	0.25	0.053	0.030	0.24
PTB	0.042	0.010	-0.18	0.037	0.005	-0.77	0.033	0.003	-1.15
NMI-VSL									
NPL 1				0.042	0.006	-0.19			
NPL 2				0.046	0.003	0.37	0.041	0.003	0.47
MIKES				0.063	0.010	0.95			
LNE									
NMISA (CSIR-NML)	0.033	0.011	-0.59	0.033	0.011	-0.52	0.033	0.011	-0.26
INMETRO				0.046	0.010	0.09			

	500 UPR	150 UPR	50 UPR
W-Mean /µm	0.046	0.044	0.039
no. labs	5	9	6
C	7.62E-06	3.13E-06	2.91E-06
u int (Xw) /µm	0.0028	0.0018	0.0017
u ext (Xw) /µm	0.0020	0.0017	0.0020
Birge ratio Rb	0.72	0.95	1.14
Rb crit	1.55	1.41	1.50



Plug 7,5 mm sn04-253 (optional measurements) – middle section

Lab Name	*Lab Submitted Value /µm*	*Lab submitted / (corrected) u(k=1) /µm*	*En (k=2)*	*En* (k=2)*	*Roundness /µm*	u_{round} *(k=1) /µm*		*Straightness (0°) /µm*	*Straightness (180°) /µm*	u_{str} *(k=1) /µm*	*Filter*	*meas length*
INRIM	7466.490	0.055	0.33	0.31	0.056	0.050		0.07	0.08	0.05		/5.5mm
METAS	7466.440	0.035	-0.20	-0.24	0.060	0.040		0.05	0.04	0.05	@0.25mm	
MKEH (OMH)	7466.600	0.120	0.61	0.60								
PTB	7466.457	0.008	0.65	0.18	0.073	0.020		0.15	0.12	0.04	@0.25mm	/ 7mm
NMI-VSL	7466.000	0.046 (0.103)	-2.21	*-2.21*								
NPL	7469.40 (*)	0.042			0.090	0.050						
LNE	7466.430	0.050	-0.24	-0.26								
NMISA (CSIR-NML)	7466.280	0.240	-0.36	-0.37	0.110	0.090		0.32	0.25	0.25	@0.8mm	/8 mm
INMETRO	7466.350	0.110	-0.47	-0.48	0.060 (^)	0.010						

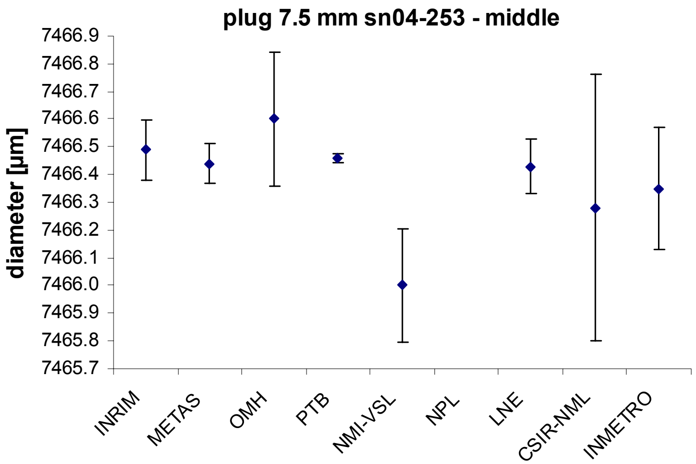
(*) not included in the W-mean

@50 UPR (^) @150 UPR

W-Mean	/µm	7466.454
no. labs		8
C		5.74E-05
u int (Xw)	/µm	0.0076
u ext (Xw)	/µm	0.0138
Birge ratio Rb		1.82
Rb crit		1.44

(*) Larger consistent subset of results

(*) W-Mean	/µm	7466.456
no. labs		7
C		5.77E-05
u int (Xw)	/µm	0.0076
u ext (Xw)	/µm	0.0060
Birge ratio Rb		0.79
Rb crit		1.47



Plug 7,5 mm sn04-253 (optional measurements) – 2 mm↑

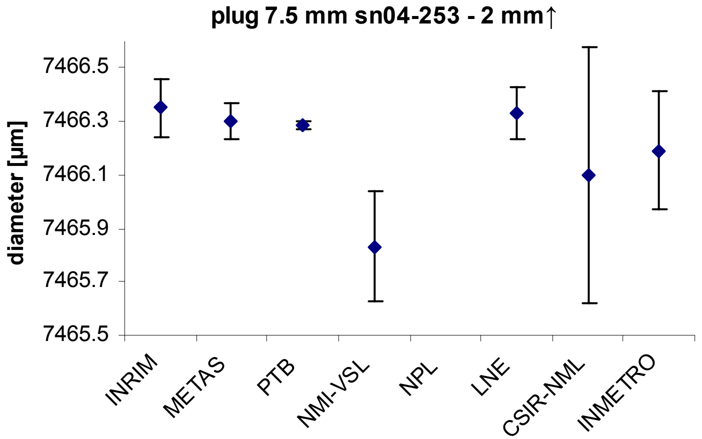
Lab Name	*Lab Submitted Value /µm*	*Lab submitted / (corrected) u(k=1) /µm*	*En (k=2)*	*En* (k=2)*		*Roundness /µm*	u_{round} *(k=1) /µm*	
INRIM	7466.350	0.055	0.57	0.55		0.073	0.050	
METAS	7466.300	0.035	0.18	0.15		0.050	0.040	
PTB	7466.288	0.008	0.08	-0.42		0.051	0.020	
NMI-VSL	7465.830	0.046 (0.103)	-2.23	-2.23				
NPL	7469.06 (*)	0.043				0.080	0.050	
LNE	7466.330	0.050	0.43	0.40				
NMISA (CSIR-NML)	7466.100	0.240	-0.39	-0.40		0.100	0.090	
INMETRO	7466.190	0.110	-0.44	-0.46		0.072 (^)	0.010	

(*) not included in the W-mean @50 UPR (^) @150 UPR

W-Mean	/µm	7466.288
no. labs		7
C		5.76E-05
u int (Xw)	/µm	0.0076
u ext (Xw)	/µm	0.0149
Birge ratio Rb		1.97
Rb crit		1.47

(*) Larger consistent subset of results

W-Mean	/µm	7466.290
no. labs		6
C		5.79E-05
u int (Xw)	/µm	0.0076
u ext (Xw)	/µm	0.0063
Birge ratio Rb		0.83
Rb crit		1.50



Plug 7,5 mm sn04-253 (optional measurements) – 2 mm↓

Lab Name	*Lab Submitted Value /µm*	*Lab submitted / (corrected) u(k=1) /µm*	*En (k=2)*	*En* (k=2)*		*Roundness /µm*	u_{round} *(k=1) /µm*	
INRIM	7466.490	0.055	0.04	0.02		0.076	0.050	
METAS	7466.440	0.035	-0.67	-0.71		0.060	0.040	
PTB	7466.492	0.008	0.27	0.75		0.069	0.020	
NMI-VSL	7466.060	0.046 (0.103)	-2.07	*-2.07*				
NPL	7469.39 (*)	0.042				0.080	0.050	
LNE	7466.460	0.050	-0.26	-0.29				
NMISA (CSIR-NML)	7466.440	0.240	-0.10	-0.10		0.110	0.090	
INMETRO	7466.400	0.110	-0.39	-0.40				

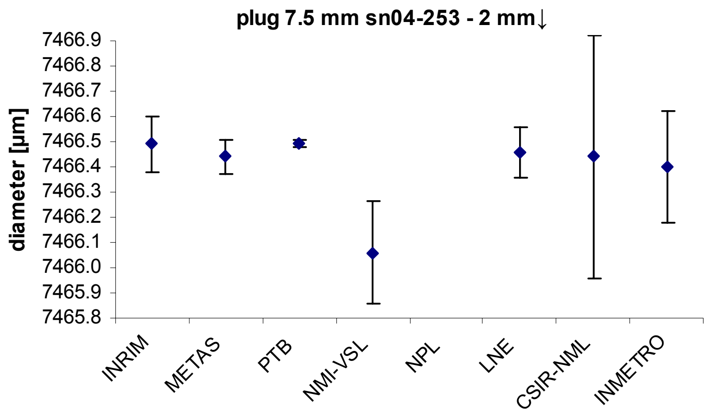
(*) not included in the W-mean

@50 UPR

W-Mean	/µm	7466.486
no. labs		7
C		5.76E-05
u int (Xw)	/µm	0.0076
u ext (Xw)	/µm	0.0140
Birge ratio Rb		1.84
Rb crit		1.47

(*) Larger consistent subset of results

(*) W-Mean	/µm	7466.488
no. labs		6
C		5.79E-05
u int (Xw)	/µm	0.0076
u ext (Xw)	/µm	0.0060
Birge ratio Rb		0.79
Rb crit		1.50



8.2 Reference values

The results of the calculations of the mean, the median, the weighted mean and the recomputed weighted mean ((*)W-mean ; weighted mean of the consistent subset) for all the measuring sections of the diameter gauges are shown in the table below. The external standard deviation is given in the table above for the W-mean and recomputed (*)W-mean.

	measuring section	*Mean /µm*	*std.dev. /µm*	*Median /µm*	*std.dev. /µm*	*W-Mean /µm*	*std.dev. /µm*	*(*)W-mean /µm*	*std. dev. /µm*
ring 3,5mm	↑	3520.571	0.060	3520.620	0.054	3520.587	0.045	3520.620	0.013
	mid	3520.516	0.058	3520.590	0.053	3520.556	0.046	3520.590	0.014
	↓	3520.483	0.063	3520.540	0.059	3520.524	0.045	3520.554	0.012
ring 40mm	↑	39999.894	0.016	39999.890	0.009	39999.883	0.011		
	mid	39999.842	0.014	39999.850	0.010	39999.817	0.017		
	↓	39999.814	0.026	39999.820	0.019	39999.744	0.038	39999.825	0.013
plug 4mm	↑	4000.066	0.083	4000.159	0.065	4000.137	0.048	4000.193	0.020
	mid	4000.119	0.062	4000.190	0.046	4000.166	0.037	4000.207	0.017
	↓	4000.144	0.049	4000.150	0.026	4000.191	0.039	4000.238	0.023
plug 50mm	↑	49999.568	0.060	49999.670	0.051	49999.611	0.048	49999.678	0.025
	mid	49999.613	0.064	49999.715	0.046	49999.659	0.049	49999.730	0.020
	↓	49999.536	0.058	49999.612	0.043	49999.570	0.042	49999.625	0.026
sphere	equator	29988.030	0.048	29988.108	0.043	29988.099	0.017	29988.104	0.008
plug 7,5mm	↑	7466.198	0.070	7466.288	0.061	7466.288	0.015	7466.290	0.006
	mid	7466.381	0.064	7466.435	0.051	7466.454	0.014	7466.456	0.006
	↓	7466.397	0.058	7466.440	0.051	7466.486	0.014	7466.488	0.006

Table 1 Mean, median, weighted mean, recomputed weighted mean and associated standard deviations

Due to significant differences of uncertainty of some results the correlations with the weighted mean may vary significantly for these data, e.g., PTB results contributed to about 60% of the total weight of the W-mean of the three sections of the plug 4 mm, and to about 80-90% of the three sections of the plug 7.5 mm.
It is worth noting that uncorrected alignment errors may cause correlated errors and bias in the reference value. As shown in previous comparisons, the bias correction may be sometimes not insignificant for diameter gauges [3].

8.3 Discussion of results

The overall results of diameter measurements are consistent for the internal diameter standards and for the sphere whereas a larger spread of results is visible from the results of the external diameter standards. At this stage of the analysis there are no obvious reason why.

The comparison also shows a very good consistency of the roundness measurements (at 500, 150 and 50 UPR) on the ceramic ball 30 mm diameter, to be done with the best measurement capability for roundness standards of the participants. Unfortunately, not all the laboratories have submitted these roundness values.

A generally good consistency is obtained from the datasets of results related to the departure from roundness of the measuring sections and to the straightness of cylindrical gauges. Some deviations occurred for roughness and straightness values, also due to different filtering and measuring length of the submitted results.

8.3.1 *Histograms of En values*

The whole set of *En* values calculated from the W-mean of the submitted results for each gauge and/or measuring section, is given in the histogram (fig.3). A significant number of *En* values exceed the range ±1. The graph show the distribution and may help to get a better understanding of biased values and/or possible outliers.

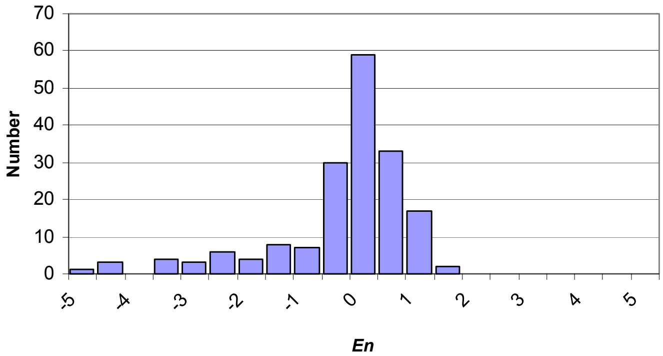


Figure 3 - Histogram of En values (at k =2) from the whole 177 element dataset of deviation from weighted mean, based on measurement results and standard uncertainties reported by the participants.

In the tables of results are also reported the recomputed weighted mean (*)W-mean and *En** values. Considering the full dataset of 177 diameter results the (*)W-mean and *En** values have been recomputed after zero weighting 26 submitted results (see par. 8.1)
The histogram of the whole set of recomputed *En** values is shown in fig.4. The number of *En* values outside the range ±1 has decreased to 29 over 177 data, which gives a percentage (16%) larger than the expected 5% consistency check [5].

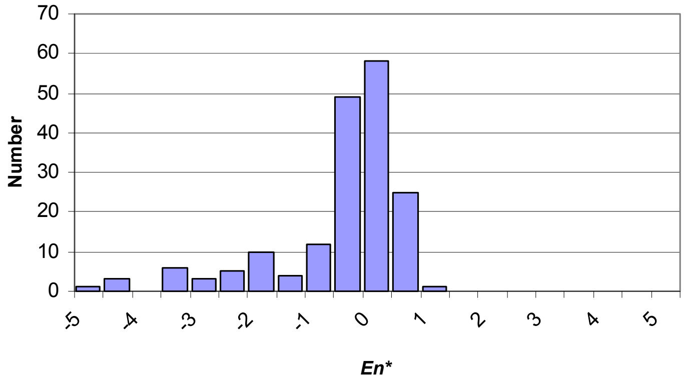


Figure 4 Histogram of En values (at k =2) from the 177 element dataset of deviation from weighted mean, as recalculated after zero weighting 26 results.*

The histogram of the *En* values (at k =2) from the full set of submitted results of the departure from roundness at the equator of the sphere (at 500, 150 and 50 UPR), is shown in fig. 5.

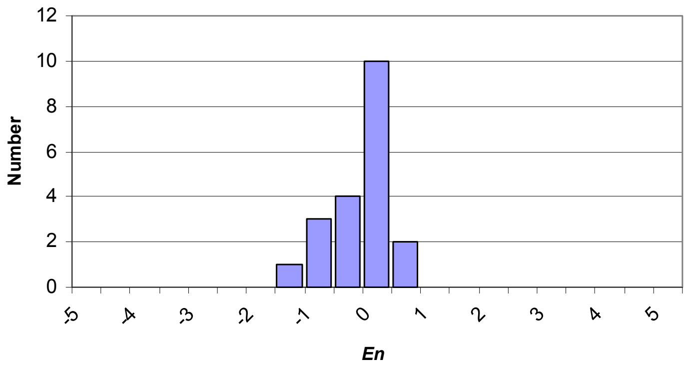


Figure 5 Histogram of En values (at k =2) of departure from roundness of the sphere at 500, 150 and 50 UPR.*

8.3.2 *Normalized differences between laboratories*

An alternative approach for the analysis of the results is based on the normalized experimental pair-difference between laboratories' results [5].

$$E_{nij} = \frac{(x_i - x_j)}{\sqrt{(u_i^2 + u_j^2)}}$$

E_{nij} values calculated for the middle section of each diameter gauge are given below. E_{nij} values less than 1 are expected for a *k*=2 coverage factor.

Ring 3,5 mm diameter, sn04-237, middle section

	INRIM	METAS	MKEH	SMD	SP	PTB	NMI-VSL	NPL	MIKES	LNE	NMISA	INMETRO
INRIM	0.00	0.08	0.14	4.09	0.92	0.48	0.58	0.71	0.19	0.14	0.49	-0.04
METAS	-0.08	0.00	0.11	4.29	0.91	0.46	0.57	0.72	0.15	0.08	0.47	-0.09
MKEH	-0.14	-0.11	0.00	2.26	0.57	0.07	0.14	0.18	0.00	-0.07	0.34	-0.15
SMD	-4.09	-4.29	-2.26	0.00	-1.69	-4.06	-3.70	-3.83	-2.82	-3.97	-1.13	-2.75
SP	-0.92	-0.91	-0.57	1.69	0.00	-0.72	-0.62	-0.59	-0.65	-0.85	-0.06	-0.77
PTB	-0.48	-0.46	-0.07	4.06	0.72	0.00	0.17	0.28	-0.10	-0.32	0.35	-0.30
NMI-VSL	-0.58	-0.57	-0.14	3.70	0.62	-0.17	0.00	0.08	-0.19	-0.44	0.30	-0.38
NPL	-0.71	-0.72	-0.18	3.83	0.59	-0.28	-0.08	0.00	-0.24	-0.55	0.28	-0.43
MIKES	-0.19	-0.15	0.00	2.82	0.65	0.10	0.19	0.24	0.00	-0.09	0.37	-0.17
LNE	-0.14	-0.08	0.07	3.97	0.85	0.32	0.44	0.55	0.09	0.00	0.44	-0.12
NMISA	-0.49	-0.47	-0.34	1.13	0.06	-0.35	-0.30	-0.28	-0.37	-0.44	0.00	-0.46
INMETRO	0.04	0.09	0.15	2.75	0.77	0.30	0.38	0.43	0.17	0.12	0.46	0.00

Ring 40 mm diameter, sn92/3, middle section

	INRIM	METAS	MKEH	SMD	SP	PTB	NMI-VSL	NPL	MIKES	LNE	NMISA 1	NMISA2	INMETRO
INRIM	0.00	-0.23	-0.34	-0.30	-0.29	0.83	-0.21	-0.38	0.00	-0.28	0.00	0.09	-0.12
METAS	0.23	0.00	-0.24	-0.13	-0.18	1.27	0.00	-0.17	0.15	-0.08	0.16	0.19	0.00
MKEH	0.34	0.24	0.00	0.16	0.05	0.69	0.24	0.17	0.30	0.20	0.31	0.32	0.20
SMD	0.30	0.13	-0.16	0.00	-0.10	0.97	0.12	0.01	0.22	0.06	0.24	0.24	0.08
SP	0.29	0.18	-0.05	0.10	0.00	0.66	0.18	0.11	0.25	0.14	0.26	0.28	0.15
PTB	-0.83	-1.27	-0.69	-0.97	-0.66	0.00	-1.09	-1.40	-0.49	-1.17	-0.56	-0.22	-0.56
NMI-VSL	0.21	0.00	-0.24	-0.12	-0.18	1.09	0.00	-0.15	0.14	-0.07	0.16	0.19	0.00
NPL	0.38	0.17	-0.17	-0.01	-0.11	1.40	0.15	0.00	0.24	0.08	0.27	0.26	0.08
MIKES	0.00	-0.15	-0.30	-0.22	-0.25	0.49	-0.14	-0.24	0.00	-0.19	0.00	0.08	-0.10
LNE	0.28	0.08	-0.20	-0.06	-0.14	1.17	0.07	-0.08	0.19	0.00	0.21	0.22	0.04
NMISA 1	0.00	-0.16	-0.31	-0.24	-0.26	0.56	-0.16	-0.27	0.00	-0.21	0.00	0.09	-0.11
NMISA 2	-0.09	-0.19	-0.32	-0.24	-0.28	0.22	-0.19	-0.26	-0.08	-0.22	-0.09	0.00	-0.16
INMETRO	0.12	0.00	-0.20	-0.08	-0.15	0.56	0.00	-0.08	0.10	-0.04	0.11	0.16	0.00

Plug 4 mm diameter, sn 2534, middle section

	INRIM	METAS	MKEH	SMD	SP	PTB	NMI-VSL	NPL	MIKES	LNE	NMISA	INMETRO
INRIM	0.00	-0.19	-0.37	0.28	-0.20	0.63	2.22	2.30	0.44	-0.06	0.53	2.00
METAS	0.19	0.00	-0.27	0.43	-0.05	1.02	2.45	2.80	0.61	0.14	0.59	2.19
MKEH	0.37	0.27	0.00	0.53	0.21	0.73	1.99	1.72	0.65	0.35	0.67	1.84
SMD	-0.28	-0.43	-0.53	0.00	-0.41	0.08	1.66	1.32	0.14	-0.34	0.38	1.50
SP	0.20	0.05	-0.21	0.41	0.00	0.72	2.19	2.09	0.56	0.16	0.59	1.99
PTB	-0.63	-1.02	-0.73	-0.08	-0.72	0.00	2.16	2.82	0.11	-0.83	0.38	1.90
NMI-VSL	-2.22	-2.45	-1.99	-1.66	-2.19	-2.16	0.00	-0.85	-1.53	-2.36	-0.52	-0.10
NPL	-2.30	-2.80	-1.72	-1.32	-2.09	-2.82	0.85	0.00	-1.15	-2.65	-0.16	0.68
MIKES	-0.44	-0.61	-0.65	-0.14	-0.56	-0.11	1.53	1.15	0.00	-0.51	0.31	1.38
LNE	0.06	-0.14	-0.35	0.34	-0.16	0.83	2.36	2.65	0.51	0.00	0.55	2.11
NMISA	-0.53	-0.59	-0.67	-0.38	-0.59	-0.38	0.52	0.16	-0.31	-0.55	0.00	0.45
INMETRO	-2.00	-2.19	-1.84	-1.50	-1.99	-1.90	0.10	-0.68	-1.38	-2.11	-0.45	0.00

Plug 50 mm diameter, sn2535, middle section

	INRIM	METAS	MKEH	SMD	SP	PTB	NMI-VSL	NPL	MIKES	LNE	NMISA	INMETRO
INRIM	0.00	0.14	1.63	2.89	0.22	0.06	1.62	1.43	0.05	0.67	0.05	-0.77
METAS	-0.14	0.00	1.60	2.98	0.14	-0.10	1.59	1.41	-0.05	0.59	-0.06	-0.88
MKEH	-1.63	-1.60	0.00	0.05	-1.28	-1.66	-0.28	-0.77	-1.42	-1.31	-1.50	-1.91
SMD	-2.89	-2.98	-0.05	0.00	-1.89	-3.22	-0.46	-1.33	-2.12	-2.41	-2.40	-2.69
SP	-0.22	-0.14	1.28	1.89	0.00	-0.20	1.16	0.83	-0.14	0.22	-0.16	-0.81
PTB	-0.06	0.10	1.66	3.22	0.20	0.00	1.69	1.56	0.01	0.74	0.01	-0.85
NMI-VSL	-1.62	-1.59	0.28	0.46	-1.16	-1.69	0.00	-0.55	-1.33	-1.23	-1.43	-1.89
NPL	-1.43	-1.41	0.77	1.33	-0.83	-1.56	0.55	0.00	-1.03	-0.89	-1.16	-1.70
MIKES	-0.05	0.05	1.42	2.12	0.14	-0.01	1.33	1.03	0.00	0.42	0.00	-0.69
LNE	-0.67	-0.59	1.31	2.41	-0.22	-0.74	1.23	0.89	-0.42	0.00	-0.49	-1.20
NMISA	-0.05	0.06	1.50	2.40	0.16	-0.01	1.43	1.16	0.00	0.49	0.00	-0.74
INMETRO	0.77	0.88	1.91	2.69	0.81	0.85	1.89	1.70	0.69	1.20	0.74	0.00

Sphere 30 mm diameter, sn D4769, equator

	INRIM	METAS	MKEH	SMD	SP	PTB	NMI-VSL	NPL	MIKES	LNE	NMISA	INMETRO
INRIM	0.00	-0.10	0.29	2.41	0.90	0.03	-0.19	-0.06	0.63	-0.17	0.45	-0.16
METAS	0.10	0.00	0.35	2.43	0.94	0.17	-0.06	0.06	0.71	-0.08	0.53	-0.08
MKEH	-0.29	-0.35	0.00	1.27	0.52	-0.31	-0.41	-0.33	0.07	-0.38	0.00	-0.37
SMD	-2.41	-2.43	-1.27	0.00	-0.53	-3.05	-2.84	-2.58	-1.95	-2.10	-1.85	-1.98
SP	-0.90	-0.94	-0.52	0.53	0.00	-0.95	-1.02	-0.94	-0.59	-0.93	-0.62	-0.90
PTB	-0.03	-0.17	0.31	3.05	0.95	0.00	-0.36	-0.12	0.89	-0.22	0.56	-0.20
NMI-VSL	0.19	0.06	0.41	2.84	1.02	0.36	0.00	0.14	0.93	-0.05	0.67	-0.04
NPL	0.06	-0.06	0.33	2.58	0.94	0.12	-0.14	0.00	0.73	-0.13	0.53	-0.12
MIKES	-0.63	-0.71	-0.07	1.95	0.59	-0.89	-0.93	-0.73	0.00	-0.65	-0.10	-0.60
LNE	0.17	0.08	0.38	2.10	0.93	0.22	0.05	0.13	0.65	0.00	0.52	0.00
NMISA	-0.45	-0.53	0.00	1.85	0.62	-0.56	-0.67	-0.53	0.10	-0.52	0.00	-0.49
INMETRO	0.16	0.08	0.37	1.98	0.90	0.20	0.04	0.12	0.60	0.00	0.49	0.00

Sphere D4769, departure from roundness, 150 UPR

	INRIM	METAS	SP	PTB	NPL1	NPL2	MIKES	NMISA	INMETRO
INRIM	0.00	0.08	-0.23	0.62	0.21	-0.10	-0.84	0.51	-0.05
METAS	-0.08	0.00	-0.25	0.52	0.13	-0.18	-0.87	0.46	-0.09
SP	0.23	0.25	0.00	0.36	0.28	0.22	-0.06	0.41	0.21
PTB	-0.62	-0.52	-0.36	0.00	-0.32	-0.77	-1.16	0.17	-0.40
NMI-VSL	-0.21	-0.13	-0.28	0.32	0.00	-0.30	-0.90	0.36	-0.17
NPL	0.10	0.18	-0.22	0.77	0.30	0.00	-0.81	0.57	0.00
MIKES	0.84	0.87	0.06	1.16	0.90	0.81	0.00	1.01	0.60
NMISA	-0.51	-0.46	-0.41	-0.17	-0.36	-0.57	-1.01	0.00	-0.44
INMETRO	0.05	0.09	-0.21	0.40	0.17	0.00	-0.60	0.44	0.00

9. KCRVs and their uncertainties

By following the guidelines for key comparisons the so-called Key Comparison Reference Values (KCRVs) and their uncertainties have been evaluated according the analysis of the reported results and the calculated reference values in the paragraph 8.2. The weighted mean calculated by zero weighting the data identified as outliers (recomputed W-mean) is determined as the KCRV. The internal standard deviation is used for determination of the standard uncertainty of the KCRV.

To ensure a common approach the laboratories were requested to estimated the individual reported uncertainties according the ISO GUM - 'Guide to the Expression of Uncertainty in Measurement'.

artefact serial number	*measuring section*	*Reference value [μm]*	*uncertainty [μm]*
ring 3,5 mm 04-437	↑	3520.620	0.017
	mid	3520.590	0.017
	↓	3520.554	0.017
ring 40 mm IMGC 92/3	↑	39999.883	0.017
	mid	39999.817	0.016
	↓	39999.825	0.019
plug 4 mm 2534	↑	4000.193	0.016
	mid	4000.207	0.015
	↓	4000.238	0.017
plug 50 mm 2535	↑	49999.678	0.021
	mid	49999.730	0.021
	↓	49999.625	0.021
sphere D4769	equator	29988.104	0.009
plug 7,5 mm 04-253	↑	7466.290	0.008
	mid	7466.456	0.008
	↓	7466.488	0.008

Table 2 Key comparison reference values (KCRVs) and associated standard uncertainties (u_{int}) rounded up to the nearest nm.

10. Differences from the KCRVs and associated uncertainties

Degrees of equivalence are determined from the differences between the laboratory results and the KCRVs with the associated expanded uncertainties *U* calculated by

$$U(\Delta d) = 2\sqrt{u_i^2 - u_{ref}^2}$$

where u_i *and* u_{ref} are the standard uncertainties of the laboratory result x_i, and of the KCRVs, respectively. The internal standard deviation is used for determination of the standard uncertainty of the KCRV.

artefact serial number	*measuring section*	INRIM	METAS	MKEH (OMH)	SMD	SP	PTB	VSL (NMI-VSL)	NPL	MIKES	LNE	NMISA (CSIR-NML)	NMISA (CSIR-NML)	INMETRO
ring 3,5 mm 04-437	↑	20 ± 95	50 ± 73	130 ± 258	-616 ± 136	-120 ± 238	-40 ± 62	0 ± 88	-20 ± 75	0 ± 187	0 ± 95			60 ± 218
	mid	50 ± 95	40 ± 73	10 ± 258	-660 ± 138	-190 ± 238	-10 ± 67	-30 ± 88	-40 ± 71	10 ± 188	30 ± 95		-160 ± 419	60 ± 218
	↓	16 ± 95	36 ± 73	-64 ± 258	-687 ± 153	-54 ± 238	-24 ± 62	-44 ± 88	-14 ± 71	-4 ± 188	66 ± 95			-4 ± 218
ring 40 mm IMGC 92/3	↑	-33 ± 95	-13 ± 73	77 ± 278	47 ± 138	117 ± 258	15 ± 92	7 ± 95	27 ± 77	-23 ± 187	-33 ± 95	-83 ± 161	-53 ± 299	87 ± 218
	mid	3 ± 96	33 ± 74	103 ± 279	54 ± 137	83 ± 259	-94 ± 52	33 ± 96	53 ± 81	3 ± 188	43 ± 96	3 ± 162	-27 ± 299	33 ± 218
	↓	-45 ± 94	-25 ± 72	25 ± 278	31 ± 140	75 ± 258	-273 ± 43	75 ± 94	-25 ± 83	-65 ± 187	15 ± 94	-5 ± 160	-25 ± 298	95 ± 217
plug 4 mm 2534	↑	67 ± 116	97 ± 96		19 ± 190	107 ± 157	-34 ± 23	-553 ± 204	-293 ± 78	-53 ± 188	67 ± 96		-123 ± 479	-703 ± 218
	mid	53 ± 116	83 ± 96	153 ± 238	-10 ± 190	93 ± 157	-25 ± 19	-477 ± 204	-287 ± 81	-47 ± 188	63 ± 96		-207 ± 479	-447 ± 218
	↓	72 ± 115	82 ± 94		-108 ± 189	62 ± 157	-21 ± 31	-398 ± 204	-268 ± 76	-88 ± 187	52 ± 94		-168 ± 479	-248 ± 218
plug 50 mm 2535	↑	-8 ± 113	-8 ± 80	-438 ± 277	-469 ± 128	22 ± 196	25 ± 71	-348 ± 210	-258 ± 137	42 ± 186	-18 ± 91	22 ± 151		112 ± 216
	mid	20 ± 103	0 ± 81	-470 ± 277	-486 ± 130	-30 ± 196	12 ± 62	-370 ± 211	-230 ± 131	10 ± 186	-80 ± 92	10 ± 151		210 ± 217
	↓	-5 ± 102	-35 ± 80	-385 ± 277	-354 ± 128	75 ± 196	-21 ± 69	-435 ± 210	-195 ± 129	15 ± 186	35 ± 92	105 ± 151		135 ± 217
sphere D4769	equator	6 ± 129	26 ± 139	-84 ± 280	-495 ± 162	-304 ± 320	2 ± 7	36 ± 93	16 ± 113	-104 ± 117	46 ± 200	-84 ± 152		46 ± 220

Plug for optional measurements

plug 7,5 mm 04-253	↑	60 ± 109	10 ± 69				-2 ± 5	-460 ± 206	2770 ± 85		40 ± 99		-190 ± 480	-100 ± 220
	mid	34 ± 109	-16 ± 69	144 ± 240			1 ± 5	-456 ± 206	2944 ± 82		-26 ± 99		-176 ± 480	-106 ± 220
	↓	2 ± 109	-48 ± 69				4 ± 5	-428 ± 206	2902 ± 84		-28 ± 99		-48 ± 480	-88 ± 220

Table 3 Differences of measured diameters with respect to the KCRVs and with the associated expanded uncertainties (K=2). Differences and uncertainties are in nm, the uncertainty is rounded up to the nearest nm.

departure from roundness	*UPR*	*Reference value [µm]*	*uncertainty [µm]*	INRIM	METAS	SP	PTB	NPL	NPL	MIKES	NMISA (CSIR-NML)	INMETRO
sphere D4769	500	0.046	0.0028	1 ± 6	0 ± 8	21 ± 60	-4 ± 20				-13 ± 22	
	150	0.044	0.0018	1 ± 8	0 ± 9	15 ± 60	-7 ± 10	-2 ± 12	2 ± 5	19 ± 20	-11 ± 21	2 ± 20
	50	0.039	0.0017	5 ± 7	1 ± 9	14 ± 60	-6 ± 5	2 ± 5			-6 ± 22	

Table 4 Differences of measured departure from roundness with respect to the reference value (W-mean) and with the associated expanded uncertainties (K=2). Differences and associated uncertainties are in nm, the uncertainty is rounded up to the nearest nm.

11. Conclusions

Eleven laboratories from EURAMET and two laboratories from other RMO's participated in the group 1 of this comparison on diameter standards. The comparison was driven according the BIPM guidelines. Some delay occurred in the circulation of the diameter gauges, partly at custom operations. Measurements reports have been submitted by all the NMIs. Unfortunately, INPL (Israel) has withdrawn.

No significant drifts due to secular changes of the gauges were observed. Some scratches and minor damages not interfering with the diameter measuring sections were reported during the circulation. The artefacts are of typical geometry and surface finish.

Measurements have been carried out with various measuring apparatus and different probing conditions by using spherical or flat tip probes and contact loads from a few milliNewtons up to 3 N, then corrected back to zero force by using elastic formulas.

The diameter results are consistent for the internal diameter standards and the sphere whereas a larger spread of results is visible for the external diameter standards. At this stage there are no obvious reason why.

From an overall view of the histogram of the whole set of *En* values calculated from the W-mean of the submitted results it is visible some spread of results towards smaller values, whereas is not evident an opposing asymmetry between the internal and external diameter results.

The whole set of the *En** values, as recomputed from the (*)W-mean by zero weighting the results with larger *En* and the process iterated until a consistent Birge ratio is achieved, does not meet the 5% consistency check.
In fact, a consistent *Rb* value required 2 or 3 iteration steps with the plug 4 mm, and 3 or 4 iteration steps with the plug 50 mm. Therefore, a significant number of data are excluded from the reference values of these two gauges.

Meanwhile, the comparison shows a very good consistency of the roundness measurements at the equator of the ceramic ball 30 mm diameter, at 500, 150 and 50 UPR. Unfortunately, not all the laboratories have submitted roundness values.

A generally good consistency is obtained from the datasets of departure from roundness of the measuring sections and straightness of cylindrical gauges. Some deviations occurred for roundness and straightness values, partly also due to different filtering and measuring length of the submitted results.

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