EURAMET.L-K4.n01
Key Comparison
Calibration of Diameter Standards
EURAMET project 1667

Technical protocol
(rev1 – September 2024)

Centro Español de Metrología

C/ del Alfar, 2

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September 2024

Contents

1 Document control

Version rev0	Issued on September 2024	
Version rev1	Issued on September 2024	Minor corrections

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

At its meeting in October 2023, the EURAMET Technical Committee for Length, decided upon a key comparison on diameter gauges, named EURAMET.L-K4.n01, with CEM as the pilot laboratory. The EURAMET comparison will be registered by June 2024, artefact circulation shall start in November 2024 and will be completed in September 2026.

The procedures outlined in this document cover the technical procedure to be followed during the measurements. The procedures are principally intended to allow for a clear description of the required measurements, handling and transportation of the circulating standards and to complete the comparison in the time scale provided for. This technical protocol was prepared following the layout principles of the documents for previous comparisons.

A goal of the CCL and RMO 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 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	email
CEM	**Rafael Muñoz Bueno** **Aelio A. Arce Criado** Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	rmunoz@cem.es aaarce@cem.es

BEV	**Matus Michael** Bundesamt für Eich- und Vermessungswesen Referat E23 – Dimensionelle Größen, Frequenz, Zeit und Photometrie. Arltgasse 35, 1160 Wien Austria	michael.matus@bev.gv.at
BFKH	**Gábor Szikszai** Government Office of the Capital City Budapest Metrology and Technical Supervisory Department Section of Mechanical Measurements Address: 37-39. Németvölgyi út, Budapest 1124, Hungary	szikszai.gabor@bfkh.gov.hu
BMM	**Tomo Bozovic** Bureau of metrology, BMM Arsenija Boljevica bb Podgorica Montenegro	tomo.bozovic@metrologija.gov.me
FSB-LPMD	**Marko Katić** Faculty of Mechanical Engineering and Naval Architecture. Laboratory for Precise Measurement of Length (FSB-LPMD) Ivana Lucica 1, Zagreb Croatia	marko.katic@fsb.unizg.hr
GUM	**Czułek Dariusz** Central Office of Measures (GUM) Elektoralna 2, P-10 00-950 Warsaw Poland	dariusz.czulek@gum.gov.pl
INM-RO	**Dragoș Teodorescu** Sos. Vitan-Barzesti Steet, No. 11 Sector 4 042 122, Bucharest Romania	teodragos@inm.ro
LNE	**José Antonio Salgado** Laboratoire National De Métrologie et D'Essais 1 rue Gaston Boissier 75724 Paris Cedex 15 France	jose-antonio.salgado@lne.fr
METAS	**Marc Trösch** Sector Length, Optics and Time Lindenweg 50 3003 Bern-Wabern Switzerland	Marc.Troesch@metas.ch
MIRS /UM-FS/LTM	**Bojan Ačko** Metrology Institute Of The Republic Of Slovenia/University Of Maribor Faculty Of Mechanical Engineering/Laboratory For Production Measurement. Smetanova Ulica 17 2000 Maribor Slovenia	bojan.acko@um.si
NPL	**Tim Coveney** Dimensional Metrology Group National Physical Laboratory Hampton Road, Teddington, Middlesex, TW11 LW UK	tim.coveney@npl.co.uk

NSAI NML	**Rory Hanrahan** NSAI National Metrology Laboratory Griffith Avenue Extension Glasnevin Dublin 11 Ireland D11 E527	rory.hanrahan@nsai.ie
PTB	**Michael Neugebauer** Physikalisch-Technische Bundesanstalt (PTB) Bundesallee 100 38116 Braunschweig, Germany	michael.neugebauer@ptb.de
RISE	**Carl-Henrik Hanquist** RISE Research Institutes of Sweden AB Brinellgatan 4, 504 62 Borås Sweden	carl-henrik.hanquist@ri.se
SASO-NMCC	**Nasser Alqahtani** **Faisal Alqahtani** National Measurement & Calibration Center (Buld.No.4) Saudi Standards, Metrology & Quality Org. (SASO). Riyadh - Imam Saud bin Abdulaziz bin Mohammed Road, the intersection of Prince Turki bin Abdulaziz I Road. BOX 3437 Riyadh 11471 Kingdom of Saudi Arabia.	n.qahtani@saso.gov.sa f.qahtany@saso.gov.sa
SMD	**Hugo Pirée** FPS Economy DG Quality and Safety, Metrology Division Boulevard du Roi Albert II 16 1000 Brussels Belgium	hugo.piree@economie.fgov.be

3.2 Schedule

The participating laboratories are asked to check a schedule, as given in table 2. If not accepted they are asked to specify a preferred timetable slot for their own measurements of the diameter gauges. Final timetable will be drawn up taking as much as possible these preferences into account. Each laboratory has five weeks that include customs clearance, calibration and transportation to the following participant. The periods including the end of year and summer holidays are extended for two weeks.

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. Draft schedule of the comparison.

Laboratory	Country	RMO	Starting date of measurement
CEM (Pilot Lab)	Spain	EURAMET	4th November 2024
BEV	Austria	EURAMET	9th December 2024
NSAI NML	Ireland	EURAMET	20th January 2025
MIRS/UM-FS/LTM	Slovenia	EURAMET	24th February 2025

INM-RO	Romania	EURAMET	31st March 2025
RISE	Sweden	EURAMET	5th May 2025
GUM	Poland	EURAMET	9th June 2025
PTB	Germany	EURAMET	14th July 2025
CEM (Pilot Lab)	Spain	EURAMET	15th September 2025
FSB-LPMD	Croatia	EURAMET	20th October 2025
BFKH	Hungary	EURAMET	24th November 2025
SMD	Belgium	EURAMET	12nd January 2026
LNE	France	EURAMET	16th February 2026
CEM (Pilot Lab)	Spain	EURAMET	23rd February 2026 Transit (no measurements)
METAS	Switzerland	EURAMET	30th March 2026
BMM	Montenegro	EURAMET	4th May 2026
NPL	UK	EURAMET	8th June 2026
SASO-NMCC	Saudi Arabia	GULFMET	13rd July 2026
CEM (Pilot Lab)	Spain	EURAMET	14th September 2026

3.3 Reception, transportation, insurance, costs

A plastic case containing 2 rings, 2 plugs and a sphere is used for the transportation of the artefacts (Figure 1). The standards will circulate together with a copy of this protocol.

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), using the form of Appendix A.

It is of utmost importance that the artefacts be transported in a manner in which they will not be lost, damaged or handled by un-authorised persons. Packaging for the artefacts has been made to be suitably robust to protect the artefacts from being deformed or damaged during transit. The packaging should be marked as ‘Fragile’.

The organization costs will be covered by the pilot laboratory, which include the standards themselves, the cases and packaging, and the shipping costs to the next laboratory. The pilot laboratory has no insurance for any loss or damage of the standards during the circulation.

Figure 1. Transporting case of the gauges

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

The package is accompanied by an ATA carnet. Outside EU 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!** For shipment inside the EU the ATA carnet may be shipped inside the box.

4 Artefacts

4.1 Description of artefacts

The package contains 5 marked gauges, two rings and two plugs made of steel (Ovako 100Cr6 / Ovako 100CrMo7-3), and a sphere made of ceramic (alumina), see Figure 2. Technical specification of the plugs are shown in Table 3.

A coefficient of thermal expansion (CTE) of $12 \cdot 10^{-6}$ K^{-1} is obtained by the manufacturer of the steel gauges, whereas a CTE of $4.6 \cdot 10^{-6}$ K^{-1} is obtained by the manufacturer of the ceramic ball. They should be used as such for any corrections to 20.0 °C.

Figure 2. Diameter gauges

Table 3. List of artefacts.

Diameter gauge	material	Serial Number	Nominal diameter /mm	Total height /mm	Manufacturer
Ring	Ovako 100Cr6/ 100CrMo7-3	R-001	5	10	Microtool
Ring	Ovako 100Cr6/ 100CrMo7-3	R-002	50	20	Microtool
Plug	Ovako 100Cr6/ 100CrMo7-3	P-001	5	12	Microtool
Plug	Ovako 100Cr6/ 100CrMo7-3	P-002	40	25	Microtool
Sphere	Ceramic (Alumina)	25-96-109	25	127 (at the equator)	Saphirwerk

5 Measuring instructions

5.1 Handling the artefact

The diameter 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 unless doing so would damage their equipment.

No participant shall try to re-finish measuring faces by burring, lapping, stoning, or whatsoever. 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. Ensure that the content of the package is complete before shipment. Always use the original packaging.

5.2 Mounting the artefacts

The ring, plug, and sphere standards shall be mounted 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 mounted 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

The measurand is the diameter of each gauge at 20°C and corrected to zero force.

Diameter measurements

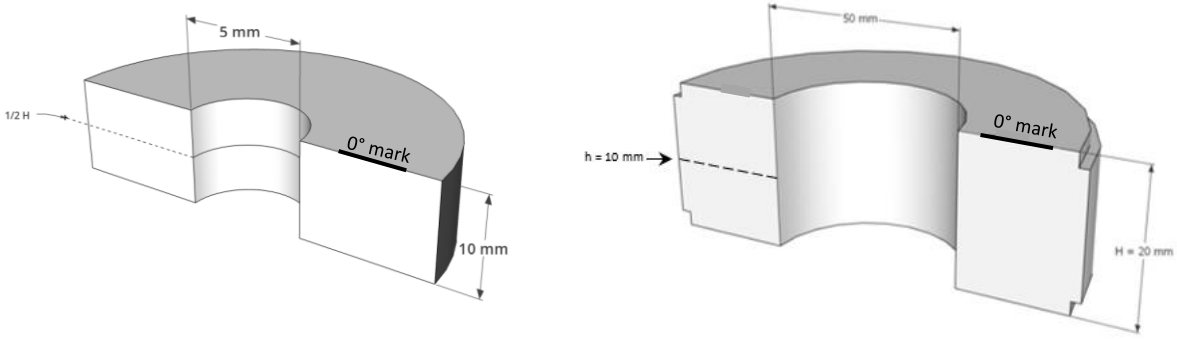

Figure 3. Measuring direction on the rings

The diameter of the rings should be measured at the marked lines at a **distance from the top/upper surface equal to half the total height of the gauge (0° mark, according figure 3)**. The upper side of the rings are defined by the inscriptions. The lines defining **the diameter measurement direction** are marked on the upper side of the two rings. 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.

The diameter of the 5 mm plug gauge should be measured at the marked line **6.15 mm below the top/upper surface (0° mark, according figure 4)**. The upper side of the 5 mm plug is at the end of the 12.3 mm worked cylindrical surface. The lines defining **the diameter measurement direction** are marked on the not worked cylindrical surface of the plug. The diameter of the 40 mm plug gauge should be measured at the marked line **12.4 mm below the top/upper surface (0° mark, according figure 4)**. The upper side of the 40 mm plug is at the end of the 24.8 mm worked cylindrical surface. The lines defining **the diameter measurement direction** are marked on the not worked cylindrical surface of the plug.

Figure 4. Measuring direction on the plugs: 5 mm plug (left) and 40 mm plug (right)

The diameter of the ceramic ball should be measured at the equator. The **diameter measurement direction** is marked on the steel base support by a mark close to the Serial Number (Figure 5).

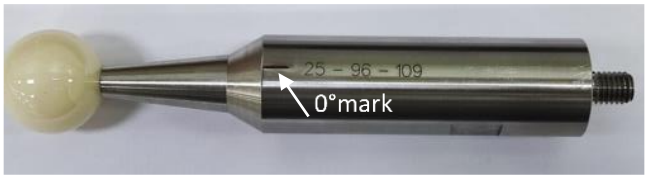

Figure 5. Measuring direction on the sphere

Table 4. The measurement details for the diameter measurements

Artefact	Serial Number	Diameter measurement direction
5 mm RING	R-001	**middle**
50 mm RING	R-002	**middle**
5 mm PLUG	P-001	**middle**
40 mm PLUG	P-002	**middle**
25 mm ceramic SPHERE	25-96-109	**Equator** (using the line marked on the steel support as 0 degree radial reference)

Form measurements

The roundness trace location for the 25 mm sphere is the equator with the line marked on the steel support of the sphere as the 0° radial reference. "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 (table 4). The roundness data should be collected using a **least squares fit (LSC-protocol)**.

The straightness measurement location will intersect with the diameter measurement locations, for both 50 mm ring and 40 mm plug (figure 6). The straightness defect should be measured on the generatrix corresponding to 0°, coinciding with the 0° mark on the plug, according to figure 6. Roundness and straightness data should be reported using the Appendix D4 of this Technical Protocol.

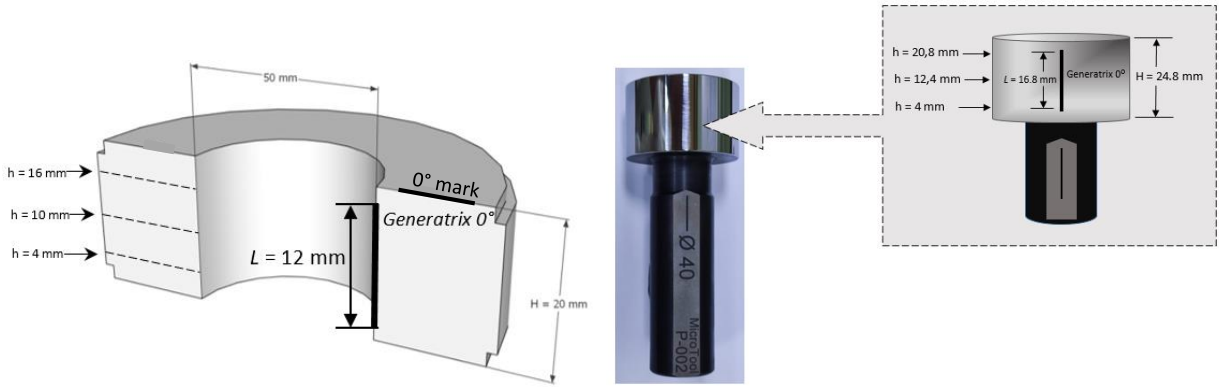

Figure 6. Straightness measurement location on the plugs: 50 mm ring (left) and 40 mm plug (right)

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 more and spherical tips smaller or equal than 1 mm in radius, the preferred conditions are given below, in accordance with the ISO/TS 12181-1:2011:

Table 5. The measurement details for the roundness measurements

Artefact	Serial Number	Recommended Roundness filter	Maximum Recommended Probe Diameter (mm)	Roundness Positions (referenced to middle of the gauging surface)
5 mm RING	R-001	15 UPR	2.0	**middle**
50 mm RING	R-002	150 UPR	2.0	**+ 6 mm↑** **middle** **- 6 mm↓**
5 mm PLUG	P-001	15 UPR	2.0	**middle**
40 mm PLUG	P-002	50 UPR	2.0	**+ 8.4 mm↑** **middle** **- 8.4 mm↓**
25 mm ceramic SPHERE	25-96-109	50 UPR	2.0	**Equator** (using the line marked on the steel support as 0 degree radial reference)

By assuming that many participants use a straightness measuring system with 1000 sample points or more and spherical tips not higher than 1 mm in radius, the preferred conditions are given below, in accordance with the ISO/TS 12181-1:2011.

Table 6. The measurement details for the straightness measurements

Artefact	Serial Number	Recommended Straightness filter cut-off values	Maximum Recommended Probe Diameter (mm)	Straightness Positions
50 mm RING	R-002	2.5 mm	2.0	**Central 12 mm of the gauge**
40 mm PLUG	P-002	2.5 mm	2.0	**Central 16.8 mm of the gauge**

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 with indication of the factor *k* used.

Additionally, in the report of the measurement technique (Appendix C) the participant should list relevant CMC(s) 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. **Within 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 3 months a first draft A.1 report on the comparison. This will be circulated to the participants for comments, additions and corrections.

7 Analysis of results

7.1 Calculation of the 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. 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 instability

Steel gauges occasionally show a growing or a shrinking and 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).

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.

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.

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. TC-L has to determine the further approach.

7.3 Correlation between laboratories

Since the topic of this project is the comparison of primary measurements, correlations between the results of different NMIs are unlikely. A possible exception is the common use of the recommended thermal expansion coefficients. A correlation will become relevant only when the 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 exist, 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:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
From:	Date: NMI:	Name: Signature:

We confirm having received the diameter gauges for the EURAMET.L-K4 comparison on the date given above.

After a visual inspection:

☐ There are no apparent damages; their precise state will be reported in the form 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. If it is necessary use additional sheets to report it.

Appendix B – Conditions of Measuring Surfaces

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
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:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
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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CMC uncertainty for the service(s) related to this comparison topic (if existing in the KCDB).....

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(use additional pages as needed)

Appendix C2 – Description of the EXTERNAL DIAMETER measurement process

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
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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CMC uncertainty for the service(s) related to this comparison topic (if existing in the KCDB) .....

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(use additional pages as needed)

Appendix C3 – Description of the SPHERE DIAMETER measurement process

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
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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CMC uncertainty for the service(s) related to this comparison topic (if existing in the KCDB) .....

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(use additional pages as needed)

Appendix C4 – Description of the ROUNDNESS/STRAIGHTNESS process

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
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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CMC uncertainty for the service(s) related to this comparison topic (if existing in the KCDB).....

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(use additional pages as needed)

Appendix D1 – Results Report Form

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
From:	Date: NMI:	Name: Signature:

Internal Diameter Ring Measurements

∅ 5 mm ring gauge, identification number: R-001

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

∅ 50 mm ring gauge, identification number: R-002

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

(*) Midway stands for a distance from the top/upper surface equal to half the total height of the gauge (see paragraph 5.4 Measurands)

Appendix D2 – Results Report Form

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
From:	Date: NMI:	Name: Signature:

External Diameter Measurements

∅ 5 mm plug gauge, identification number: P-001

Location	Meas. diameter /mm	std. uncert. *k* = 1 /µm	mat. temp. /°C	Probe config. & size /mm Meas. force used /mN
6.15 mm below the top/upper surface (**) 0 deg.				

(**) see paragraph 5.4 Measurands

∅ 40 mm plug gauge, AISI440C, identification number: P-002

Location	Meas. diameter /mm	std. uncert. *k* = 1 /µm	mat. temp. /°C	Probe config. & size /mm Meas. force used /mN
12.4 mm below the top/upper surface (**) 0 deg				

(**) see paragraph 5.4 Measurands

Appendix D3 – Results Report Form

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
From:	Date: NMI:	Name: Signature:

Sphere Diameter Measurements

∅ 25 mm sphere, identificationnumber: 25-96-109

Location	Meas. diameter /mm	std. uncert. $k = 1$ /µm	mat. temp. /°C	Probe config. & size /mm Meas. force used /mN
Equator 0°				

Appendix D4 – Results Report Form

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
From:	Date: NMI:	Name: Signature:

Roundness and straightness measurements

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

Gauge	Out-of-Roundness /µm	U_{RONt} $k = 1$ /µm	Peak to Valley Straightness	u_{Str} $k = 1$ /µm
∅ 5 mm ring gauge	Midway 0°		--	--
∅ 50 mm ring gauge	+6 mm↑ Midway 0° -6 mm↓		Central 12 mm	
∅ 5 mm plug gauge	Midway 0°		--	--
∅ 40 mm plug gauge	+8.4 mm↑ Midway 0° -8.4 mm↓		Central 16.8 mm	
∅ 20 mm Sphere	equator			

Appendix E1 – Uncertainty Component Reporting Form

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
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 $\lvert c_i \rvert \equiv \partial l / \partial x_i$	Combined Standard Uncertainty $u_i \equiv \lvert c_i \rvert \cdot u(x_i)$

COMBINED STANDARD UNCERTAINTY (k = 1)

Appendix E2 – Functional Uncertainty Report Form

To:	Rafael Muñoz Bueno Centro Español de Metrología (CEM) C/del Alfar, 2 28760 Tres Cantos (Madrid) Spain	Tel: +34 918 07 47 92 Tel: +34 918 07 48 01 Fax: +34 91 807 48 07 rmunoz@cem.es
From:	Date: NMI:	Name: Signature:

Functional form of standard uncertainty for diameter measurements

$$u(e_c) = Q[a, b \cdot l_n] = \sqrt{a^2 + (b \cdot l_n)^2}$$

	***a* / nm**	***b* / 1**	**Comment**
Internal Diameter - Rings			
External Diameter - Plugs			
Sphere			

Notes:

(use additional pages as needed)