EURAMET.L-K4.2015
Key Comparison
Calibration of Diameter Standards
EURAMET project 1410

Final Report

(October 2021)

Istituto Nazionale di Ricerca Metrologica

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Contents

1 Document control

Version DraftA (group1)	Issued on January 24th, 2019;
Version DraftA (group2)	Issued on September 30th, 2019;
Version DraftB_rev1.0	Issued on December 2020;
Version DraftB_rev2.0	Issued on March 2021;
Version DraftB_rev3	Issued on April 2021;
Version DraftB_rev4	Issued on August 2021;
Final Report	Issued on October 1st, 2021, final approved report.

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 2014, the EURAMET TC for Length, decided upon a key comparison on diameter gauges, named EURAMET.L-K4.2015, with INRIM as the pilot laboratory, following the comparison CCL-K4.2015. The EURAMET comparison was registered in November 2016, the circulation of the artefacts started in November 2016 and completed in February 2018.

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

Due to the large number of participants, it was decided to have 2 groups in the project. Two sets of diameter gauges of the same type and size were circulated in parallel in the two groups. An ATA Carnet was provided for circulation of the group 2, which includes several NMIs outside Europe. Some delays in circulation occurred in both groups, mainly due to minor changes in schedule, shipping and customs operations.

Twelve laboratories from EURAMET participated in group 1, while eleven laboratories from EURAMET and two laboratories from other RMOs participated in group 2. CEM, INRIM and METAS participated in both groups to link them.

The comparison followed the guidelines for CIPM key comparisons [1]. Data and results are reported as the first version of the draft B using the document layout principles for previous comparisons [2-3]. The allowance to use parts of this prior work wherever possible is gratefully acknowledged.

3 Organization

3.1 Participants

BEV, CEM, CMI, DTI, EIM, FSB, GUM, INM, INRIM, LNE, MBM, METAS, MKEH, NSAI, PTB, SASO-NMCC, SP, UME, VSL, VTT/MIKES. EMI – UAE (*) withdrew from the comparison.

Table 1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
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RISE-SP	Marianne Äremann; Sten Bergstrand SP Sveriges Tekniska Forskningsinstitut Brinellgatan 4 Borås SE-50462 Sweden	Tel: marianne.aremann@ri.se ;

UME	Okhan Ganioglu, İlker Meral, Murat Aksulu TÜBİTAK UME Ulusal Metroloji Enstitüsü TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr.ZekiAcarCad. No:1 41470 Gebze / Kocaeli Türkiye	Tel: +90 262 679 50 00 (ext. 5303) okhan.ganioglu@tubitak.gov.tr ilker.meral@tubitak.gov.tr murat.aksulu@tubitak.gov.tr
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3.2 Circulation

Due to the number of participating laboratories the comparison was divided into two independent groups of laboratories, three of which (CEM, INRIM, METAS) as linking laboratories in both groups.

Five weeks were granted to each laboratory for customs clearance, calibration and shipping to the next laboratory. The periods at the turn of the end of the year and the summer holidays were extended by two weeks. Each participating laboratory covered the costs of shipping and transport insurance against loss or damage to the next laboratory.

An ATA carnet was provided for the circulation outside EU. However, the ATA carnet is not accepted by all the countries of participating labs. Thus, some delay occurred at customs operations in the circulation of the group 2 gauges.

Table 2. Circulation timetables.

Group1

RMO	Laboratory	Reception of standards
EURAMET	INRIM	10 October 2016
	BEV	23 November 2016
	CEM	09 January 2017
	CMI	13 February 2017
	DTI	20 March 2017
	FSB	24 April 2017
	GUM	29 May 2017
	INM	03 July 2017
	LNE	21 August 2017
	METAS	02 October 2017
	VSL	06 November 2017
	EIM	11 December 2017
Pilot Lab	INRIM	29 January 2018

Group2

RMO	Laboratory	Reception of standards
EURAMET	INRIM	05 December 2016
	METAS	23 January 2017
	SP	27 February 2017
	MKEH	03 April 2017
	NSAI	08 May 2017
	CEM	12 June 2017
	VTT MIKES	31 July 2017
	UME	18 September 2017
	MBM	23 October 2017
	PTB	27 November 2017
GULFMET	SASO-NMCC	08 January 2018
	EMI-UAE	12 February 2018
SIM	INTI	19 March 2018
Pilot Lab	INRIM	23 April 2018

4 Measurement standards

Plastic/metal cases containing 2 rings, 2 plugs and a sphere were used for the transportation of the artefacts.

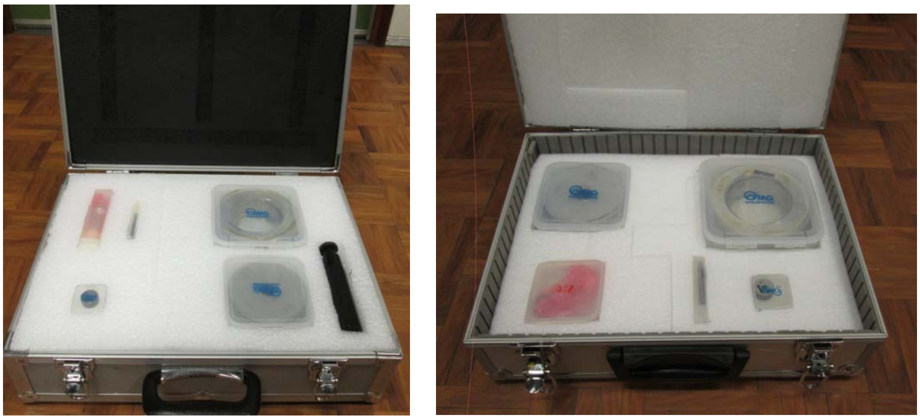


Figure 1 – Transporting cases of the gauges (group1 left, group 2 right)

4.1 Description of artefacts

Five gauges, two rings and two plugs made of steel (AISI440C), and a ball made of ceramic (alumina), were circulated within each group.
A coefficient of thermal expansion (CTE) of (10.1 ± 0.5) x 10^{-6} K^{-1} by the manufacturer of the steel gauges, and a CTE of (4.6 ± 0.5) x 10^{-6} K^{-1} by the manufacturer of the ceramic ball were provided in the technical protocol.

Table 3. List of artefacts.

Group1

Diameter gauge	material	Identification	Nominal diameter /mm	Total height /mm	Manufacturer
Ring	AISI440C	1655264	5	10	MG Marposs
Ring	AISI440C	1655173	80	32	MG Marposs
Plug	AISI440C	1655135	5	55 8.5 (worked length)	MG Marposs
Plug	AISI440C	B49096	100	20	MG Marposs
Ball	Ceramic (Alumina)	S2813	20	56 (at the equator)	Saphirwerk

Group2

Diameter gauge	material	Identification	Nominal diameter /mm	Total height /mm	Manufacturer
Ring	AISI440C	1655263	5	10	MG Marposs
Ring	AISI440C	1655174	80	32	MG Marposs
Plug	AISI440C	1655136	5	55 8.5 (worked length)	MG Marposs
Plug	AISI440C	B50315	100	20	MG Marposs
Ball	Ceramic (Alumina)	S2812	20	56 (at the equator)	Saphirwerk

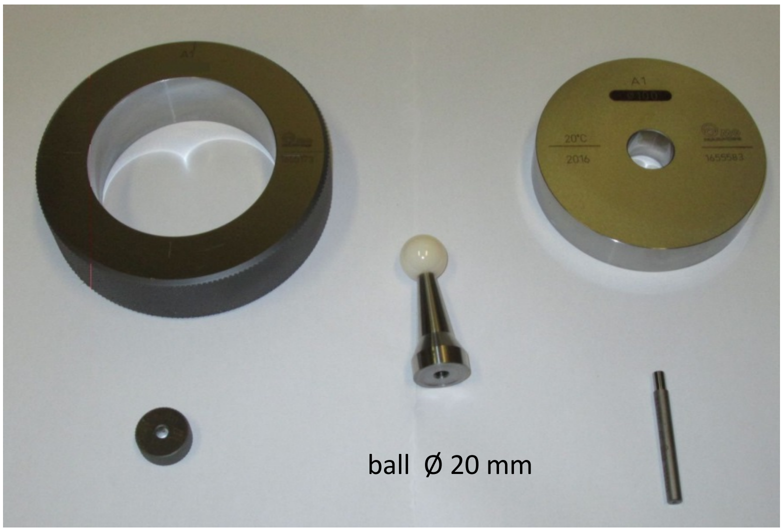


Figure 2 – Diameter gauges

5 Measuring instructions

5.1 Mounting the artefacts

Participants were asked to mount ring, plug, and sphere standards according to each laboratory's usual methods, which are to be described in their measurement report.

5.2 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).

5.3 Measurands

Straightness, departure from roundness and diameter of each gauge at 20°C and corrected to zero force.

The diameter of the two rings and of the 100 mm plug to be measured at the marked lines at a distance from the top/upper surface equal to half the total height of the gauge. The upper side of the rings and of the plug are defined by the inscriptions. The lines that define the direction of measurement of the diameter are marked on the upper side of the two rings and of the 100 mm plug (SN B49096). The direction of measurement of the diameter with the 100 mm plug (SN B50315) is that given by the direction of the "MARPOSS" inscription.

The diameter of the 5 mm plug gauge to be measured at the marked line 4 mm below the top/upper surface. The upper side of the 5 mm plug is at the end of the 8 mm worked cylindrical surface. The lines that define the direction of measurement of the diameter are marked on the not worked cylindrical surface of the plug.

The lines that define the direction of measurement of the diameter do not always cross precisely the centre of the cylinder/ring. Thus, measurement direction to be parallel to these lines, but not necessarily coincident.

The diameter of the ceramic ball to be measured at the equator. The direction of measurement of the diameter is marked on the steel base support by a conical imprint.

The roundness trace location for the 20 mm sphere is the equator with the line marked on the steel support of the sphere as the 0° radial reference.

The participants were invited to report the roundness and straightness deviations at a given cut-off frequencies (in UPR) of the long-pass filter, in order to achieve a better comparability of the results. Probe diameter was also recommended for roundness measurements.

Table 4. The measurement details for the roundness measurements

Artefact	Serial Number	Recommended Roundness filter	Recommended Probe Diameter (mm)	Roundness Positions (referenced to middle of the gauging surface)
80 mm RING		50 UPR	3.0	+ 8 mm↑ middle - 8 mm↓
100 mm PLUG		50 UPR	3.0	+ 5 mm↑ middle - 5 mm↓
20 mm ceramic SPHERE		50 UPR	3.0	Equator (using the line marked on the steel support as 0 degree radial reference)

Table 5. The measurement details for the straightness measurements

Artefact	Serial Number	Recommended Straightness filter cut-off values	Recommended Probe Diameter (mm)	Straightness Positions
80 mm RING		2.5 mm	3.0	Central 16 mm of the gauge
5 mm RING		0.8 mm	2.0	Central 5 mm of the gauge
100 mm PLUG		2.5 mm	3.0	Central 10 mm of the gauge
5 mm PLUG		0.8 mm	2.0	Central 4 mm of the gauge

5.4 Measurement uncertainty

The uncertainty of measurement to be estimated according to the GUM (*JCGM 100:2008 Evaluation of measurement data – Guide to the expression of uncertainty in measurement*). The participating laboratories were encouraged to use their usual model for the uncertainty calculation.

All measurement uncertainties to be stated as standard uncertainties, and the individual components of uncertainty to be detailed for each artefact or artefact type, for submission. Also indicate the corresponding effective degree of freedom for each component. If not available, ∞ is assumed.

An uncertainty statement in a functional form was required for efficient evaluation and subsequent evaluation of the CMC statements. This is typically either $u = Q[a, b \cdot l] = \sqrt{a^2 + (b \cdot l)^2}$ or $u = a + b \cdot l$ where a and b are constants and *l* is the measured dimension.

Additionally, the participants were asked to list relevant CMC(s) for the service(s) related to the comparison.

6 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. It is worth noting that the CMC entries in the table 6 are given as quantities or quantity equations as reported in the KCDB (https://www.bipm.org/kcdb/).

Table 6. Instrumentation, traceability and CMC entries of participant laboratories.

Participant	Measurand	Instruments used	Probing force (mN)	Probe diameter (mm)	Traceability	CMC Entry
						Expanded uncertainty
INRIM	diameter	1D comparator with a proportional probe and a laser interferometer	3	(2 - 5)	laser, gauge block, TPU meters	Q[0.1 µm, 0.5E-06 *D*]
	straightness					
	roundness	rotating table RTH TR30, modified at INRIM, with an indexing table (AA gauge Ultradex)	27	3	displacement actuator	Q[7 nm, 10E-03 *R*] (multistep)
						Q[100 nm, 10E-03 *R*] (1-profile)
BEV	diameter	SIP 3002 length measuring machine with a standard laser interferometer	500 - 3000	(3 - 5) ; flat	ring and plug traceable to METAS, laser interferometer and TPU sensors calibrated by BEV	ring (2 - 6) mm: 0.7 µm
						ring (6 - 250) mm: 0.5 µm
						plug: Q[0.3 µm, 0.8E-06 *L*]
						sphere: Q[0.3 µm, 0.8E-06 L]
	straightness					
	roundness					

BFKH (formerly MKEH)	diameter	Length measuring machine SIP 550M and TESATRONIC TTA20 electronic linear measuring instrument	200 - 2000	(1,2 - 7)	rings and plugs traceable to LNE; gauge blocks traceable to NPL, laser interferometer and Temperature sensors calibrated by BFKH	Q[0.3 µm, 3E-06 *L*]
	straightness	Roundness measuring machine, manufacturer MITUTOYO, model RA-120P			thickness standard for stylus calibration, reference plug, ring	
	roundness					
CEM	diameter	RING: MITUTOYO 3D CNC Ultra Quick Vision Measuring Machine, using touch probes			step gauge	ring: 0.3 µm
		PLUG and SPHERE: Labmaster Universal Length comparator (PRATT & WHITNEY)			gauge blocks	plug: 0.15 µm
						sphere: 0.1 µm
	straightness	MITUTOYO rotary table form measuring machine Roundtest RA-H5100			flick standard	
	roundness					Q[17 nm, 14E-03 *R*]
CMI	diameter	SIP 1002M	Int. 20 ext. 500	1,2; 4 7	gauge blocks, laser interferometer, thermometer	Q[0.40 µm, 2.6E-06 *D*]
	straightness	Talyrond 595S, Taylor Hobson	10	2		
	roundness					Q[25 nm, 10E-03 *R*]
DTI	diameter	Zeiss ULM 02-600 with Mahr stylus, setting rings	1500	2 ; flat	ring traceable to PTB	Q[0.5 µm, 4E-06 *L*]
	straightness	FAG 2100, Formtester			ring traceable to PTB	
	Roundness					Q[0.09 µm, 0.06 *R*]

EIM	diameter	Mahr 828 and a Renishaw Laser interferometer			Laser	
	straightness	Talyrond 290				
	roundness					

FSB	diameter	Universal length machine (ULM), Microrep Joint instruments DMS 680	2400 For ring Φ 5 mm: 100	(2 - 8) ; flat ; knife tips	gauge blocks, ring gauges, laser	ring Φ80 mm: 0.7 µm ; 0.6 µm + 0.7E-06 *D* plug Φ100 mm: 1 µm plug Φ5 mm: 0.7 µm
	straightness	MAHR MMQ 3, Form tester stylus instrument	300	2	reference sphere, ULM with interferometer	
	roundness					ring, plug: Q[0.11 µm, 20E-03 *R*] sphere: Q[0.09 µm, 20E-03 *R*]

GUM	diameter	Length measuring machine SIP 3002M with incremental scale and HP laser interferometer	1000	Spherical (1 – 3); flat 5	ring and plug gauges traceable to GUM and METAS, laser interferometer traceable to GUM	ring Φ 5 mm: 0,8 µm ring Φ80 mm : 0.7 µm plug Φ5 mm and Φ100 mm: 0,2 µm sphere: Q[0.7 µm, 1.2E-06 *D*]
	straightness	Taylor Hobson Form Talysurf i-Series profilometer	1	0,002	glass hemisphere, flick standard, depth setting standard traceable to GUM and PTB	0.5 µm
	roundness	Rank Taylor Hobson Talyrond 210		1		sphere: 0.05 µm cylinder: 0.1 µm

INM	diameter	Length measuring machine MAHR ULM 800L			ring gauges traceable to METAS, gauge blocks traceable to INM	rings, plugs: Q[0.78 µm, 5.2E-06 *L*]
	straightness	Roundness measuring machine TALYROND 365			glass roundness standard, flick standard, gauge blocks traceable to INM	
	roundness					rings, plugs, spheres Q[80 nm, 20E-03 *R*]

INTI	diameter	CMM SIP, model 420-M, Laser HP, model 5529A, Probe Tesa, model I-DIM			gauge blocks, laser	rings: Q[0.30, 0.0008*L*] µm, *L* in mm plugs: Q[0.26, 0.0010*L*] µm, *L* in mm
	straightness					
	roundness	Federal Rotary Inspection Table model ATE-7. Rotary table Moore 1440 and Tesa I-DIM Probe		2	Laser	

LNE	diameter	GSIP MU 214 bench with laser interferometer, Cary I-DIM 0.442 N/mm			gauge blocks, laser	Q[0.10 µm, 0.45E-06 *D*]
	straightness	Homemade straightness bench with reversal measurement for error separation			Laser	110 nm
	roundness	Kosaka roncorder EC 1600W for roundness			gauge blocks	50 nm

MBM	diameter	Microrep Joint DMS 680, one-dimensional measuring device	4600	flat and knife contact tips	gauge blocks traceable to DMDM, Serbia	
	straightness					
	roundness					

METAS	diameter	Length measuring machine SIP/EAM LMM5 spheres: Abbe type length comparator SIP 3002 with laser interferometer and flat probes	1000	(2 - 4); flat	laser, gauge block, reference sphere	rings, plugs: Q[0.063 µm, 0.28E-06 *L*] sphere: 80 nm
	straightness	cylinders: Form measuring instrument Accretech Rondcom 65 B spheres: Talyrond 73 with METAS upgrade		(2 - 3)	glass hemisphere ceramic straight edge flick-standard	
	roundness					cylinders: Q[0.075 µm, 16E-03 *R*] spheres: Q[7.0 nm, 17E-03 *R*]

NSAI	diameter	OKM ULM OPAL 600	1500	(3 – 2) chisel	rings & gauge blocks traceable to PTB & GUM	rings: (0.9 to 1.2) µm plugs, spheres: 0.15 µm + 1E-06 *L*
	straightness					
	roundness					

PTB	diameter	Mahr MFU8-PTB with integrated plane mirror laser interferometer	5	2; 3	Laser, gauge block	rIngs, plugs: Q[48 nm, 0.4E-06 *L*]
	straightness	Mahr MFU8-PTB			laser, reversal procedure	Q[50 nm, 0.4E-06 *L*, 10E-03 *S*]
	roundness	Mahr MFU8-PTB			laser, flick-standard, glass hemisphere	rings, plugs, spheres Q[6 nm, 10E-03 *R*] (CMC based on other instrumentation - Talyrond 73)
RISE (formerly SP)	diameter	CMM SIP 305 equipped with an Agilent laser interferometer	2000; 4000	2; 8 ; brackets; flat	laser, gauge blocks	rings, plugs: Q[0.2 µm, 2.5E-06 *L*] spheres: Q[0.3 µm, 2.5E-06 *L*]
	straightness	Taylor Hobson, TR 260 form instrument		2	laser interferometer, inductive probe	Q[0.3 µm, 10E-03 *S*]
	roundness	Talyrond TR 73		3	laser interferometer, inductive probe	cylinders: Q[20 nm, 30E-03 *R*] spheres: Q[5 nm, 20E-03 *R*]
SASO-NMCC	diameter	Mahr 828 CiM 1000 length measuring machine	Internal diameter (200-400); External diameter (1000-2000)	3; 5	ring gauges traceable to TUBITAK UME; gauge blocks calibrated by SASO-NMCC.	
	straightness	Mahr MMQ 400-2CNC form measuring machine	200	1.5	traceable to TUBITAK UME	
	roundness	Mahr MMQ 400-2CNC form measuring machine	200	1.5	traceable to TUBITAK UME	

VSL	diameter	CMM UC550 Zeiss			laser interferometer, gauge blocks	rings: Q[0.10 µm, 1.1E-06 *D*] plugs: Q[0.2 µm, 1E-06 *D*] spheres: Q[0.10 µm, 0.8E-06 *D*]
	straightness	Mitutoyo Roundtest RA-5100CNC		1,6	laser interferometer, precision translator	Q[0.4 µm, 0.6E-06 *L*]
	roundness			1,6		cylinders: Q[60 nm, 30E-03 *R*] spheres: Q[10 nm, 30E-03 *R*]

VTT MIKES	diameter	rings: length measuring machine SIP-550M;	0,2	3	laser interferometer, gauge blocks	Q[0.2 µm, 0.87E-06 *L*]
		plugs, spheres: length measuring machine Mahr Precimar PLM 600	800 -1200	5	gauge blocks	plugs: Q[0.2 µm, 0.87E-06 *L*] spheres: Q[0.15 µm, 0.7E-06 *L*]
	straightness	Cylindricity measuring machine Talyrond 262		0,8; 2; 2,5	Magnification, roundness and straightness standards	Q[0.1 µm, 0.3E-06 *L*]
	roundness					Q[0.1 µm, 0.017 *R*]

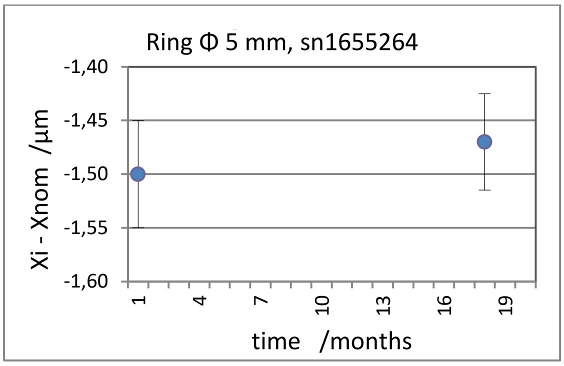
UME	diameter	Mahr 828 CIM 1000 Universal length measuring machine	200 - 400	3; 5	laser interferometer; gauge blocks; ring gauges (ring traceable to METAS)	Q[0.2 µm, 5E-06 *L*]
	straightness	Mahr MFU800 Form measuring machine		1,5; 3	roundness/straightness standards traceable to UME	
	roundness					cylinders: Q[49 nm, 2.4E-03 R] spheres: Q[49 nm, 2.4E-03 R]

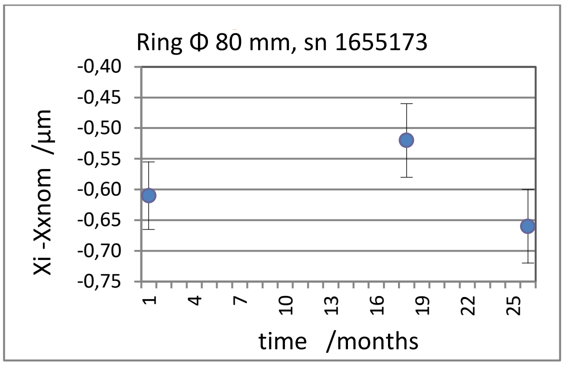
7 Stability of Artefacts

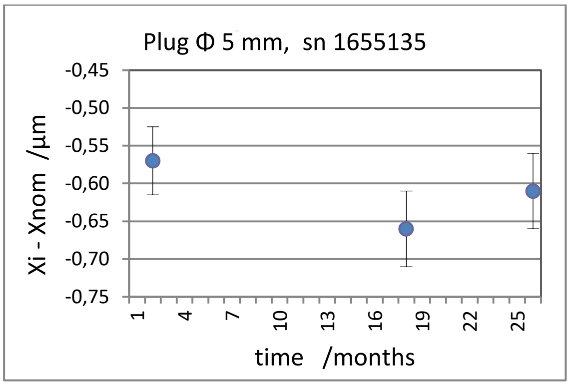
All the diameter gauges were acquired (no history) for this comparison. To check the stability of the gauges in and after the circulation initial, mid (if any) and final measurements were taken by the pilot.

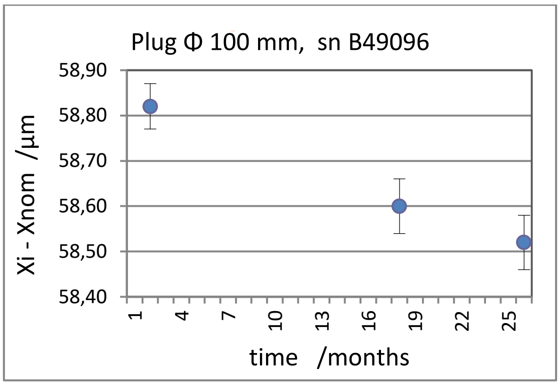
Measurements at mid of the circulation were only taken on a couple of gauges of the group 2, at the time they were back at INRIM for the renewal of the CARNET ATA. In addition, measurements "after final", i.e., several months after the measurements at the end of the circulation, were taken by the pilot on several gauges of both groups. The results of the pilot measurements are shown in the graphs below with reference to the time interval between measurements. The bars represent the standard uncertainty of measurements.

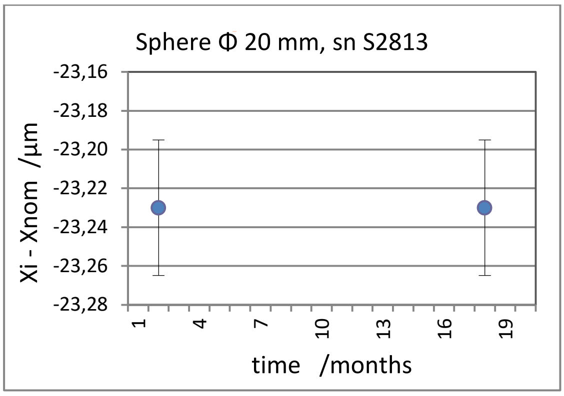
Group 1



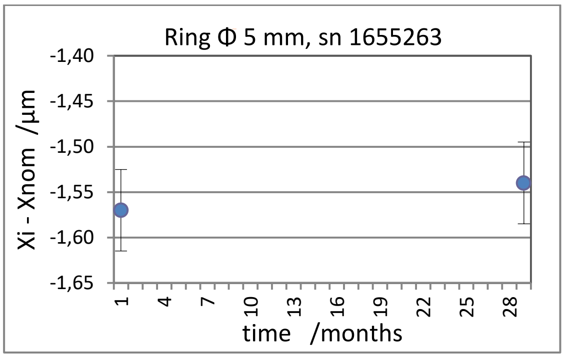


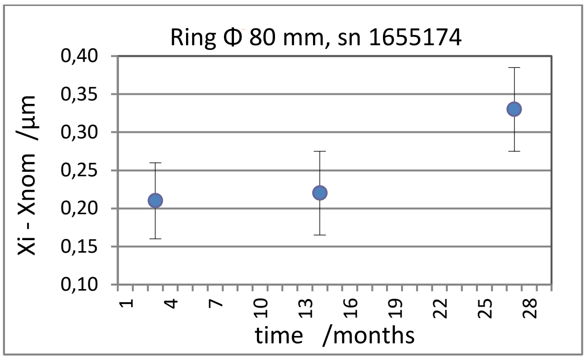


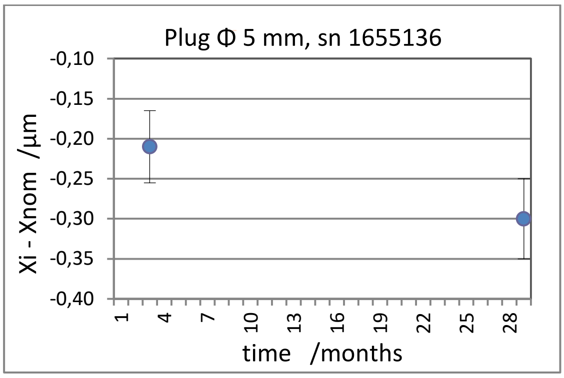


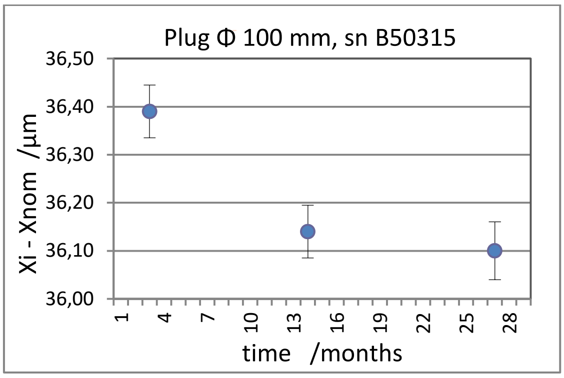


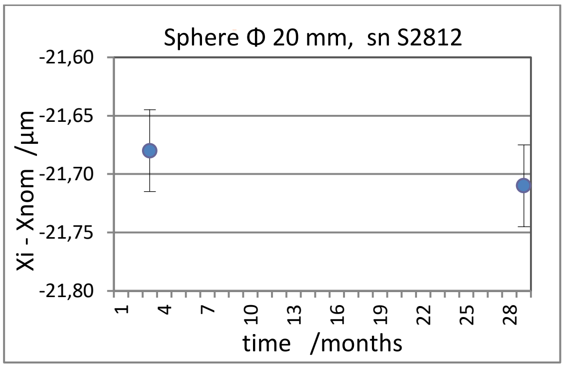
Group 2











With the exception of the two plugs 100 mm, the apparent changes in length are within the k = 2 uncertainty of the pilot laboratory, i.e., the apparent changes are probably not statistically significant. This is not the case of the two 100 mm plugs, with which apparent changes outside the k = 2 uncertainty of the pilot laboratory have been observed. From the pilot measurements a shrinkage drift of about -12 nm/month with a standard uncertainty of about 3,5 nm/month was obtained for both plugs of 100 mm diameter. Thus, maximum apparent changes in length of 200 nm and 240 nm have been estimated for the two artefacts within the duration of the circulation of 16 months for the group 1 and of 20 months for the group 2, respectively. Consequently, an artifact uncertainty is calculated by assuming this contribution as a rectangular distribution of half width of 100 nm and 120 nm and a standard uncertainty of 58 nm and 70 nm, respectively for the two 100 mm plugs [2].
When calculated by taking the three pilot measurements and all the laboratory measurements, the shrinkage drift of the 100 nm plugs is approximately -12 nm/month for group1 gauge, and approximately -7 nm/month for group2 gauge, with a standard uncertainty of about 3 nm/month for both.

8 Reporting of results

8.1 Results and standard uncertainties as reported by participants

The submitted results are collected in the tables below. The numbers within brackets (XXX) represent 1st reported results, which were checked for numerical errors and corrected by the own NMIs before the circulation of the draft A [2]. The revised results are those outside parentheses.

Participants were asked to report diameter (appropriately corrected to the reference temperature of20 °C and the measuring force of zero), roundness and straightness of the circulating gauges. A least squares (LS) fit analysis was recommended for straightness and roundness.

Group 1

Laboratory	Ring Φ 5 mm, sn1655264				Ring Φ 80 mm, sn 1655173									
	diameter		straightness		diameter		roundness						straightness	
							midway		up (+8 mm)		down (-8 mm)			
	$x_i - x_{nom}$ µm	u_i µm	x_i µm	u_i µm	$x_i - x_{nom}$ µm	u_i µm	x_i µm	u_i µm	x_i µm	u_i µm	x_i µm	u_i µm	x_i µm	u_i µm
INRIM Oct16	-1,50	0,05	0,06	0,05	-0,61	0,055	0,13	0,02	0,17	0,02	0,17	0,02	0,09	0,05
BEV	-1,25	0,30 (0,09)			-0,52	0,15								
CEM	-1,25	0,15	0,051	0,031	-0,39	0,15	0,133	0,009	0,141	0,009	0,166	0,009	0,047	0,031
CMI	-1,55	0,20	0,11	0,10	-0,32	0,23	0,137	0,015	0,155	0,015	0,179	0,015	0,11	0,10
DTI	-1,6	0,45	0,04	0,041	-0,4	0,6	0,15	0,045	0,16	0,045	0,17	0,045	0,04	0,041
FSB	-1,6	0,38			0,0	0,34	0,077	0,055	0,122	0,055	0,102	0,055		
GUM	-1,45	0,27 (0,25)			-0,77	0,19 (0,16)	0,135	0,035	0,132	0,035	0,156	0,036	0,0305	0,2
INM	-1,7	0,26	0,142	0,08	-0,25	0,32	0,068	0,040	0,064	0,040	0,070	0,040	0,105	0,08
LNE	-1,40	0,050	0,063	0,055	-0,72	0,054	0,157	0,025	0,145	0,025	0,190	0,025	0,089	0,055
METAS	-1,51	0,025	0,04	0,018	-0,59	0,040	0,16	0,025	0,14	0,025	0,19	0,025	0,04	0,011
VSL	-1,53	0,10 (0,05)	0,040	0,012	-0,69	0,11 (0,05)	0,296	0,011	0,143	0,007	0,155	0,007	0,051	0,012
EIM	-1,52	0,243	0,05	0,06	-0,57	0,255	0,314	0,07	0,330	0,07	0,301	0,07	0,07	0,08
INRIM Mar18	-1,47	0,045	0,04	0,05	-0,52	0,06	0,13	0,02	0,15	0,02	0,16	0,02	0,08	0,05
INRIM Nov18					-0,66	0,06								

Laboratory	Plug Φ 5 mm, sn 1655135				Plug Φ 100 mm, sn B49096									
	diameter		straightness		diameter		roundness						straightness	
							midway		up (+5 mm)		down (-5 mm)			
	$x_i - x_{nom}$	u_i	x_i	u_i	$x_i - x_{nom}$	u_i	x_i	u_i	x_i	u_i	x_i	u_i	x_i	u_i
	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm
INRIM Nov16	-0,57	0,045	0,045	0,050	58,82	0,05	0,07	0,02	0,10	0,02	0,07	0,02	0,065	0,050
BEV	-0,58	0,10			58,71	0,16								
CEM	-0,57	0,075	0,044	0,032	58,72	0,075	0,087	0,009	0,128	0,009	0,076	0,009	0,035	0,030
CMI	-0,67	0,20	0,06	0,10	58,77	0,25	0,105	0,015	0,120	0,020	0,093	0,015	0,13	0,10
DTI	-0,6	0,26	0,03	0,041	58,5	0,45	0,11	0,043	0,14	0,044	0,11	0,043	0,05	0,042
FSB	-0,7	0,35			58,6	0,5	0,119	0,055	0,115	0,055	0,089	0,055		
GUM	0,08	0,25 (0,10)	0,0239	0,2	59,90	0,26 (0,12)	0,108	0,035	0,110	0,035	0,122	0,035	0,0394	0,2
INM	-0,79	0,25	0,133	0,08	58,96	0,34	0,070	0,040	0,090	0,040	0,098	0,040	0,165	0,08
LNE	-0,51	0,050	0,103	0,055	58,91	0,056	0,088	0,025	0,107	0,025	0,068	0,025	0,095	0,055
METAS	-0,59	0,053	0,06	0,018	58,69	0,032	0,10	0,025	0,14	0,025	0,09	0,025	0,05	0,01
VSL	-0,60	0,10 (0,05)	0,042	0,012	58,55	0,11 (0,05)	0,138	0,007	0,124	0,007	0,073	0,007	0,033	0,012
EIM	-0,878	0,173	0,05	0,06	58,656	0,202	0,118	0,07	0,133	0,07	0,115	0,07	0,06	0,06
INRIM Mar18	-0,66	0,05	0,055	0,050	58,6	0,06	0,10	0,02	0,10	0,02	0,08	0,02	0,09	0,05
INRIM Nov18	-0,61	0,05			58,52	0,06								

Laboratory	Sphere Φ 20 mm, sn S2813			
	diameter		roundness / 50 UPR	
	$x_i - x_{nom}$ µm	u_i µm	x_i µm	u_i µm
INRIM Nov16	-23,23	0,035	0,025	0,004
BEV	-23,35	0,14		
CEM	-23,02	0,050	0,029	0,010
CMI	-23,34	0,21	0,027	0,013
DTI	-23,5	0,3	0,06	0,042
FSB	-23,4	0,35	0,119	0,045
GUM	-22,84	0,24 (0,11)	0,084	0,036
INM	-23,52	0,23	0,045	0,040
LNE	-23,22	0,050	0,040	0,025
METAS	-23,20	0,034	0,021	0,015
VSL	-23,13	0,10 (0,05)	0,047	0,020
EIM	-23,387	0,174	0,066	0,07
INRIM Mar18	-23,23	0,035	0,029	0,004

Group 2

Laboratory	Ring Φ 5 mm, sn 1655263				Ring Φ 80 mm, sn 1655174									
	diameter		straightness		diameter		roundness						straightness	
							midway		*up (+8 mm)*		*down (-8 mm)*			
	$x_i - x_{nom}$ *µm*	u_i *µm*	x_i *µm*	u_i *µm*	$x_i - x_{nom}$ *µm*	u_i *µm*	x_i *µm*	u_i *µm*	x_i *µm*	u_i *µm*	x_i *µm*	u_i *µm*	x_i *µm*	u_i *µm*
INRIM Oct16_Dec16	-1,57	0,045	0,07	0,05	0,21	0,05	0,18	0,02					0,05	0,05
METAS	-1,56	0,032	0,05	0,013	0,31	0,038	0,19	0,025	0,17	0,025	0,23	0,025	0,05	0,014
RISE (SP)	-1,47	0,07	0,11	0,15	0,36	0,08	0,21	0,01	0,20	0,01	0,27	0,01	0,10	0,15
BFKH (MKEH)	-1,96	0,12			0,04	0,14	0,205	0,053	0,223	0,053	0,261	0,053		
NSAI	-1,46	0,61			-0,275	0,44								
CEM	-0,55	0,15	0,058	0,030	0,22	0,15	0,219	0,009	0,186	0,009	0,258	0,009	0,036	0,030
VTT MIKES	-1,75	0,10	0,14	0,05	0,24	0,11	0,24	0,070	0,18	0,070	0,25	0,070	0,09	0,050
UME	" -1,70 (-0,17)	0,109	0,084	0,05	0,02	0,207	0,205	0,028	0,182	0,028	0,257	0,028	0,040	0,049
MBM					-0,01	0,447								
SASO-NMCC	-1,76	0,162	0,09	0,051	0,18	0,215	0,22	0,023	0,19	0,023	0,27	0,023	0,03	0,051
INTI	-1,58	0,07			0,28	0,09	0,212	0,044	0,190	0,044	0,265	0,044		
PTB	-1,60	0,036	0,048	0,050	0,32	0,041	0,237	0,050	0,205	0,050	0,253	0,050	0,048	0,050
INRIM Dec17					0,22	0,055	0,21	0,02	0,19	0,02	0,26	0,02	0,07	0,05
INRIM Dec18_Feb19	-1,54	0,045	0,05	0,05	0,33	0,055	0,22	0,02	0,20	0,02	0,23	0,02	0,08	0,05

Laboratory	Plug Φ 5 mm, sn 1655136				Plug Φ 100 mm, sn B50315									
	diameter		straightness		diameter		roundness						straightness	
							midway		up (+5 mm)		down (-5 mm)			
	$x_i - x_{nom}$ µm	u_i µm	x_i µm	u_i µm	$x_i - x_{nom}$ µm	u_i µm	x_i µm	u_i µm	x_i µm	u_i µm	x_i µm	u_i µm	x_i µm	u_i µm
INRIM Dec16	-0,21	0,045	0,05	0,05	36,39	0,055	0,12	0,02					0,08	0,05
METAS	-0,19	0,034	0,05	0,013	36,37	0,051	0,11	0,025	0,13	0,025	0,12	0,025	0,06	0,013
RISE (SP)	"-0,32 (-0,45)	0,10 (0,08)	0,10	0,15	36,22	0,10	0,12	0,01	0,14	0,01	0,11	0,01	0,14	0,15
BFKH (MKEH)	0,06	0,11			36,19	0,15	0,124	0,053	0,139	0,053	0,204	0,053		
NSAI	-0,272	0,076			36,035	0,124								
CEM	-0,09	0,075	0,030	0,030	36,16	0,075	0,124	0,009	0,137	0,009	0,106	0,009	0,055	0,031
VTT MIKES	-0,17	0,10	0,05	0,03	36,25	0,11	0,16	0,070	0,15	0,070	0,13	0,070	0,05	0,050
UME	-0,24	0,107	0,033	0,049	36,09	0,231	0,109	0,028	0,143	0,029	0,097	0,028	0,062	0,049
MBM	-0,16	0,347			36,45	0,375								
SASO-NMCC	-0,15	0,113	0,06	0,051	36,2	0,192	0,12	0,023	0,13	0,023	0,13	0,023	0,07	0,051
INTI	-0,13	0,07			36,21	0,09	0,103	0,049	0,129	0,049	0,195	0,049		
PTB	-0,17	0,037			36,27	0,045	0,107	0,050	0,121	0,050	0,180	0,050	0,053	0,050
INRIM Dec17					36,14	0,055	0,13	0,02	0,13	0,02	0,12	0,02	0,06	0,05
INRIM Dec18_Feb19	-0,30	0,05	0,04	0,05	36,10	0,06	0,13	0,02	0,14	0,02	0,14	0,02	0,07	0,05

Laboratory	Sphere Φ 20 mm, sn S2812			
	diameter		roundness / 50 UPR	
	x_i - x_{nom} *µm*	u_i *µm*	x_i *µm*	u_i *µm*
INRIM Dec16	-21,68	0,035	0,021	0,004
METAS	-21,67	0,034	0,014	0,010
RISE (SP)	-21,75	0,08	0,017	0,002
BFKH (MKEH)	-22,03	0,12	0,042	0,052
NSAI	-21,695	0,084		
CEM	-21,63	0,050	0,035	0,010
VTT MIKES	-21,72	0,075	0,10	0,070
UME	-21,88	0,104	0,032	0,026
MBM	-21,91	0,585		
SASO-NMCC	-21,51	0,118	0,03 (0,13)	0,023
INTI	-21,70	0,07	0,037	0,035
PTB	-21,68	0,036	0,034	0,050
INRIM Feb19	-21,71	0,035	0,019	0,004

9 Analysis of results

9.1 Calculation of the 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 [1-3]. The check for consistency of the comparison results with their associated uncertainties is made based on Birge ratio. The degrees of equivalence for each laboratory and each artefact with respect to the KCRV is evaluated using E_n values, along the lines of the *WG-MRA-KC-report-template*.

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

For a dataset of submitted results (diameter, roundness, straightness), the weighted Mean, W-mean *Xw* (*Xref* in the following tables) of the *n* submitted values *Xi* is :

$$\boldsymbol{Xw} = \sum_{i=1}^{n} Wi \cdot Xi \tag{1}$$

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

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

with the normalising factor *C*:

$$\boldsymbol{C = \frac{1}{\sum_{i=1}^{n}(\frac{1}{u(Xi)})^2}} \tag{3}$$

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

$$\boldsymbol{u_{int}(Xw) = \sqrt{\frac{1}{\sum_{i=1}^{n}(\frac{1}{u(Xi)})^2}}} \tag{4}$$

$$\boldsymbol{u_{ext}(Xw) = \sqrt{\frac{1}{(I-1)}\frac{\sum_{i=1}^{n} Wi\,(Xi-Xw)^2}{\sum_{i=1}^{n} Wi}}} \tag{5}$$

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

$$\boldsymbol{En = \frac{Xi-Xw}{\sqrt{[u(Xi)]^2-[u_{int}(Xw)]^2}}} \tag{6}$$

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

$$\boldsymbol{En} = \frac{\boldsymbol{Xi - Xw}}{\sqrt{[\boldsymbol{u(Xi)}]^2 + [\boldsymbol{u_{int}(Xw)}]^2}} \quad (7)$$

En values less than one (<1.0) are expected with a coverage factor *k*=2.

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.

$$\boldsymbol{R_B} = \frac{\boldsymbol{u_{ext}\ (Xw)}}{\boldsymbol{u_{int}(Xw)}} \quad (8)$$

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

$$\boldsymbol{R_B} < \sqrt{\boldsymbol{1} + \sqrt{\frac{\boldsymbol{8}}{\boldsymbol{n-1}}}} \quad (9)$$

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

Tables and graphs of the analysis of results are presented in the following for each gauge and measurand (diameter, roundness and straightness). *In primis*, the analysis is performed for the two independent groups/loops while the linking of the two groups is discussed in a subsequent section of this report.

The graphs show the differences of the submitted results from the calculated *KCRV* with the expanded (*k=2*) uncertainty of the difference. Together with the *W-mean* (X_{ref}) and *En* values (coverage factor *k*=2) are given the uncertainty $u_{ext}(X_{ref})$, the normalising factor *C* and Birge ratio R_B . The two red dashed lines represent the ± U_{Xref} .

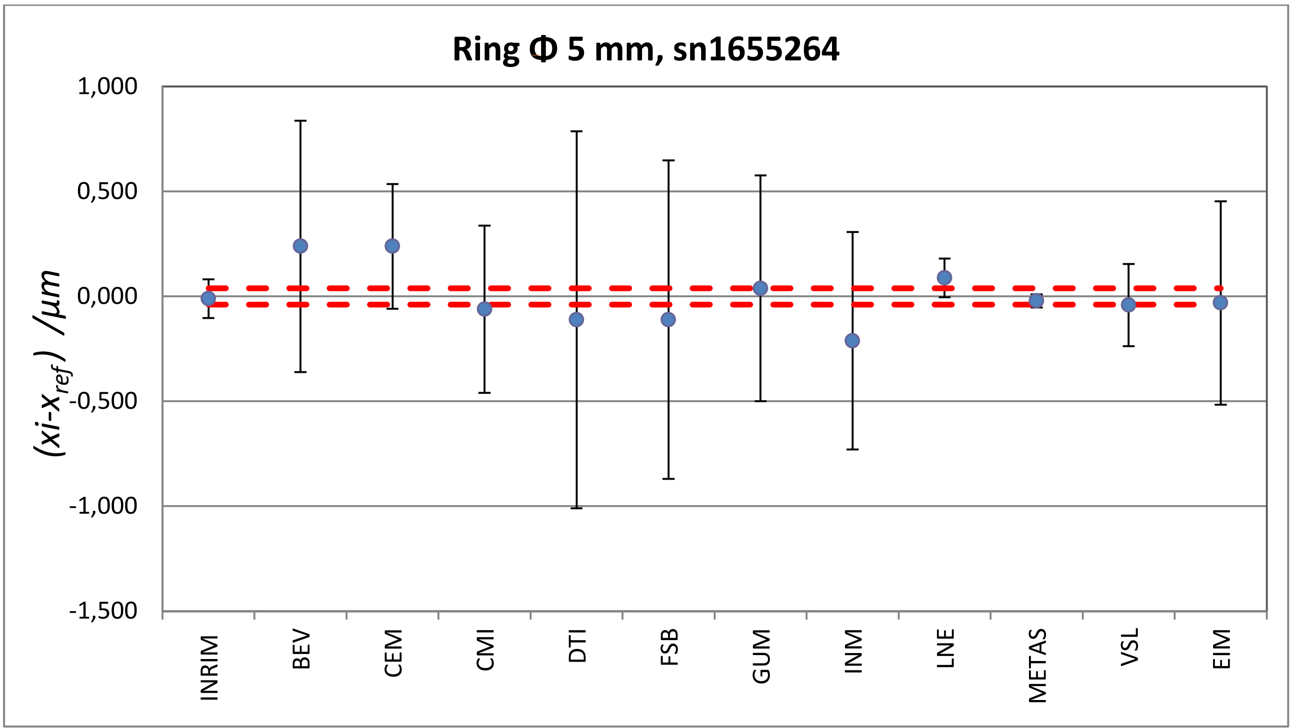
The pilot laboratory contributes only once to the calculation of the reference values, namely by the measurements performed just before starting the circulation of gauges. Thus, mid, final and after final (if any) measurements by the pilot are excluded. Due to a lack of time, roundness measurements of the 80 mm ring and of the 100 mm plug of the group2 were not completed by pilot before starting the circulation as it was scheduled. Thus, the results from final measurements by the pilot of the roundness of these gauges are contributing to the calculation of the reference values.

When the Birge ratio is greater than the expected value (9) the reference value is recalculated by excluding, step by step, the possible outliers, i.e., the results with the highest En values. The table with all the results “on” and the table with some excluded results, if any, are subsequently shown for each gauge.

Group1 - Tables of results

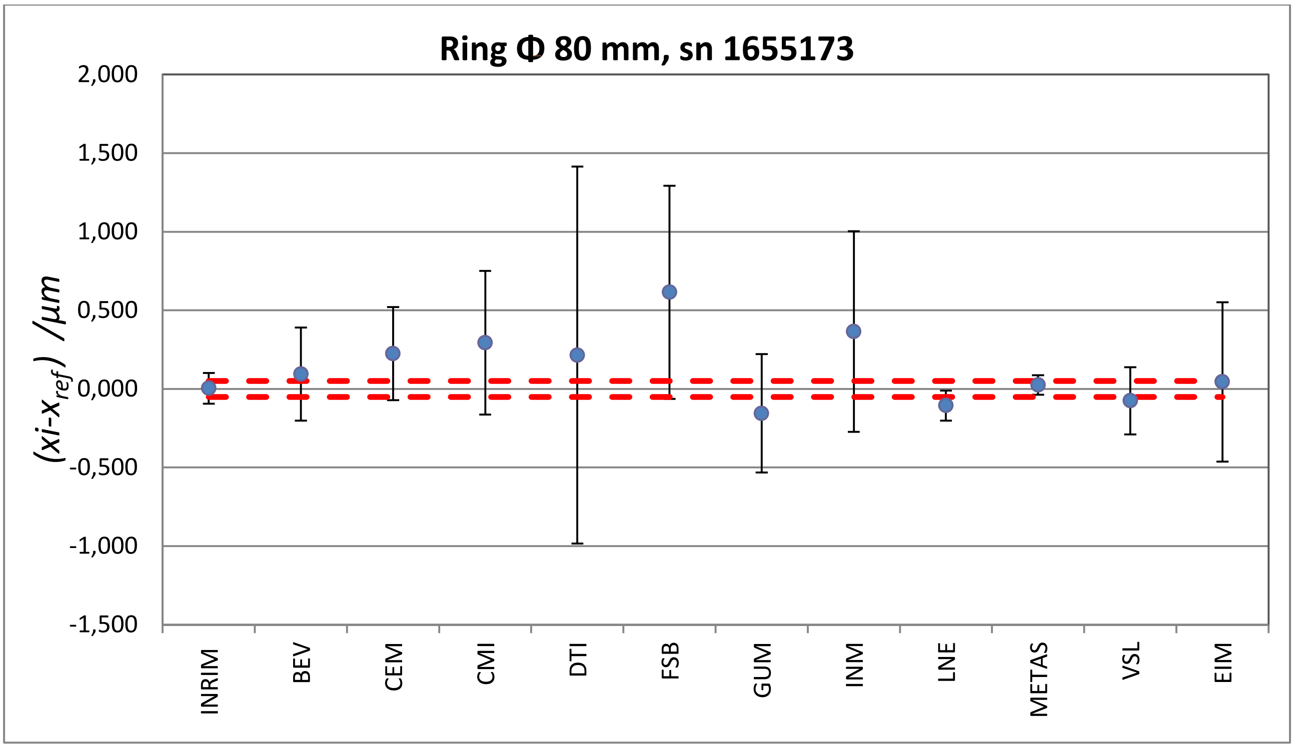
Laboratory	Ring Φ 5 mm, sn1655264						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	-1,500	0,050	1	-0,01	0,09	0,12	0,15
BEV	-1,250	0,300	1	0,24	0,60	0,40	0,00
CEM	-1,250	0,150	1	0,24	0,30	0,80	0,02
CMI	-1,550	0,200	1	-0,06	0,40	0,15	0,01
DTI	-1,600	0,450	1	-0,11	0,90	0,12	0,00
FSB	-1,600	0,380	1	-0,11	0,76	0,15	0,00
GUM	-1,450	0,270	1	0,04	0,54	0,07	0,01
INM	-1,700	0,260	1	-0,21	0,52	0,41	0,01
LNE	-1,400	0,050	1	0,09	0,09	0,96	0,15
METAS	-1,510	0,025	1	-0,02	0,03	0,68	0,61
VSL	-1,530	0,100	1	-0,04	0,20	0,21	0,04
EIM	-1,520	0,243	1	-0,03	0,48	0,06	0,01

Reference value				Consistency	
x_{ref} µm	C µm^2	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
-1,489	0,00038	0,019	0,017	0,86	1,36



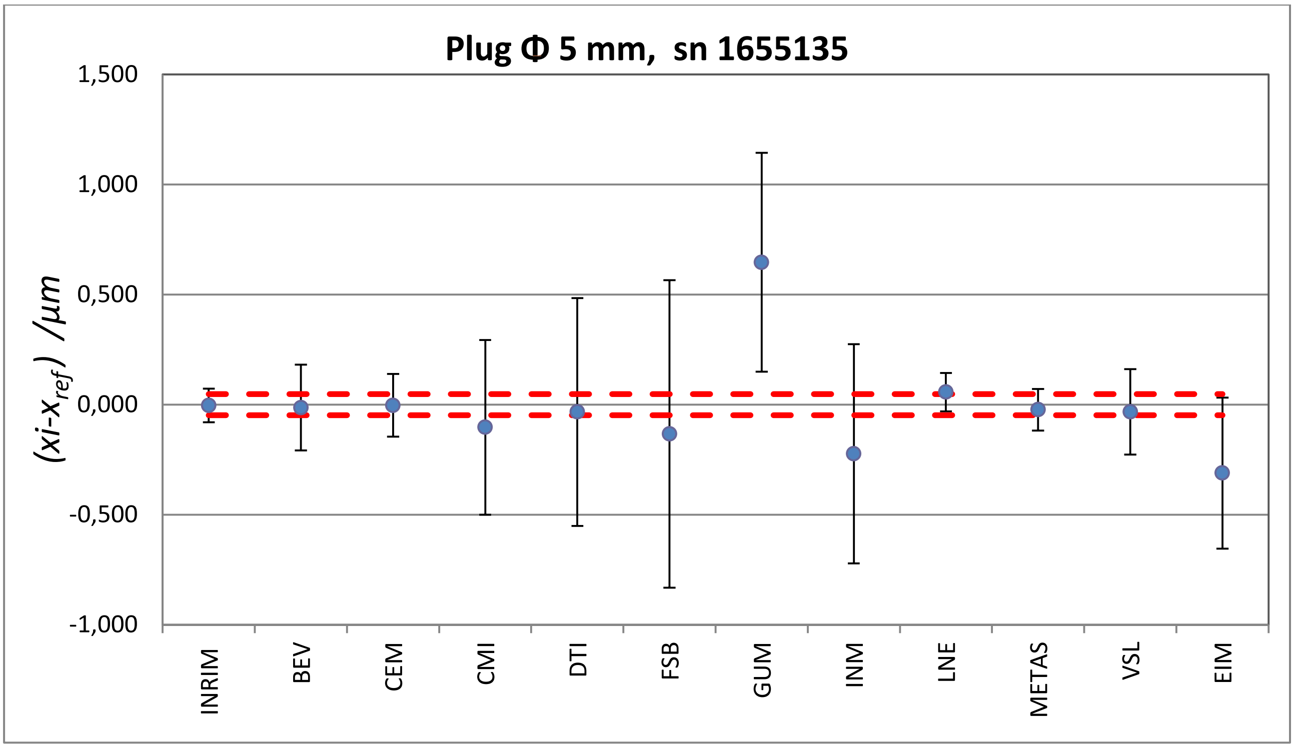
Laboratory	Ring Φ 80 mm, sn 1655173						
	x_i - x_{nom} µm	u_i µm	on/off	$(x_i$-$x_{ref})$ µm	$U(x_i$-$x_{ref})$ µm	En	w_i
INRIM	-0,610	0,055	1	0,00	0,10	0,05	0,21
BEV	-0,520	0,150	1	0,09	0,30	0,32	0,03
CEM	-0,390	0,150	1	0,22	0,30	0,76	0,03
CMI	-0,320	0,230	1	0,29	0,46	0,64	0,01
DTI	-0,400	0,600	1	0,21	1,20	0,18	0,00
FSB	0,000	0,340	1	0,61	0,68	0,91	0,01
GUM	-0,770	0,190	1	-0,16	0,38	0,41	0,02
INM	-0,250	0,320	1	0,36	0,64	0,57	0,01
LNE	-0,720	0,054	1	-0,11	0,10	1,11	0,22
METAS	-0,590	0,040	1	0,02	0,06	0,40	0,40
VSL	-0,690	0,110	1	-0,08	0,21	0,35	0,05
EIM	-0,570	0,255	1	0,04	0,51	0,09	0,01

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
-0,615	0,00064	0,025	0,029	1,14	1,36



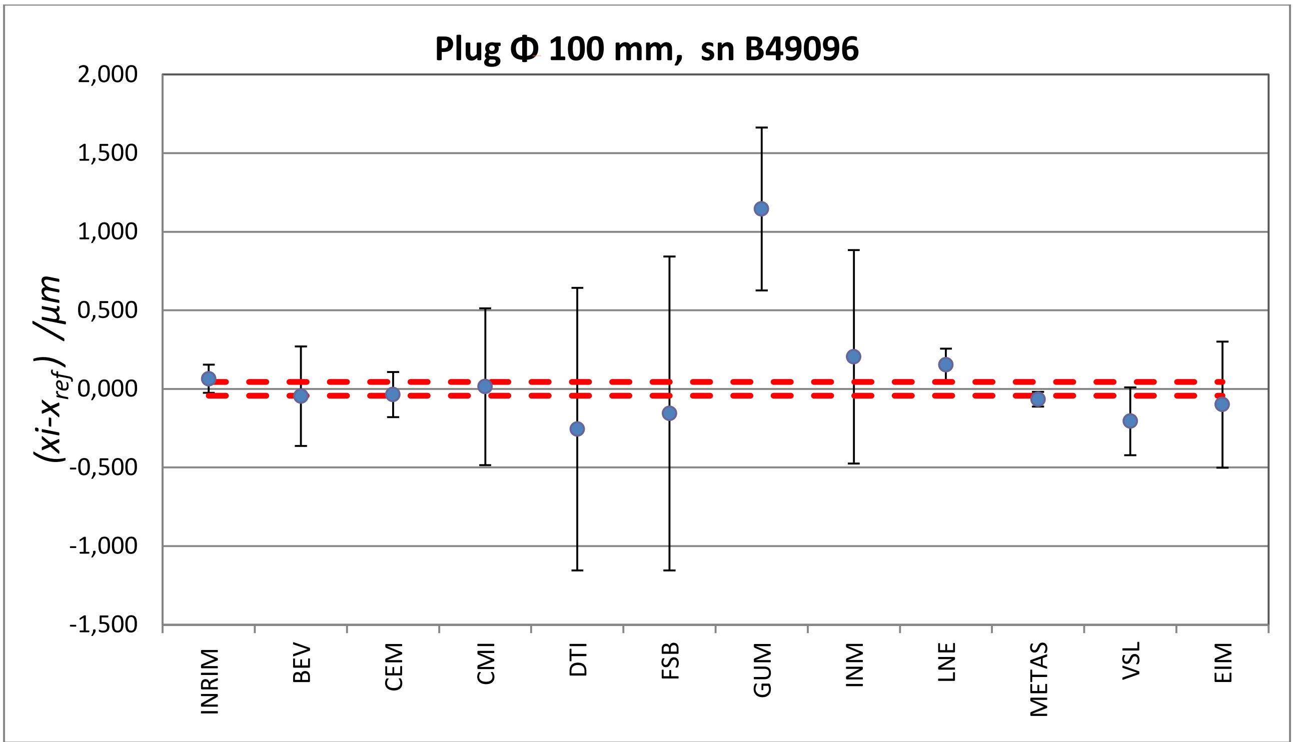
Laboratory	Plug Φ 5 mm, sn 1655135						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	-0,570	0,045	1	0,00	0,08	0,04	0,28
BEV	-0,580	0,100	1	-0,01	0,19	0,07	0,06
CEM	-0,570	0,075	1	0,00	0,14	0,02	0,10
CMI	-0,670	0,200	1	-0,10	0,40	0,26	0,01
DTI	-0,600	0,260	1	-0,03	0,52	0,06	0,01
FSB	-0,700	0,350	1	-0,13	0,70	0,19	0,00
GUM	0,080	0,250	1	0,65	0,50	1,30	0,01
INM	-0,790	0,250	1	-0,22	0,50	0,45	0,01
LNE	-0,510	0,050	1	0,06	0,09	0,65	0,23
METAS	-0,590	0,053	1	-0,02	0,09	0,24	0,20
VSL	-0,600	0,100	1	-0,03	0,19	0,17	0,06
EIM	-0,878	0,173	1	-0,31	0,34	0,91	0,02

Reference value				Consistency	
x_{ref} µm	C $µm^2$	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
-0,567	0,00057	0,024	0,026	1,08	1,36



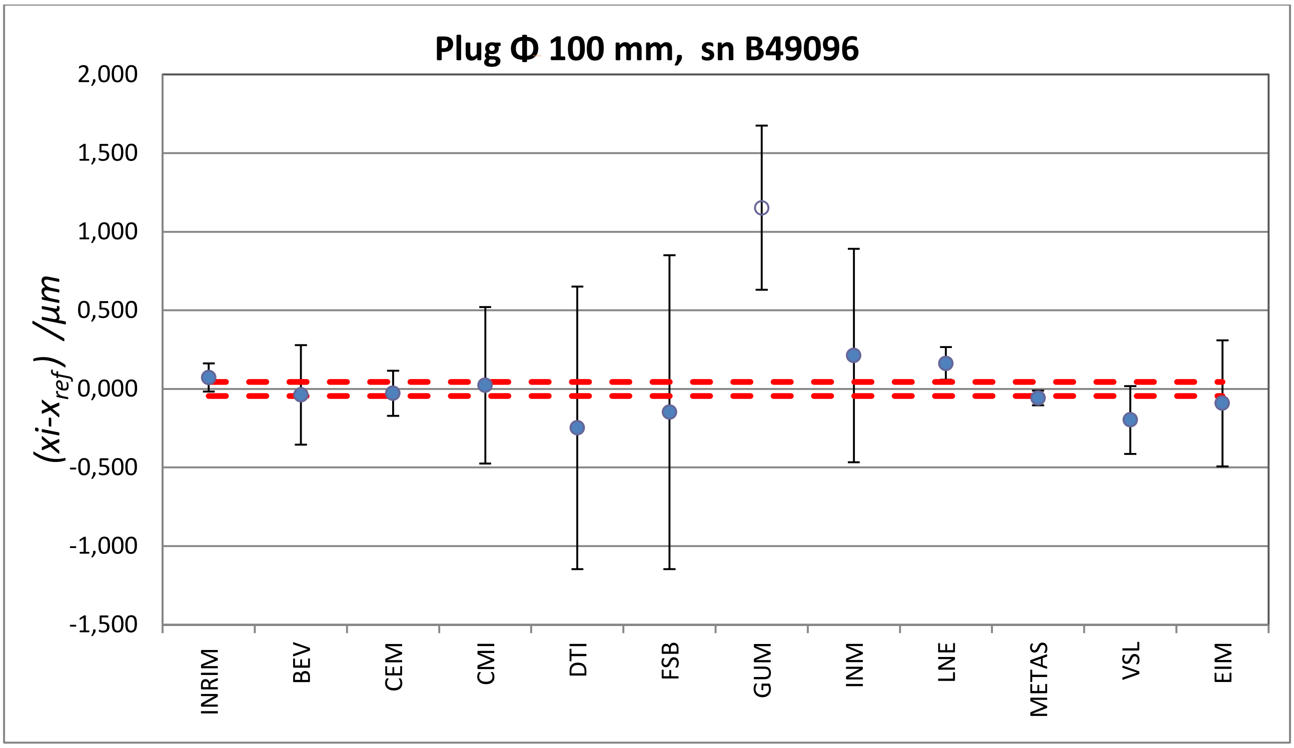
Laboratory	Plug Φ 100 mm, sn B49096						
	x_i - x_{nom} µm	u_i µm	on/off	$(x_i$-$x_{ref})$ µm	$U(x_i$-$x_{ref})$ µm	En	w_i
INRIM	58,820	0,050	1	0,06	0,09	0,71	0,19
BEV	58,710	0,160	1	-0,05	0,32	0,14	0,02
CEM	58,720	0,075	1	-0,04	0,14	0,25	0,09
CMI	58,770	0,250	1	0,01	0,50	0,03	0,01
DTI	58,500	0,450	1	-0,26	0,90	0,28	0,00
FSB	58,600	0,500	1	-0,16	1,00	0,16	0,00
GUM	59,900	0,260	1	1,14	0,52	2,21	0,01
INM	58,960	0,340	1	0,20	0,68	0,30	0,00
LNE	58,910	0,056	1	0,15	0,10	1,50	0,15
METAS	58,690	0,032	1	-0,07	0,05	1,42	0,47
VSL	58,550	0,110	1	-0,21	0,22	0,95	0,04
EIM	58,656	0,202	1	-0,10	0,40	0,25	0,01

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
58,756	0,00048	0,022	0,041	1,85	1,36



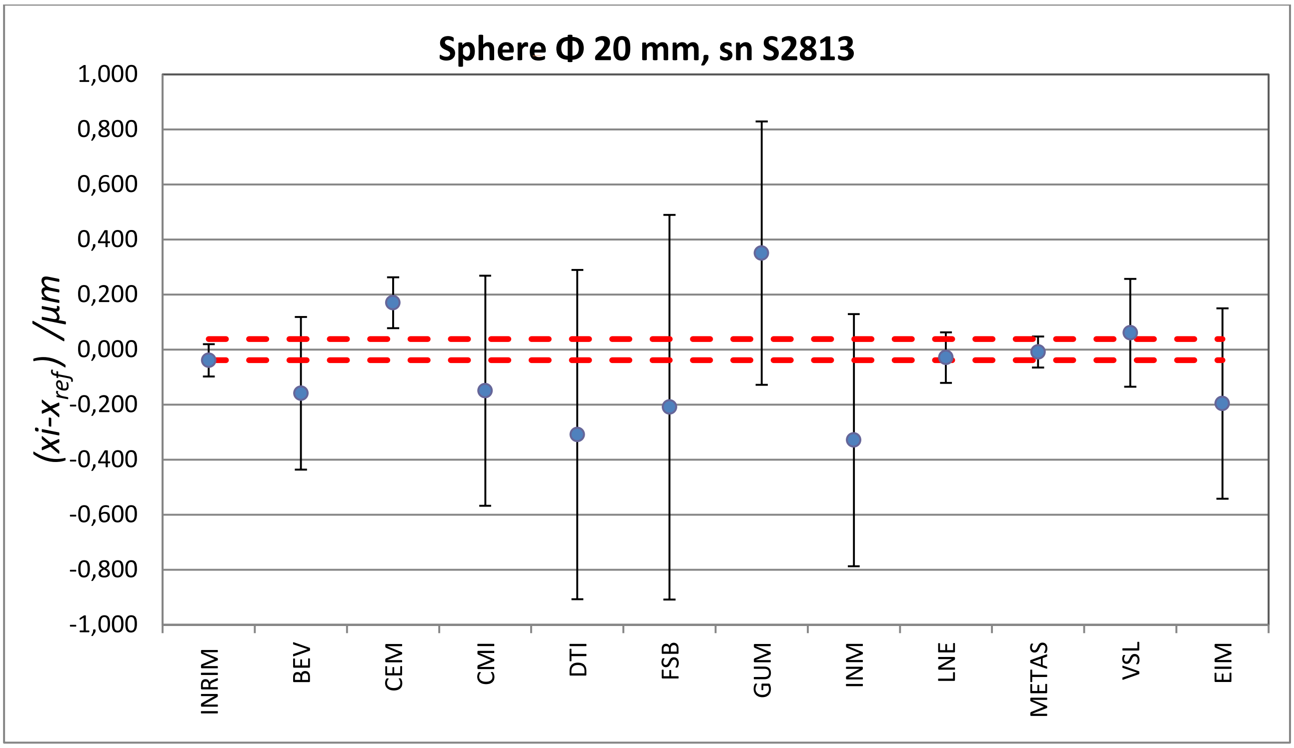
Laboratory	Plug Φ 100 mm, sn B49096						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	$U(x_i$-$x_{ref})$ µm	En	w_i
INRIM	58,820	0,050	1	0,07	0,09	0,81	0,19
BEV	58,710	0,160	1	-0,04	0,32	0,12	0,02
CEM	58,720	0,075	1	-0,03	0,14	0,19	0,09
CMI	58,770	0,250	1	0,02	0,50	0,05	0,01
DTI	58,500	0,450	1	-0,25	0,90	0,28	0,00
FSB	58,600	0,500	1	-0,15	1,00	0,15	0,00
GUM	59,900	0,260	0	1,15	0,52	2,21	0,00
INM	58,960	0,340	1	0,21	0,68	0,31	0,00
LNE	58,910	0,056	1	0,16	0,10	1,58	0,16
METAS	58,690	0,032	1	-0,06	0,05	1,24	0,48
VSL	58,550	0,110	1	-0,20	0,22	0,92	0,04
EIM	58,656	0,202	1	-0,09	0,40	0,23	0,01

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
58,748	0,00049	0,022	0,030	1,35	1,38



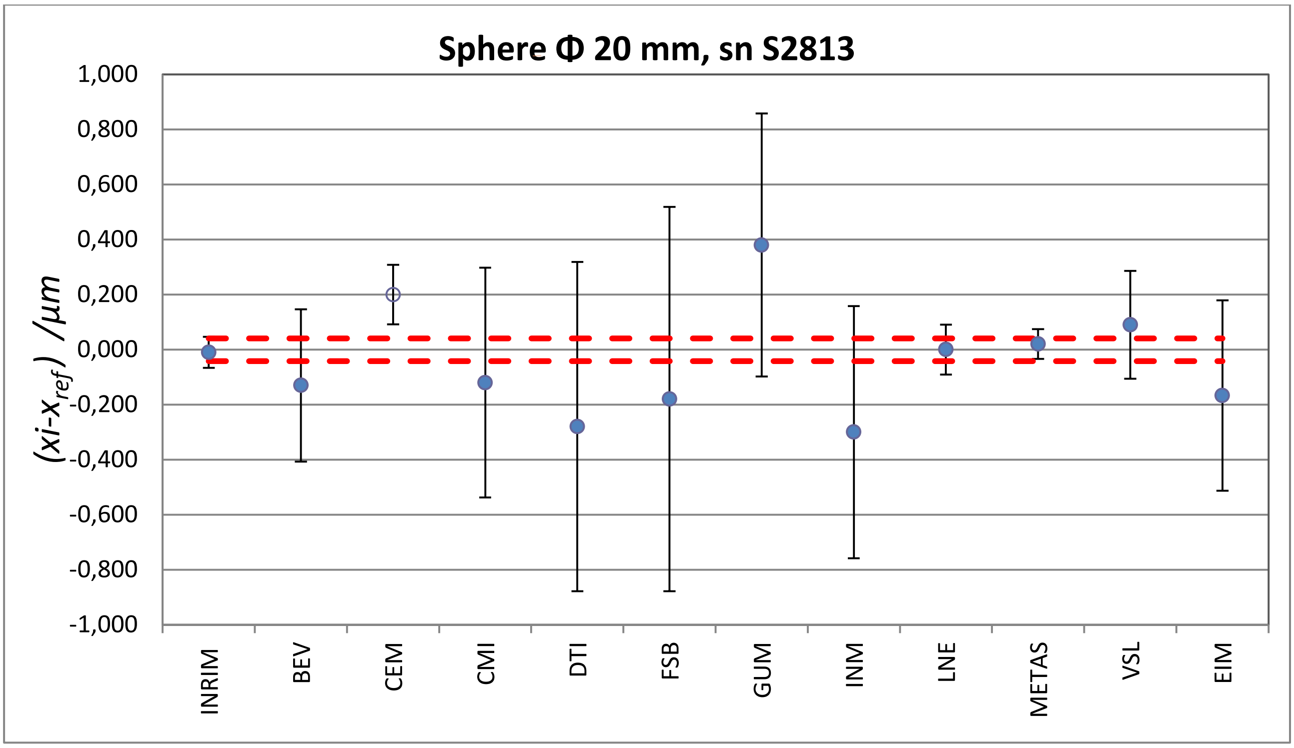
Laboratory	Sphere Φ 20 mm, sn S2813						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	-23,230	0,035	1	-0,04	0,06	0,67	0,30
BEV	-23,350	0,140	1	-0,16	0,28	0,57	0,02
CEM	-23,020	0,050	1	0,17	0,09	1,85	0,15
CMI	-23,340	0,210	1	-0,15	0,42	0,36	0,01
DTI	-23,500	0,300	1	-0,31	0,60	0,52	0,00
FSB	-23,400	0,350	1	-0,21	0,70	0,30	0,00
GUM	-22,840	0,240	1	0,35	0,48	0,73	0,01
INM	-23,520	0,230	1	-0,33	0,46	0,72	0,01
LNE	-23,220	0,050	1	-0,03	0,09	0,31	0,15
METAS	-23,200	0,034	1	-0,01	0,06	0,16	0,32
VSL	-23,130	0,100	1	0,06	0,20	0,31	0,04
EIM	-23,387	0,174	1	-0,20	0,35	0,57	0,01

Reference value				Consistency	
x_{ref} µm	C µm²	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
-23,191	0,00036	0,019	0,027	1,43	1,36



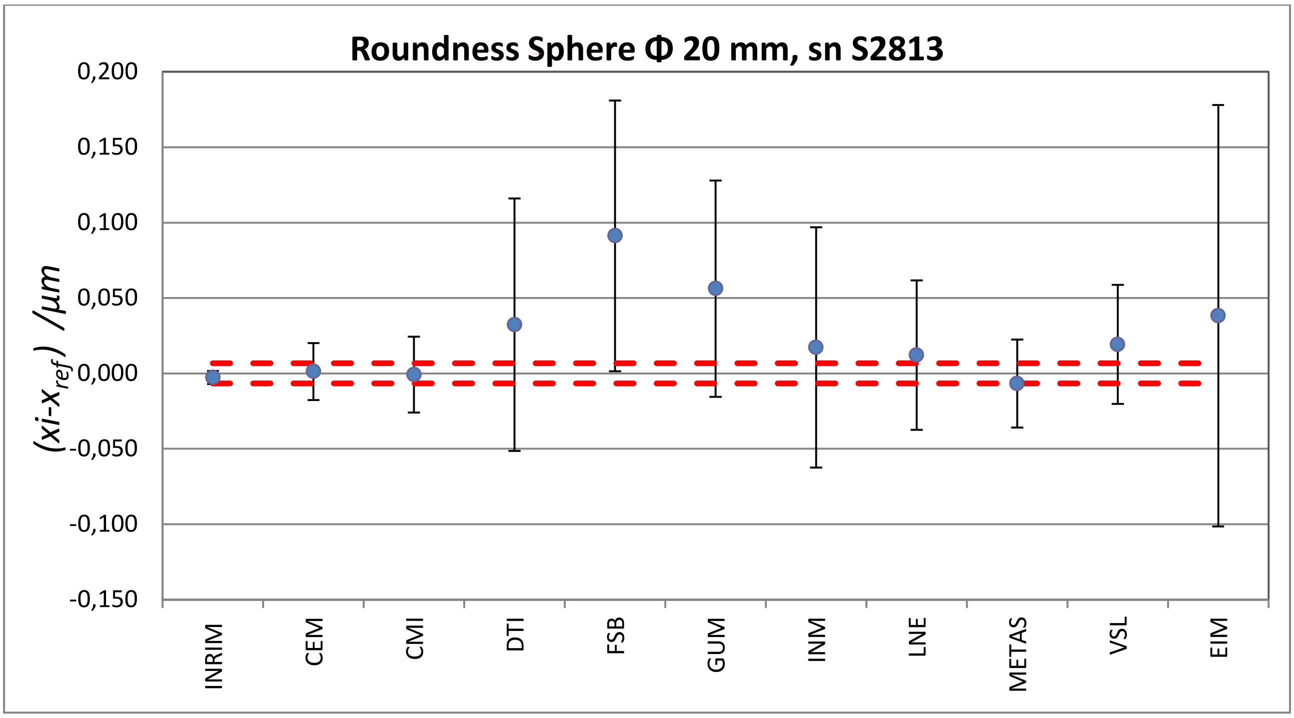
Laboratory	Sphere Φ 20 mm, sn S2813						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	-23,230	0,035	1	-0,01	0,06	0,17	0,35
BEV	-23,350	0,140	1	-0,13	0,28	0,47	0,02
CEM	-23,020	0,050	0	0,20	0,11	1,85	0,00
CMI	-23,340	0,210	1	-0,12	0,42	0,29	0,01
DTI	-23,500	0,300	1	-0,28	0,60	0,47	0,00
FSB	-23,400	0,350	1	-0,18	0,70	0,26	0,00
GUM	-22,840	0,240	1	0,38	0,48	0,79	0,01
INM	-23,520	0,230	1	-0,30	0,46	0,65	0,01
LNE	-23,220	0,050	1	0,00	0,09	0,00	0,17
METAS	-23,200	0,034	1	0,02	0,05	0,37	0,37
VSL	-23,130	0,100	1	0,09	0,20	0,46	0,04
EIM	-23,387	0,174	1	-0,17	0,35	0,48	0,01

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
-23,220	0,00043	0,021	0,019	0,93	1,38



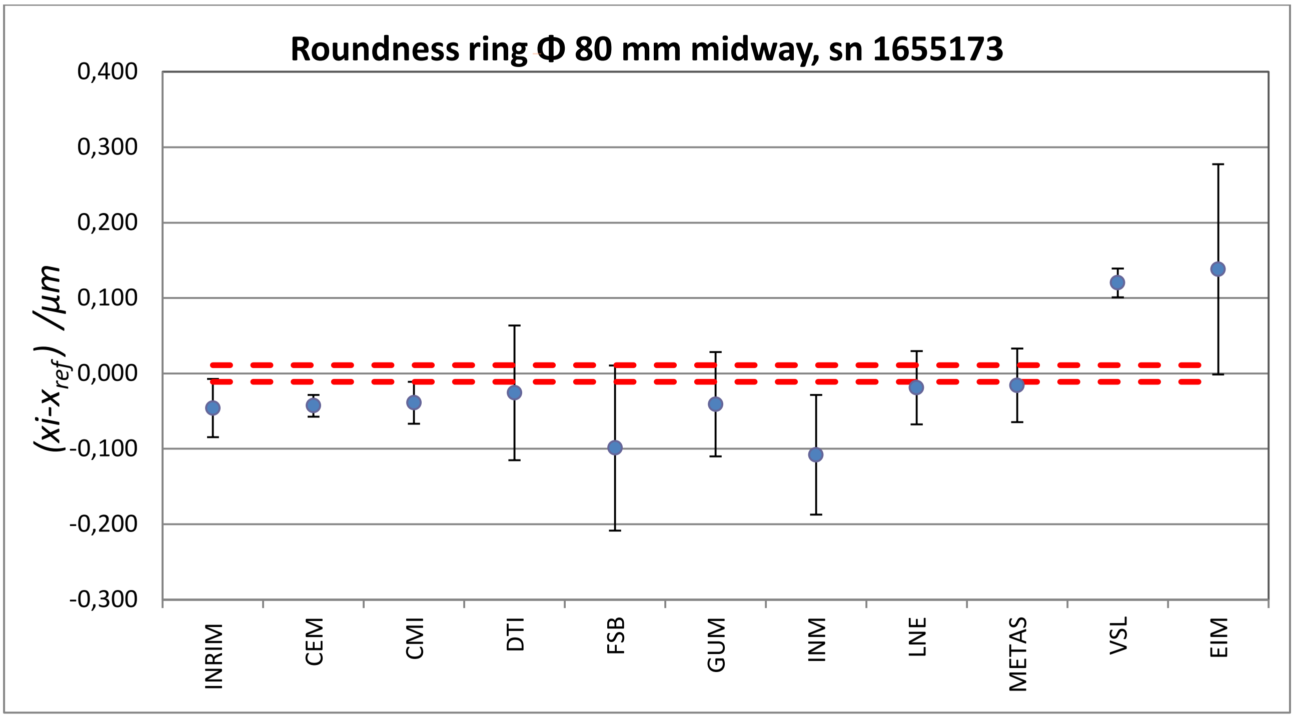
Laboratory	Roundness Sphere Φ 20 mm, sn S2813						
	x_i - x_{nom} µm	u_i µm	on/off	$(x_i$-$x_{ref})$ µm	$U(x_i$-$x_{ref})$ µm	En	w_i
INRIM	0,025	0,004	1	-0,003	0,004	0,62	0,70
CEM	0,029	0,010	1	0,001	0,019	0,07	0,11
CMI	0,027	0,013	1	-0,001	0,025	0,03	0,07
DTI	0,060	0,042	1	0,032	0,084	0,39	0,01
FSB	0,119	0,045	1	0,091	0,090	1,02	0,01
GUM	0,084	0,036	1	0,056	0,072	0,78	0,01
INM	0,045	0,040	1	0,017	0,080	0,22	0,01
LNE	0,040	0,025	1	0,012	0,050	0,25	0,02
METAS	0,021	0,015	1	-0,007	0,029	0,23	0,05
VSL	0,047	0,020	1	0,019	0,039	0,49	0,03
EIM	0,066	0,070	1	0,038	0,140	0,27	0,00

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,028	1,12E-05	0,003	0,003	0,97	1,38



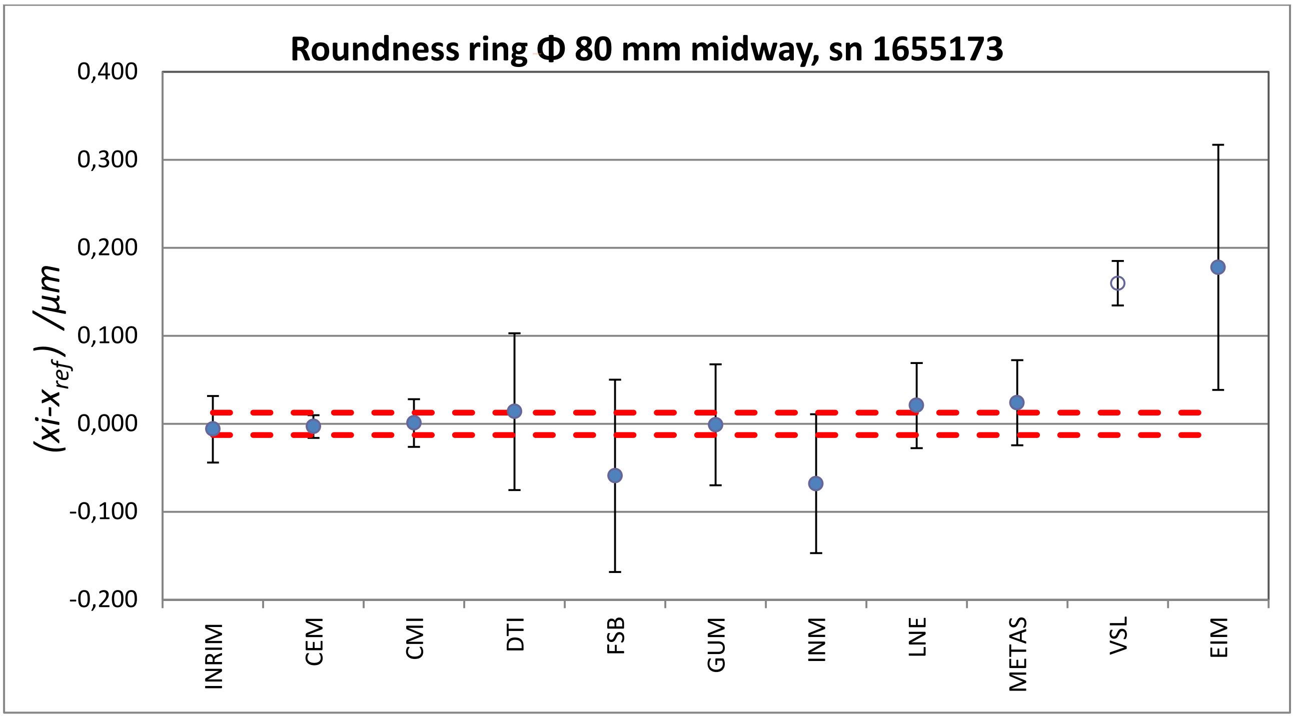
Laboratory	Roundness ring Φ 80 mm midway, sn 1655173						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,130	0,020	1	-0,046	0,038	1,19	0,08
CEM	0,133	0,009	1	-0,043	0,014	3,01	0,37
CMI	0,137	0,015	1	-0,039	0,028	1,39	0,13
DTI	0,150	0,045	1	-0,026	0,089	0,29	0,01
FSB	0,077	0,055	1	-0,099	0,109	0,90	0,01
GUM	0,135	0,035	1	-0,041	0,069	0,59	0,02
INM	0,068	0,040	1	-0,108	0,079	1,36	0,02
LNE	0,157	0,025	1	-0,019	0,049	0,39	0,05
METAS	0,160	0,025	1	-0,016	0,049	0,33	0,05
VSL	0,296	0,011	1	0,120	0,019	6,30	0,25
EIM	0,314	0,070	1	0,138	0,140	0,99	0,01

Reference value				Consistency	
x_{ref}	C	$u(x_{ref})$	u_{ext}	R_B	Limit
µm	µm^2	µm	µm		
0,176	3,01E-05	0,005	0,023	4,14	1,38



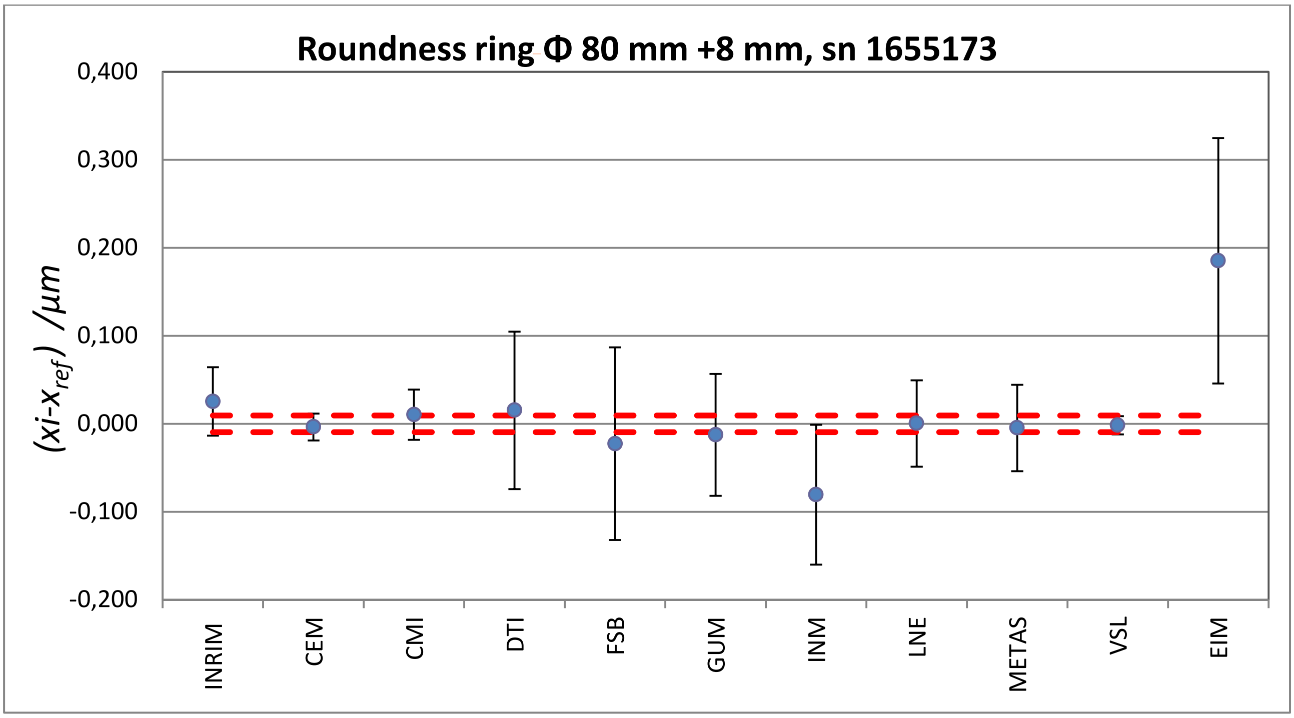
Laboratory	Roundness ring Φ 80 mm midway, sn 1655173						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,130	0,020	1	-0,006	0,038	0,16	0,10
CEM	0,133	0,009	1	-0,003	0,013	0,25	0,49
CMI	0,137	0,015	1	0,001	0,027	0,03	0,18
DTI	0,150	0,045	1	0,014	0,089	0,15	0,02
FSB	0,077	0,055	1	-0,059	0,109	0,54	0,01
GUM	0,135	0,035	1	-0,001	0,069	0,02	0,03
INM	0,068	0,040	1	-0,068	0,079	0,86	0,03
LNE	0,157	0,025	1	0,021	0,048	0,43	0,06
METAS	0,160	0,025	1	0,024	0,048	0,49	0,06
VSL	0,296	0,011	0	0,160	0,025	6,30	0,00
EIM	0,314	0,070	1	0,178	0,139	1,28	0,01

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,136	4,01E-05	0,006	0,007	1,18	1,39



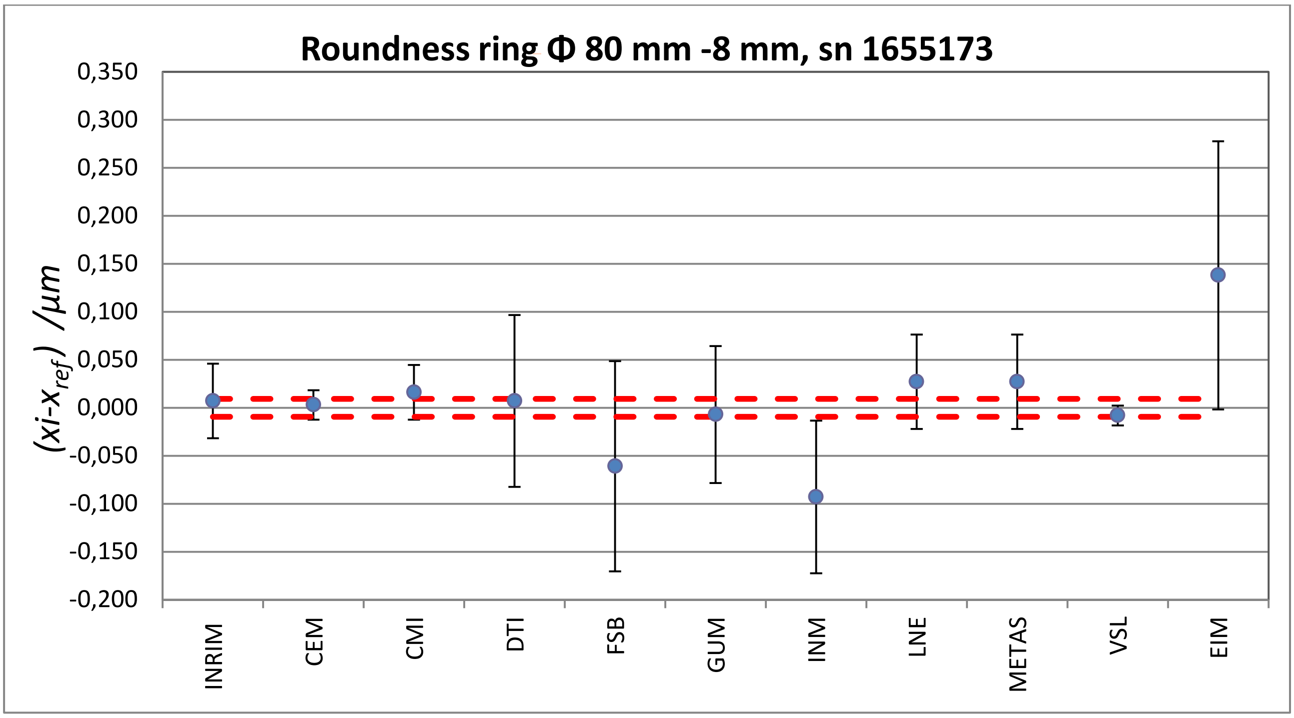
Laboratory	Roundness ring Φ 80 mm +8 mm, sn 1655173						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,170	0,020	1	0,025	0,039	0,65	0,06
CEM	0,141	0,009	1	-0,004	0,015	0,24	0,27
CMI	0,155	0,015	1	0,010	0,028	0,36	0,10
DTI	0,160	0,045	1	0,015	0,090	0,17	0,01
FSB	0,122	0,055	1	-0,023	0,110	0,21	0,01
GUM	0,132	0,035	1	-0,013	0,069	0,18	0,02
INM	0,064	0,040	1	-0,081	0,079	1,02	0,01
LNE	0,145	0,025	1	0,000	0,049	0,01	0,04
METAS	0,140	0,025	1	-0,005	0,049	0,10	0,04
VSL	0,143	0,007	1	-0,002	0,010	0,16	0,45
EIM	0,330	0,070	1	0,185	0,140	1,33	0,00

Reference value				Consistency	
x_{ref} µm	C µm²	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
0,145	2,20E-05	0,005	0,006	1,18	1,38



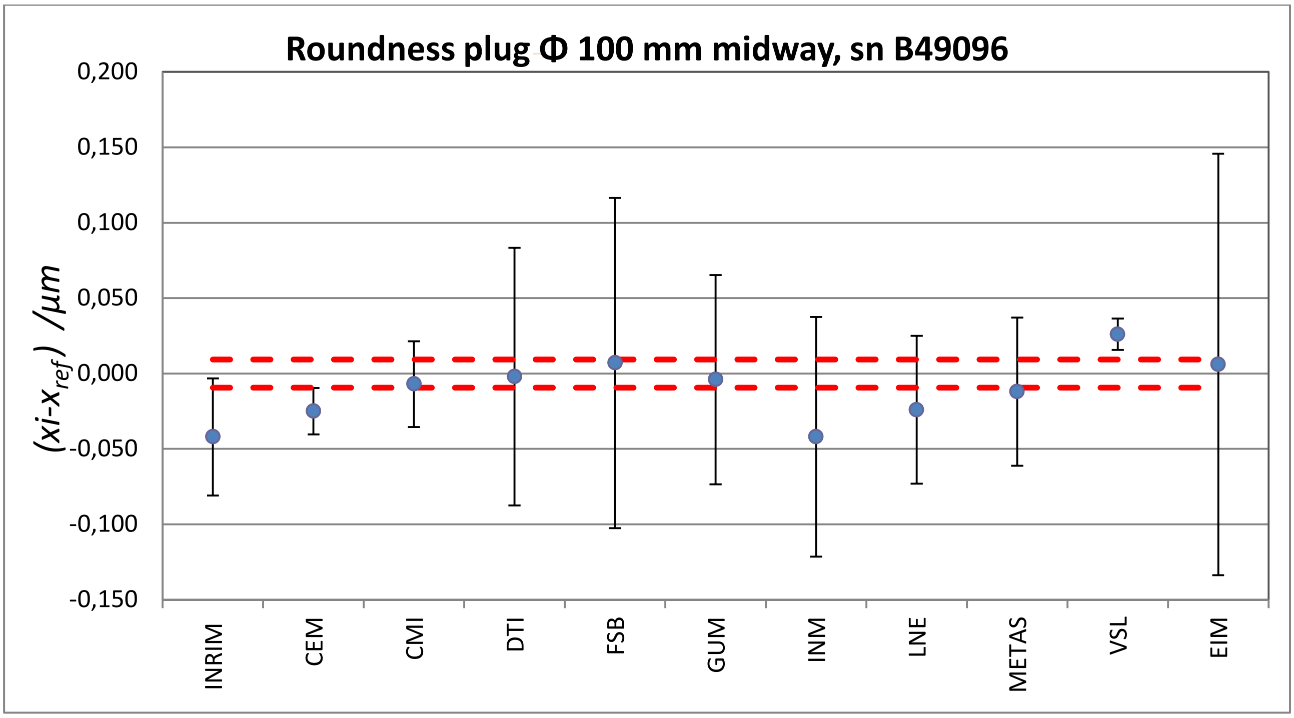
Laboratory	Roundness ring Φ 80 mm -8 mm, sn 1655173						
	x_i - x_{nom} µm	u_i µm	*on/off*	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	*En*	w_i
INRIM	0,170	0,020	1	0,007	0,039	0,18	0,06
CEM	0,166	0,009	1	0,003	0,015	0,20	0,27
CMI	0,179	0,015	1	0,016	0,028	0,56	0,10
DTI	0,170	0,045	1	0,007	0,090	0,08	0,01
FSB	0,102	0,055	1	-0,061	0,110	0,56	0,01
GUM	0,156	0,036	1	-0,007	0,071	0,10	0,02
INM	0,070	0,040	1	-0,093	0,079	1,17	0,01
LNE	0,190	0,025	1	0,027	0,049	0,55	0,04
METAS	0,190	0,025	1	0,027	0,049	0,55	0,04
VSL	0,155	0,007	1	-0,008	0,010	0,76	0,45
EIM	0,301	0,070	1	0,138	0,140	0,99	0,00

Reference value				Consistency	
x_{ref}	C	u(x_{ref})	u_{ext}	R_B	Limit
µm	µm²	µm	µm		
0,163	2,21E-05	0,005	0,006	1,25	1,38



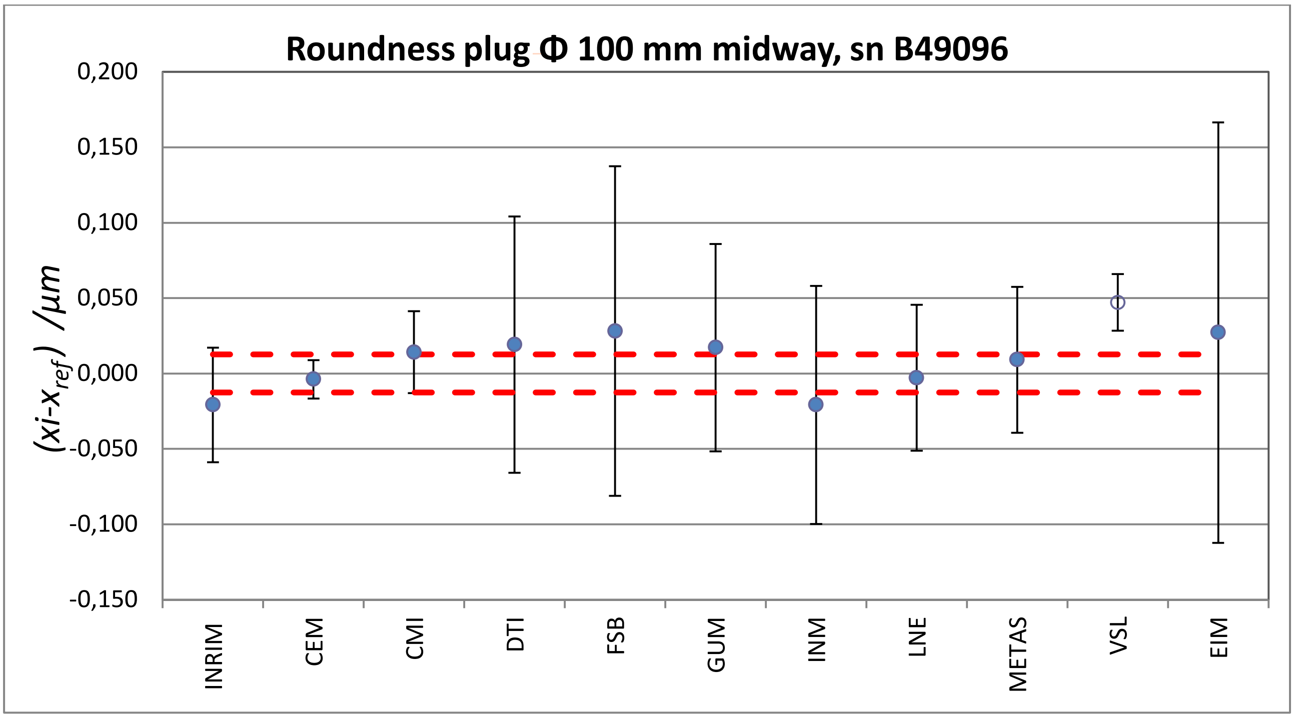
Laboratory	Roundness plug Φ 100 mm midway, sn B49096						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,070	0,020	1	-0,042	0,039	1,08	0,06
CEM	0,087	0,009	1	-0,025	0,015	1,63	0,27
CMI	0,105	0,015	1	-0,007	0,028	0,25	0,10
DTI	0,110	0,043	1	-0,002	0,085	0,02	0,01
FSB	0,119	0,055	1	0,007	0,110	0,06	0,01
GUM	0,108	0,035	1	-0,004	0,069	0,06	0,02
INM	0,070	0,040	1	-0,042	0,079	0,53	0,01
LNE	0,088	0,025	1	-0,024	0,049	0,49	0,04
METAS	0,100	0,025	1	-0,012	0,049	0,24	0,04
VSL	0,138	0,007	1	0,026	0,010	2,50	0,45
EIM	0,118	0,070	1	0,006	0,140	0,04	0,00

Reference value				Consistency	
x_{ref} µm	C µm^2	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
0,112	2,20E-05	0,005	0,008	1,69	1,38



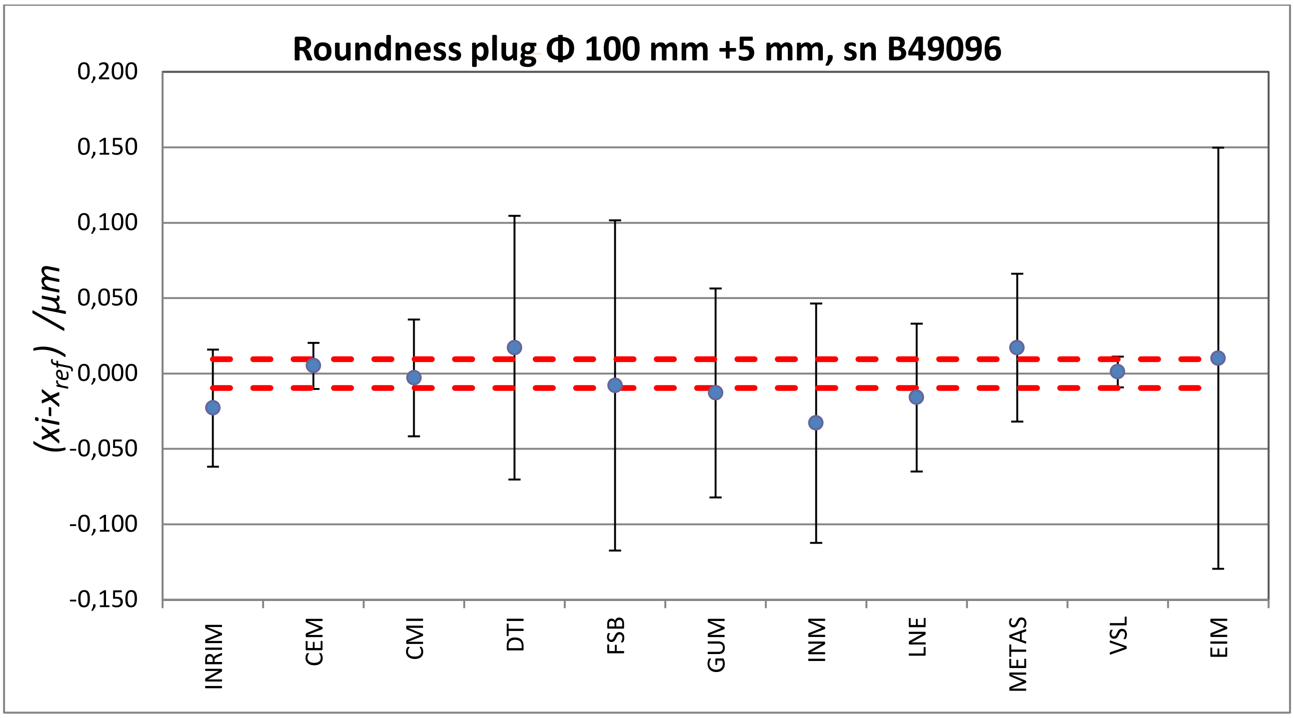
Laboratory	Roundness plug Φ 100 mm midway, sn B49096						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,070	0,020	1	-0,021	0,038	0,55	0,10
CEM	0,087	0,009	1	-0,004	0,013	0,30	0,49
CMI	0,105	0,015	1	0,014	0,027	0,52	0,18
DTI	0,110	0,043	1	0,019	0,085	0,23	0,02
FSB	0,119	0,055	1	0,028	0,109	0,26	0,01
GUM	0,108	0,035	1	0,017	0,069	0,25	0,03
INM	0,070	0,040	1	-0,021	0,079	0,26	0,02
LNE	0,088	0,025	1	-0,003	0,048	0,06	0,06
METAS	0,100	0,025	1	0,009	0,048	0,19	0,06
VSL	0,138	0,007	0	0,047	0,019	2,50	0,00
EIM	0,118	0,070	1	0,027	0,139	0,19	0,01

Reference value				Consistency	
x_{ref}	C	u(x_{ref})	u_{ext}	R_B	Limit
µm	µm^2	µm	µm		
0,091	4,00E-05	0,006	0,004	0,62	1,39



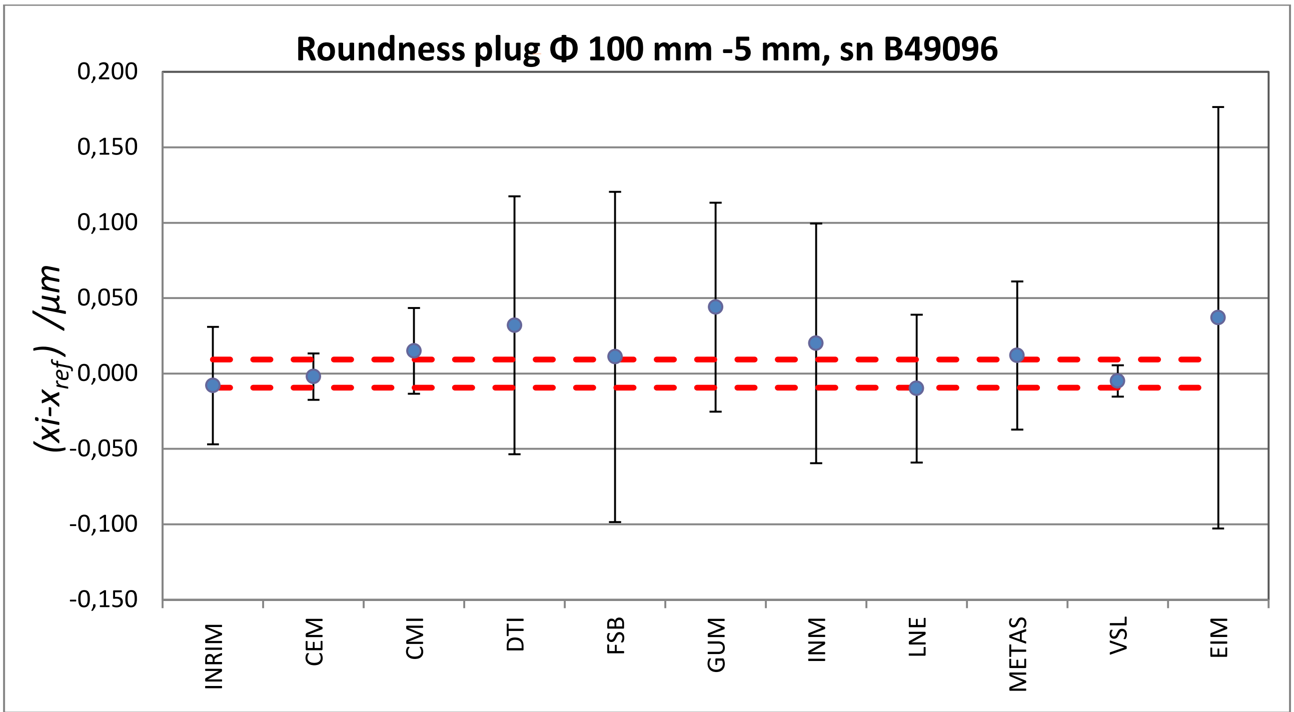
Laboratory	Roundness plug Φ 100 mm +5 mm, sn B49096						
	x_i - x_{nom} µm	u_i µm	*on/off*	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	*En*	w_i
INRIM	0,100	0,020	1	-0,023	0,039	0,59	0,06
CEM	0,128	0,009	1	0,005	0,015	0,33	0,28
CMI	0,120	0,020	1	-0,003	0,039	0,07	0,06
DTI	0,140	0,044	1	0,017	0,087	0,20	0,01
FSB	0,115	0,055	1	-0,008	0,110	0,07	0,01
GUM	0,110	0,035	1	-0,013	0,069	0,19	0,02
INM	0,090	0,040	1	-0,033	0,079	0,41	0,01
LNE	0,107	0,025	1	-0,016	0,049	0,32	0,04
METAS	0,140	0,025	1	0,017	0,049	0,35	0,04
VSL	0,124	0,007	1	0,001	0,010	0,11	0,47
EIM	0,133	0,070	1	0,010	0,140	0,07	0,00

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,123	2,30E-05	0,005	0,003	0,60	1,38



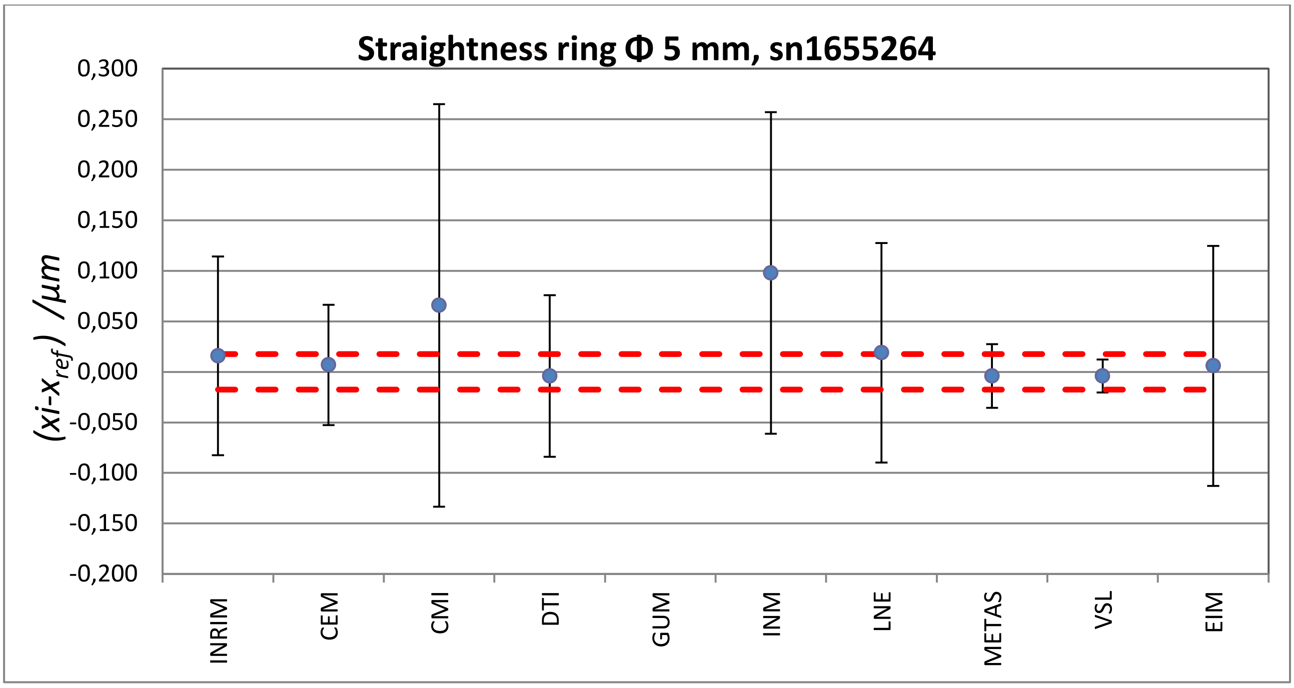
Laboratory	Roundness plug Φ 100 mm -5 mm, sn B49096						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,070	0,020	1	-0,008	0,039	0,21	0,06
CEM	0,076	0,009	1	-0,002	0,015	0,13	0,27
CMI	0,093	0,015	1	0,015	0,028	0,53	0,10
DTI	0,110	0,043	1	0,032	0,085	0,37	0,01
FSB	0,089	0,055	1	0,011	0,110	0,10	0,01
GUM	0,122	0,035	1	0,044	0,069	0,63	0,02
INM	0,098	0,040	1	0,020	0,079	0,25	0,01
LNE	0,068	0,025	1	-0,010	0,049	0,20	0,04
METAS	0,090	0,025	1	0,012	0,049	0,24	0,04
VSL	0,073	0,007	1	-0,005	0,010	0,48	0,45
EIM	0,115	0,070	1	0,037	0,140	0,26	0,00

Reference value				Consistency	
x_{ref} µm	C µm²	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
0,078	2,20E-05	0,005	0,003	0,69	1,38



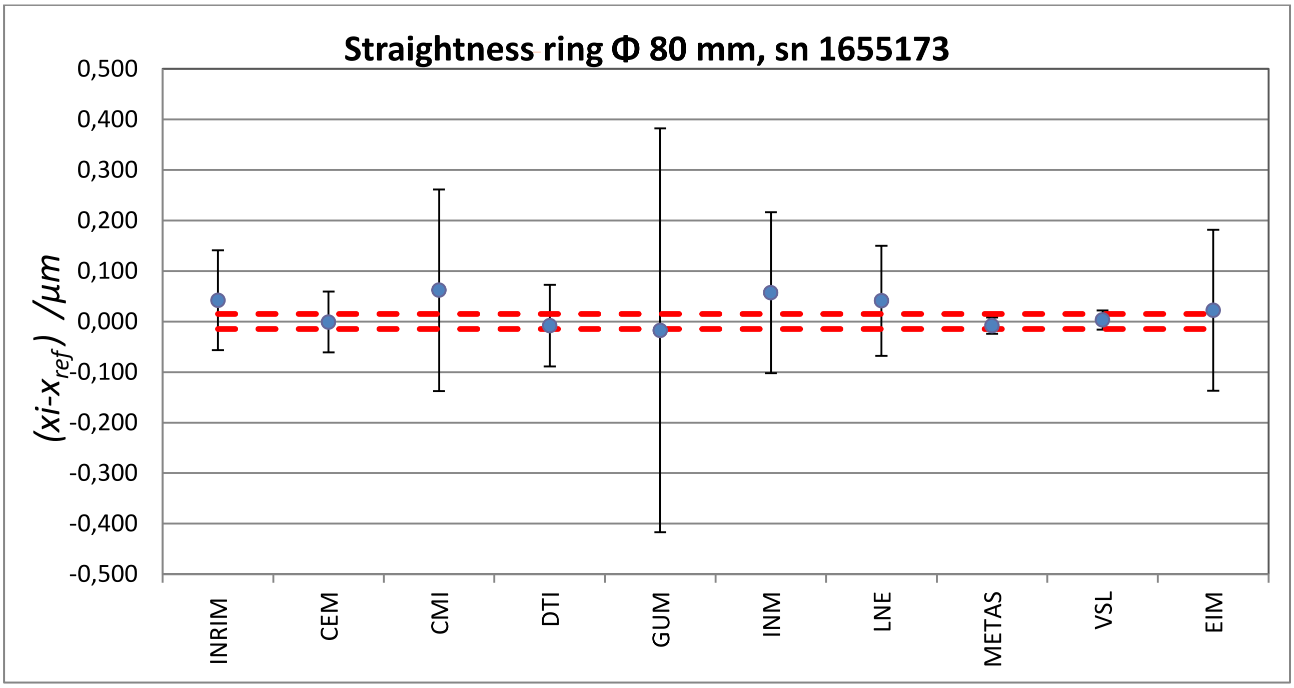
Laboratory	Straightness ring Φ 5 mm, sn1655264						
	$x_i - x_{nom}$ µm	u_i µm	*on/off*	$(x_i\text{-}x_{ref})$ µm	$U(x_i\text{-}x_{ref})$ µm	*En*	w_i
INRIM	0,060	0,050	1	0,016	0,098	0,16	0,03
CEM	0,051	0,031	1	0,007	0,059	0,12	0,08
CMI	0,110	0,100	1	0,066	0,199	0,33	0,01
DTI	0,040	0,041	1	-0,004	0,080	0,05	0,05
GUM							
INM	0,142	0,080	1	0,098	0,159	0,62	0,01
LNE	0,063	0,055	1	0,019	0,109	0,17	0,03
METAS	0,040	0,018	1	-0,004	0,031	0,13	0,24
VSL	0,040	0,012	1	-0,004	0,016	0,25	0,54
EIM	0,050	0,060	1	0,006	0,119	0,05	0,02

Reference value				Consistency	
x_{ref} µm	*C* µm²	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,044	7,73E-05	0,009	0,005	0,55	1,41



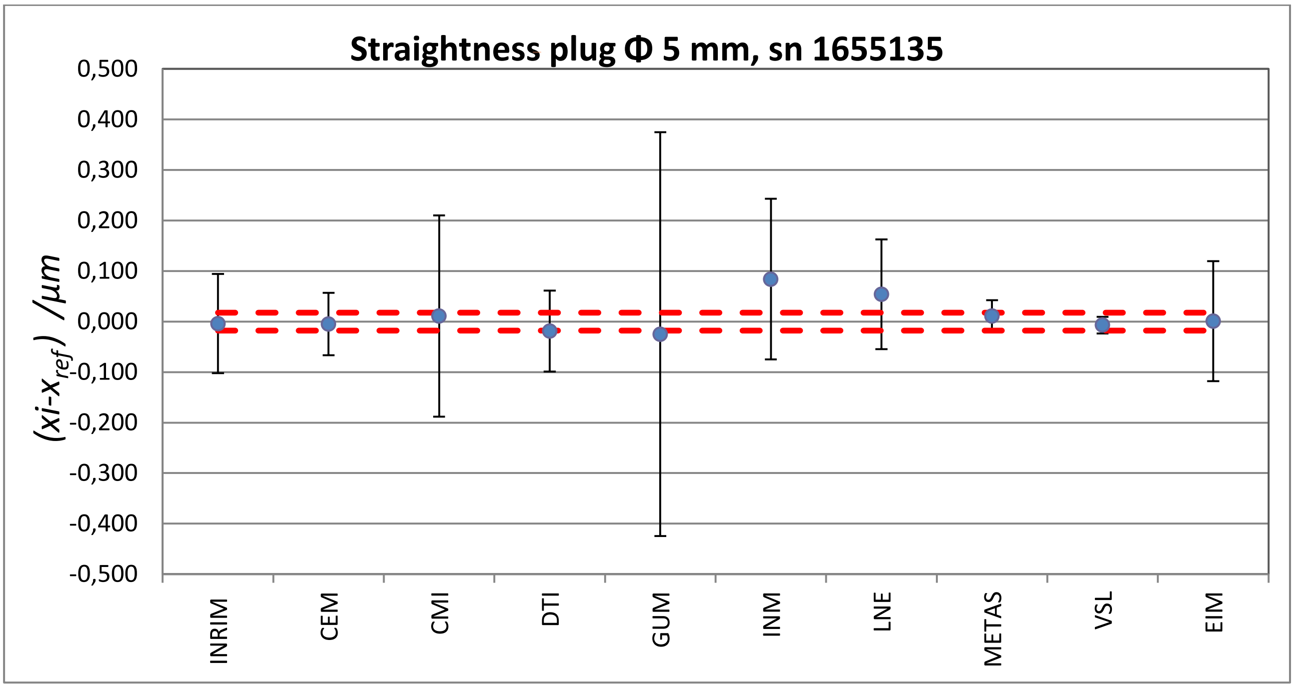
Laboratory	Straightness ring Φ 80 mm, sn 1655173						
	$x_i - x_{nom}$ µm	u_i µm	*on/off*	(x_i-x_{ref}) µm	$U(x_i-x_{ref})$ µm	*En*	w_i
INRIM	0,090	0,050	1	0,042	0,099	0,43	0,02
CEM	0,047	0,031	1	-0,001	0,060	0,01	0,06
CMI	0,110	0,100	1	0,062	0,199	0,31	0,01
DTI	0,040	0,041	1	-0,008	0,081	0,10	0,03
GUM	0,031	0,200	1	-0,017	0,400	0,04	0,00
INM	0,105	0,080	1	0,057	0,159	0,36	0,01
LNE	0,089	0,055	1	0,041	0,109	0,38	0,02
METAS	0,040	0,011	1	-0,008	0,016	0,49	0,46
VSL	0,051	0,012	1	0,003	0,019	0,17	0,39
EIM	0,070	0,080	1	0,022	0,159	0,14	0,01

Reference value				Consistency	
x_{ref} µm	C µm²	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,048	5,55E-05	0,007	0,004	0,56	1,39



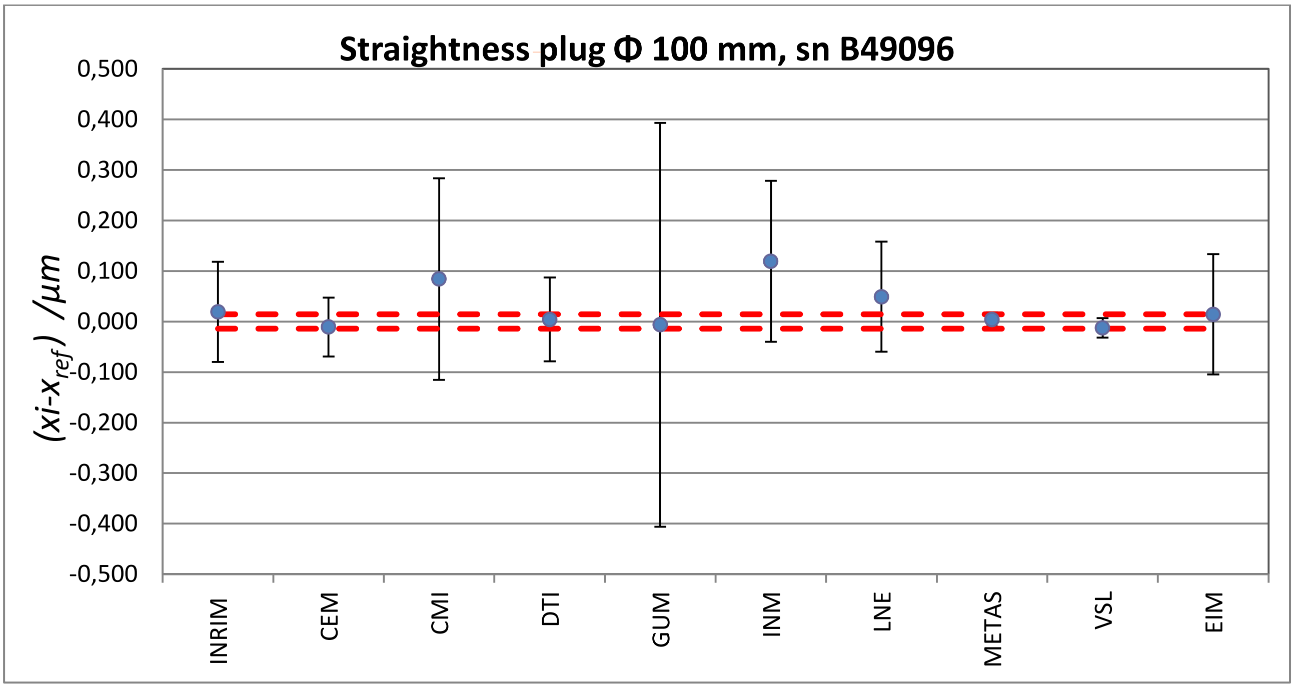
Laboratory	Straightness plug Φ 5 mm, sn 1655135						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,045	0,050	1	-0,004	0,098	0,04	0,03
CEM	0,044	0,032	1	-0,005	0,062	0,08	0,08
CMI	0,060	0,100	1	0,011	0,199	0,06	0,01
DTI	0,030	0,041	1	-0,019	0,080	0,24	0,05
GUM	0,024	0,200	1	-0,025	0,400	0,06	0,00
INM	0,133	0,080	1	0,084	0,159	0,53	0,01
LNE	0,103	0,055	1	0,054	0,109	0,50	0,03
METAS	0,060	0,018	1	0,011	0,031	0,35	0,24
VSL	0,042	0,012	1	-0,007	0,016	0,43	0,54
EIM	0,050	0,060	1	0,001	0,119	0,01	0,02

Reference value				Consistency	
x_{ref} µm	C µm^2	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
0,049	7,76E-05	0,009	0,005	0,58	1,39



Laboratory	Straightness plug Φ 100 mm, sn B49096						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,065	0,050	1	0,019	0,099	0,19	0,02
CEM	0,035	0,030	1	-0,011	0,058	0,18	0,06
CMI	0,130	0,100	1	0,084	0,199	0,42	0,01
DTI	0,050	0,042	1	0,004	0,083	0,05	0,03
GUM	0,039	0,200	1	-0,006	0,400	0,02	0,00
INM	0,165	0,080	1	0,119	0,159	0,75	0,01
LNE	0,095	0,055	1	0,049	0,109	0,45	0,02
METAS	0,050	0,010	1	0,004	0,014	0,30	0,50
VSL	0,033	0,012	1	-0,013	0,019	0,66	0,35
EIM	0,060	0,060	1	0,014	0,119	0,12	0,01

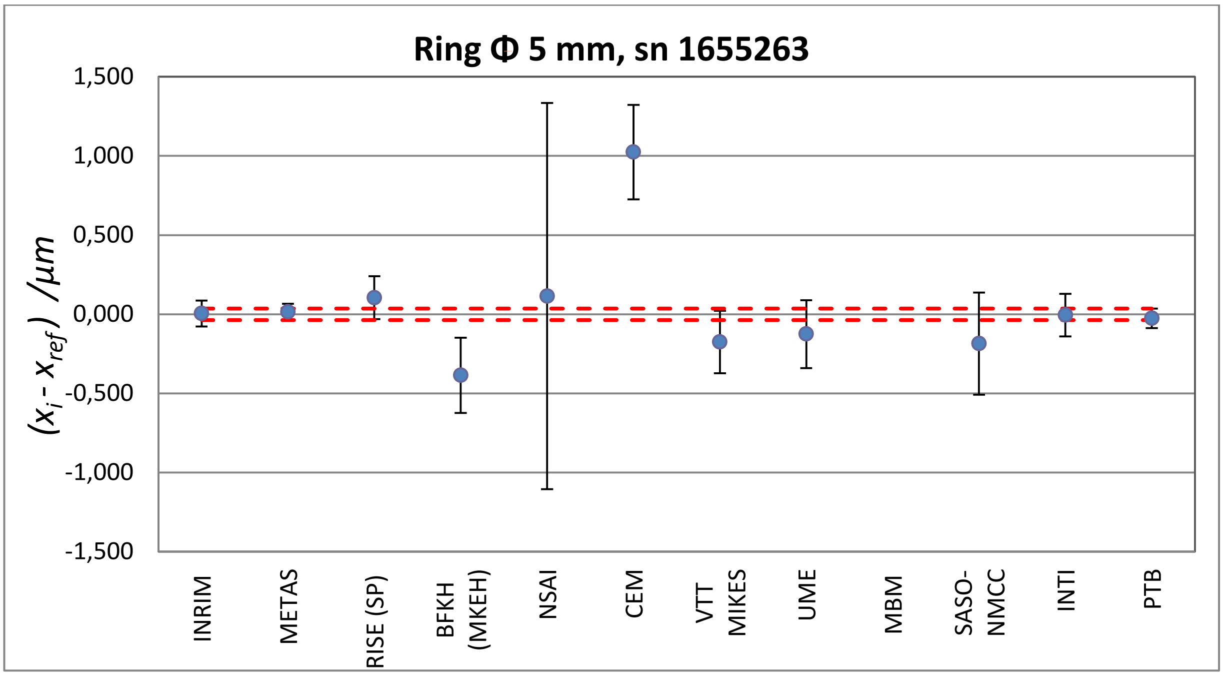
Reference value				Consistency	
x_{ref} µm	C µm^2	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
0,046	5,02E-05	0,007	0,005	0,77	1,39



Group2 - Tables of results

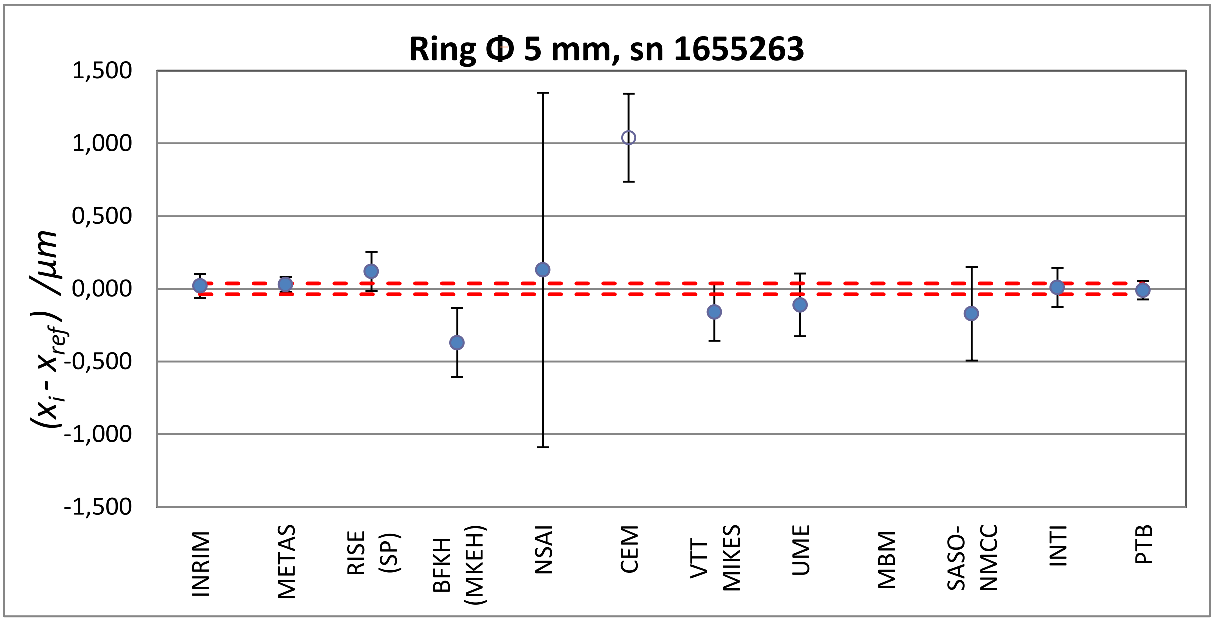
Laboratory	Ring Φ 5 mm, sn1655263						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	$U(x_i-x_{ref})$ µm	En	w_i
INRIM	-1,570	0,045	1	0,00	0,08	0,05	0,17
METAS	-1,560	0,032	1	0,01	0,05	0,27	0,33
RISE (SP)	-1,470	0,070	1	0,10	0,14	0,77	0,07
BFKH (MKEH)	-1,960	0,120	1	-0,39	0,24	1,63	0,02
NSAI	-1,460	0,610	1	0,11	1,22	0,09	0,00
CEM	-0,550	0,150	1	1,02	0,30	3,44	0,01
VTT MIKES	-1,750	0,100	1	-0,18	0,20	0,89	0,03
UME	-1,700	0,109	1	-0,13	0,21	0,59	0,03
MBM	-	-					
SASO-NMCC	-1,760	0,162	1	-0,19	0,32	0,58	0,01
INTI	-1,580	0,070	1	-0,01	0,14	0,04	0,07
PTB	-1,600	0,036	1	-0,03	0,06	0,42	0,26

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
-1,574	0,00033	0,018	0,045	2,44	1,36



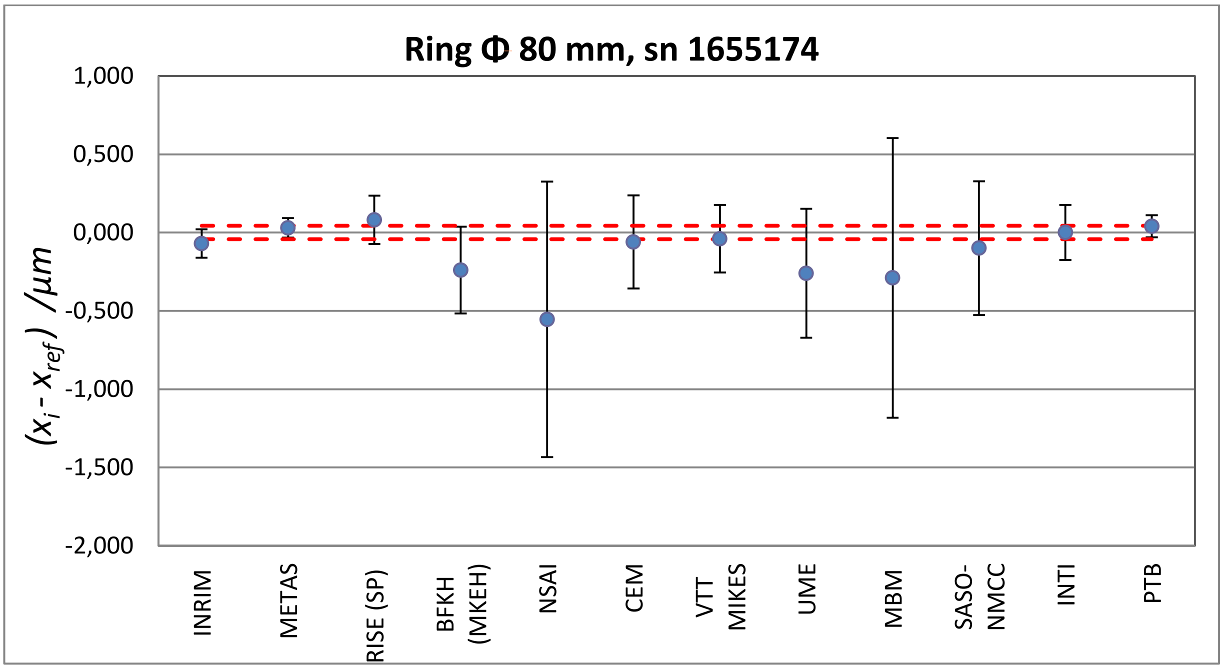
Laboratory	Ring Φ 5 mm, sn 1655263						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	-1,570	0,045	1	0,02	0,08	0,24	0,17
METAS	-1,560	0,032	1	0,03	0,05	0,57	0,33
RISE (SP)	-1,470	0,070	1	0,12	0,14	0,89	0,07
BFKH (MKEH)	-1,960	0,120	1	-0,37	0,24	1,56	0,02
NSAI	-1,460	0,610	1	0,13	1,22	0,11	0,00
CEM	-0,550	0,150	0	1,04	0,30	3,44	0,00
VTT MIKES	-1,750	0,100	1	-0,16	0,20	0,82	0,03
UME	-1,700	0,109	1	-0,11	0,21	0,51	0,03
MBM	-	-					
SASO-NMCC	-1,760	0,162	1	-0,17	0,32	0,53	0,01
INTI	-1,580	0,070	1	0,01	0,14	0,07	0,07
PTB	-1,600	0,036	1	-0,01	0,06	0,17	0,26

Reference value				Consistency	
x_{ref}	C	u(x_{ref})	u_{ext}	R_B	Limit
µm	µm^2	µm	µm		
-1,590	3,40E-04	0,018	0,025	1,35	1,38



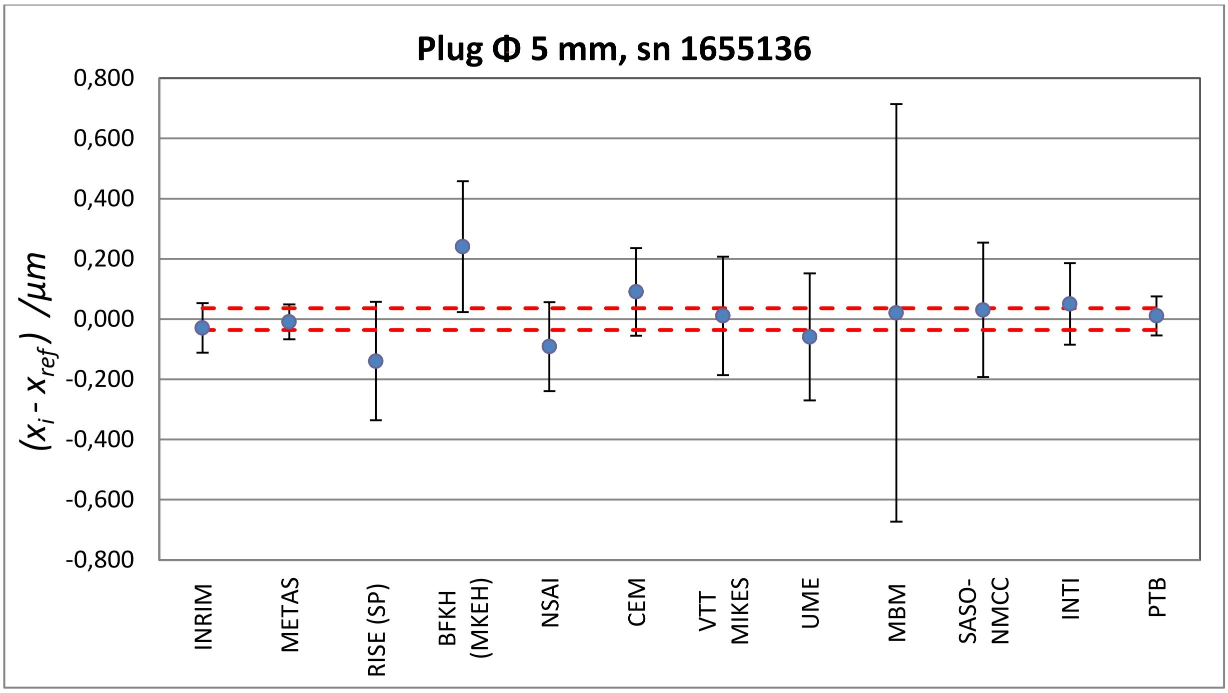
Laboratory	Ring Φ 80 mm, sn 1655174						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,210	0,050	1	-0,07	0,09	0,77	0,18
METAS	0,310	0,038	1	0,03	0,06	0,49	0,31
RISE (SP)	0,360	0,080	1	0,08	0,15	0,52	0,07
BFKH (MKEH)	0,040	0,140	1	-0,24	0,28	0,86	0,02
NSAI	-0,275	0,440	1	-0,55	0,88	0,63	0,00
CEM	0,220	0,150	1	-0,06	0,30	0,20	0,02
VTT MIKES	0,240	0,110	1	-0,04	0,22	0,18	0,04
UME	0,020	0,207	1	-0,26	0,41	0,63	0,01
MBM	-0,010	0,447	1	-0,29	0,89	0,32	0,00
SASO-NMCC	0,180	0,215	1	-0,10	0,43	0,23	0,01
INTI	0,280	0,090	1	0,00	0,17	0,00	0,06
PTB	0,320	0,041	1	0,04	0,07	0,58	0,27

Reference value				Consistency	
x_{ref} µm	C µm^2	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
0,279	0,00045	0,021	0,022	1,03	1,36



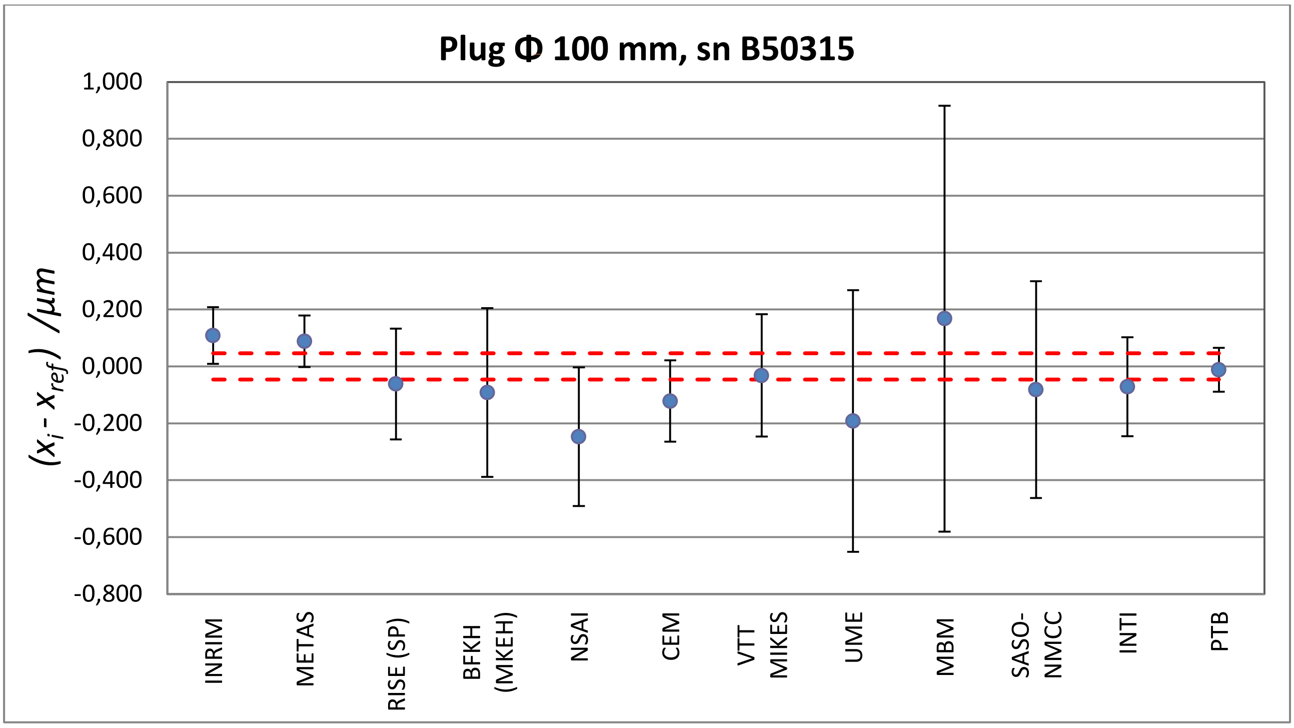
Laboratory	Plug Φ 5 mm, sn 1655136						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	$U(x_i$-$x_{ref})$ µm	En	w_i
INRIM	-0,210	0,045	1	-0,03	0,08	0,36	0,16
METAS	-0,190	0,034	1	-0,01	0,06	0,16	0,28
RISE (SP)	-0,320	0,100	1	-0,14	0,20	0,71	0,03
BFKH (MKEH)	0,060	0,110	1	0,24	0,22	1,11	0,03
NSAI	-0,272	0,076	1	-0,09	0,15	0,62	0,06
CEM	-0,090	0,075	1	0,09	0,15	0,62	0,06
VTT MIKES	-0,170	0,100	1	0,01	0,20	0,05	0,03
UME	-0,240	0,107	1	-0,06	0,21	0,28	0,03
MBM	-0,160	0,347	1	0,02	0,69	0,03	0,00
SASO-NMCC	-0,150	0,113	1	0,03	0,22	0,14	0,03
INTI	-0,130	0,070	1	0,05	0,14	0,37	0,07
PTB	-0,170	0,037	1	0,01	0,06	0,16	0,24

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
-0,181	0,00032	0,018	0,018	1,01	1,36



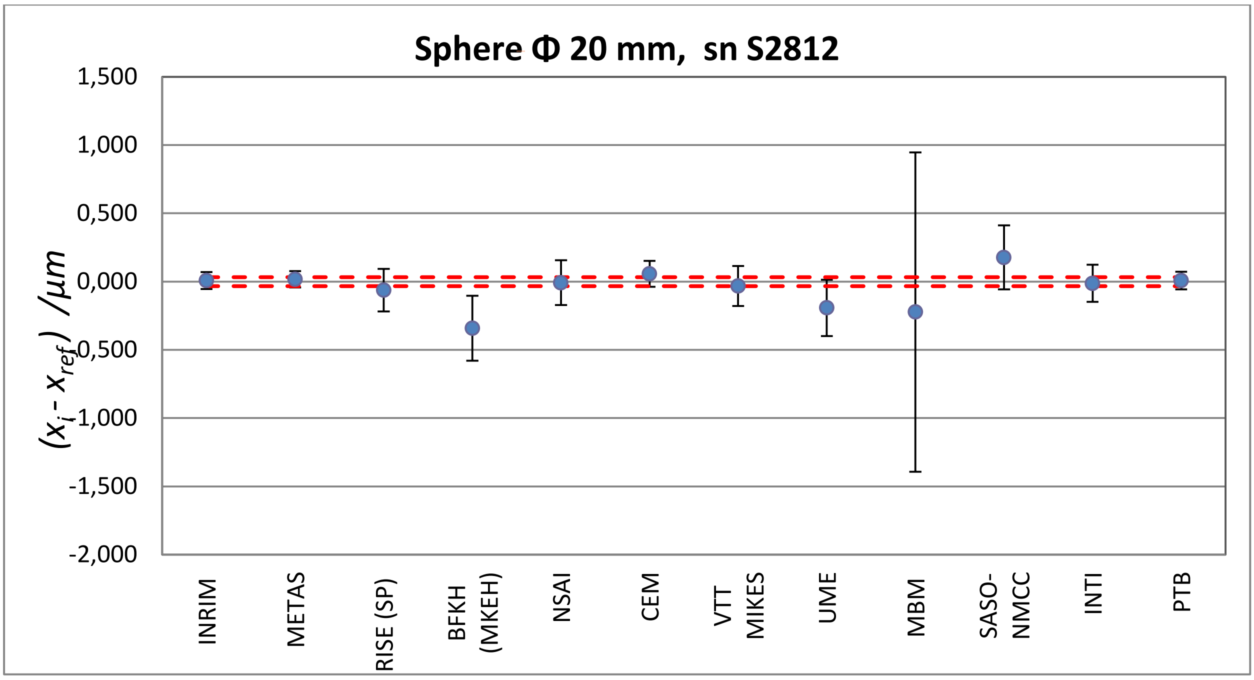
aboratory	Plug Φ 100 mm, sn B50315						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	36,390	0,055	1	0,11	0,10	1,09	0,18
METAS	36,370	0,051	1	0,09	0,09	0,97	0,21
RISE (SP)	36,220	0,100	1	-0,06	0,19	0,32	0,05
BFKH (MKEH)	36,190	0,150	1	-0,09	0,30	0,31	0,02
NSAI	36,035	0,124	1	-0,25	0,24	1,01	0,04
CEM	36,160	0,075	1	-0,12	0,14	0,85	0,10
VTT MIKES	36,250	0,110	1	-0,03	0,22	0,15	0,04
UME	36,090	0,231	1	-0,19	0,46	0,42	0,01
MBM	36,450	0,375	1	0,17	0,75	0,22	0,00
SASO-NMCC	36,200	0,192	1	-0,08	0,38	0,21	0,01
INTI	36,210	0,090	1	-0,07	0,17	0,41	0,07
PTB	36,270	0,045	1	-0,01	0,08	0,15	0,27

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
36,282	0,00054	0,023	0,028	1,21	1,36



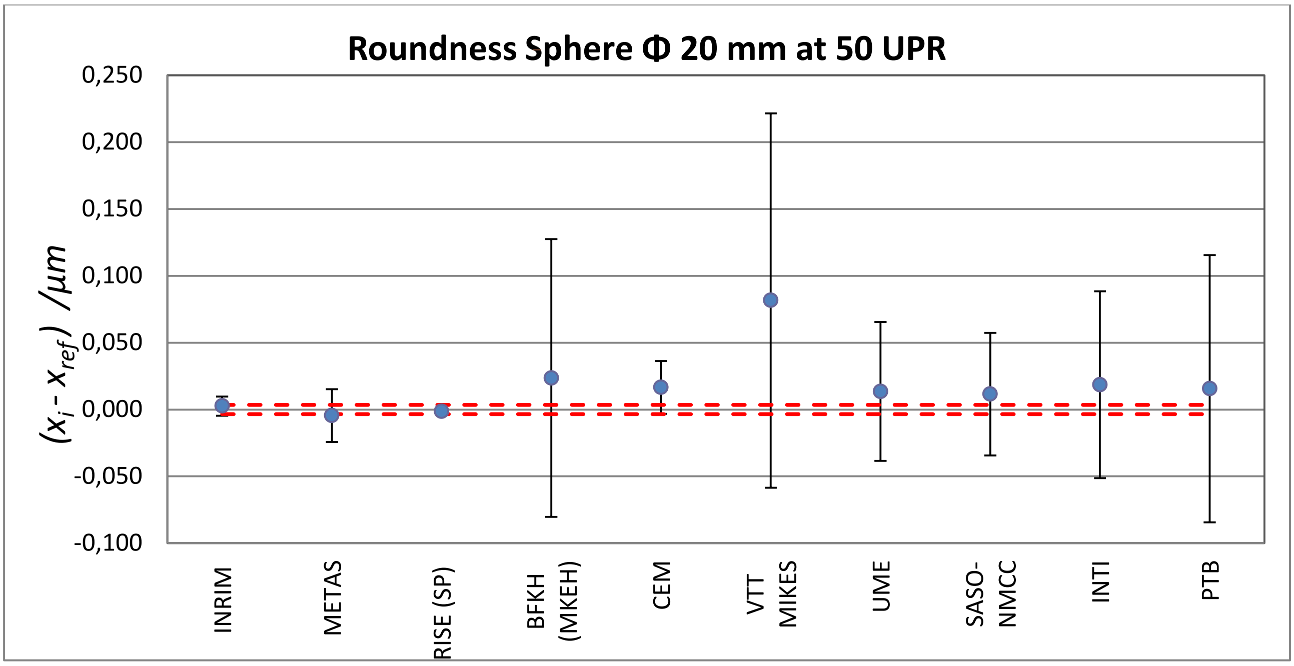
Laboratory	Sphere Φ 20 mm, sn S2812						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	-21,680	0,035	1	0,01	0,06	0,12	0,22
METAS	-21,670	0,034	1	0,02	0,06	0,29	0,23
RISE (SP)	-21,750	0,080	1	-0,06	0,16	0,40	0,04
BFKH (MKEH)	-22,030	0,120	1	-0,34	0,24	1,44	0,02
NSAI	-21,695	0,084	1	-0,01	0,16	0,05	0,04
CEM	-21,630	0,050	1	0,06	0,09	0,60	0,11
VTT MIKES	-21,720	0,075	1	-0,03	0,15	0,22	0,05
UME	-21,880	0,104	1	-0,19	0,21	0,94	0,02
MBM	-21,910	0,585	1	-0,22	1,17	0,19	0,00
SASO-NMCC	-21,510	0,118	1	0,18	0,23	0,76	0,02
INTI	-21,700	0,070	1	-0,01	0,14	0,09	0,05
PTB	-21,680	0,036	1	0,01	0,06	0,11	0,20

Reference value				Consistency	
x_{ref} µm	C µm^2	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
-21,687	0,00027	0,016	0,020	1,22	1,36



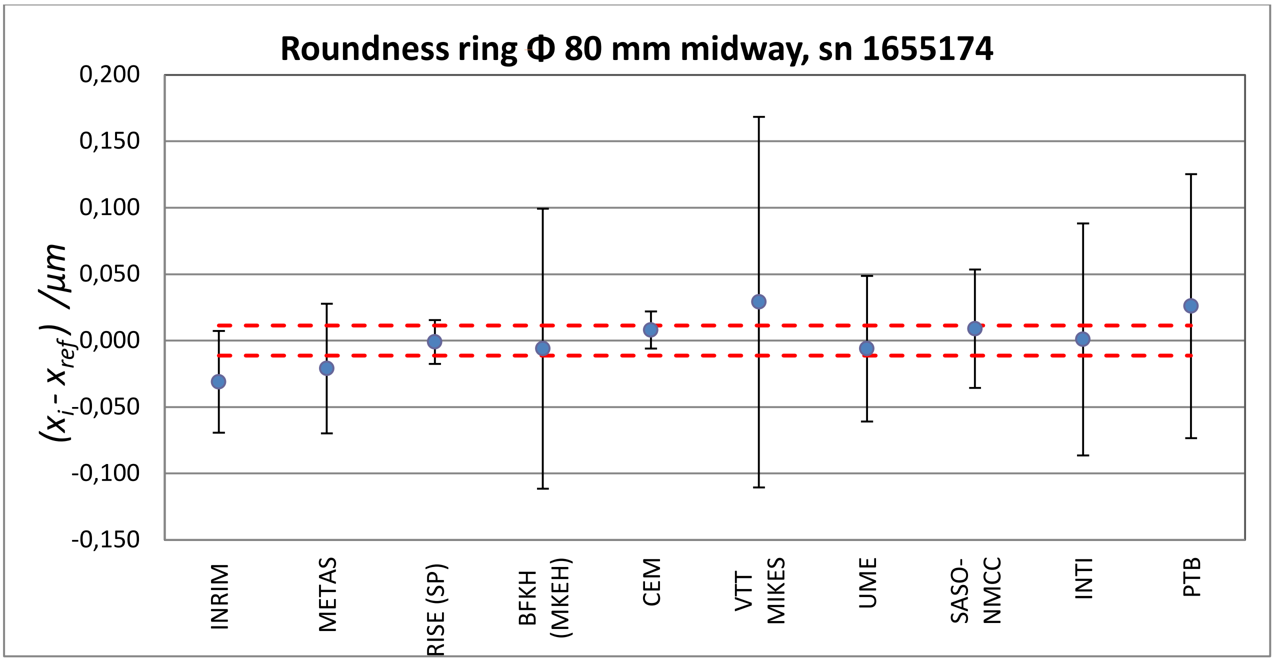
Laboratory	Roundness Sphere Φ 20 mm at 50 UPR						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,021	0,004	1	0,00	0,01	0,35	0,19
METAS	0,014	0,010	1	0,00	0,02	0,23	0,03
RISE (SP)	0,017	0,002	1	0,00	0,00	0,72	0,74
BFKH (MKEH)	0,042	0,052	1	0,02	0,10	0,23	0,00
CEM	0,035	0,010	1	0,02	0,02	0,84	0,03
VTT MIKES	0,100	0,070	1	0,08	0,14	0,58	0,00
UME	0,032	0,026	1	0,01	0,05	0,26	0,00
SASO-NMCC	0,030	0,023	1	0,01	0,05	0,25	0,01
INTI	0,037	0,035	1	0,02	0,07	0,27	0,00
PTB	0,034	0,050	1	0,02	0,10	0,16	0,00

Reference value				Consistency	
x_{ref}	C	u(x_{ref})	u_{ext}	R_B	Limit
µm	µm^2	µm	µm		
0,018	2,96E-06	0,002	0,001	0,84	1,39



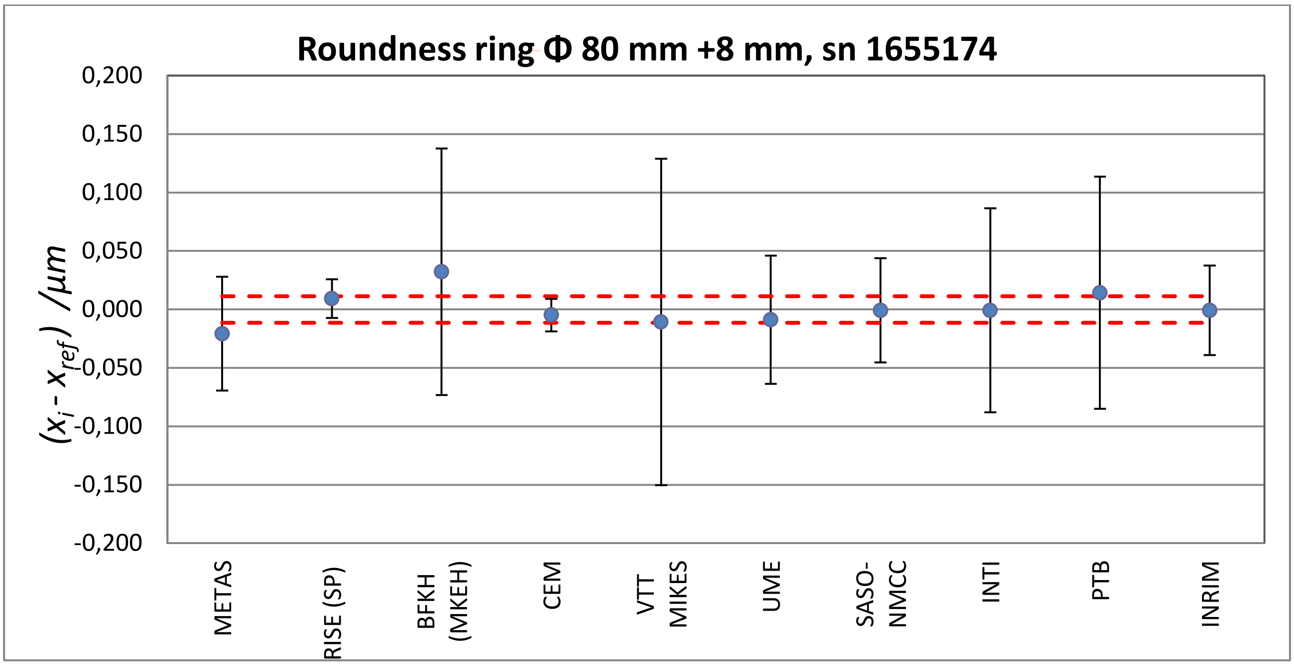
Laboratory	Roundness ring Φ 80 mm midway, sn 1655174						
	x_i - x_{nom} µm	u_i µm	on/off	$(x_i$-$x_{ref})$ µm	$U(x_i$-$x_{ref})$ µm	En	w_i
INRIM	0,180	0,020	1	-0,03	0,04	0,81	0,08
METAS	0,190	0,025	1	-0,02	0,05	0,43	0,05
RISE (SP)	0,210	0,010	1	0,00	0,02	0,06	0,32
BFKH (MKEH)	0,205	0,053	1	-0,01	0,11	0,06	0,01
CEM	0,219	0,009	1	0,01	0,01	0,57	0,40
VTT MIKES	0,240	0,070	1	0,03	0,14	0,21	0,01
UME	0,205	0,028	1	-0,01	0,05	0,11	0,04
SASO-NMCC	0,220	0,023	1	0,01	0,04	0,20	0,06
INTI	0,212	0,044	1	0,00	0,09	0,01	0,02
PTB	0,237	0,050	1	0,03	0,10	0,26	0,01

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,211	3,22E-05	0,006	0,004	0,71	1,39



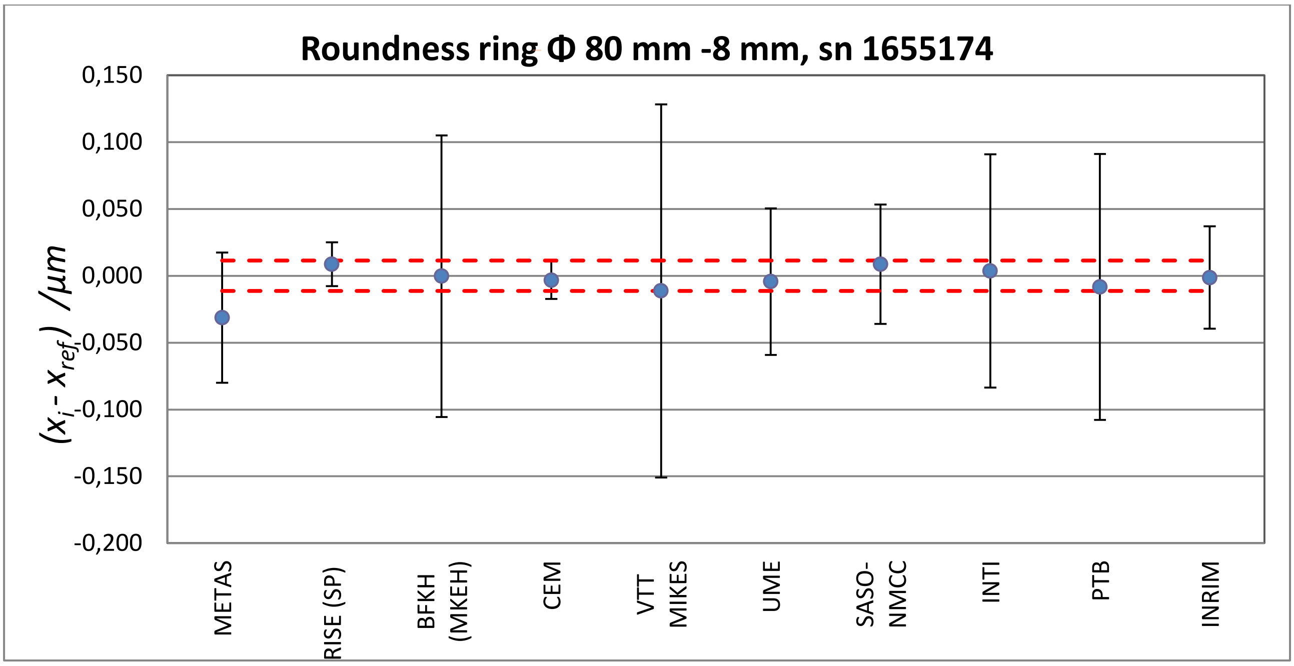
Laboratory	Roundness ring Φ 80 mm +8 mm, sn 1655174						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
METAS	0,170	0,025	1	-0,02	0,05	0,43	0,05
RISE (SP)	0,200	0,010	1	0,01	0,02	0,56	0,32
BFKH (MKEH)	0,223	0,053	1	0,03	0,11	0,31	0,01
CEM	0,186	0,009	1	0,00	0,01	0,34	0,40
VTT MIKES	0,180	0,070	1	-0,01	0,14	0,08	0,01
UME	0,182	0,028	1	-0,01	0,05	0,16	0,04
SASO-NMCC	0,190	0,023	1	0,00	0,04	0,02	0,06
INTI	0,190	0,044	1	0,00	0,09	0,01	0,02
PTB	0,205	0,050	1	0,01	0,10	0,14	0,01
INRIM	0,190	0,020	1	0,00	0,04	0,02	0,08

Reference value				Consistency	
x_{ref} µm	C µm^2	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
0,191	3,22E-05	0,006	0,003	0,52	1,39



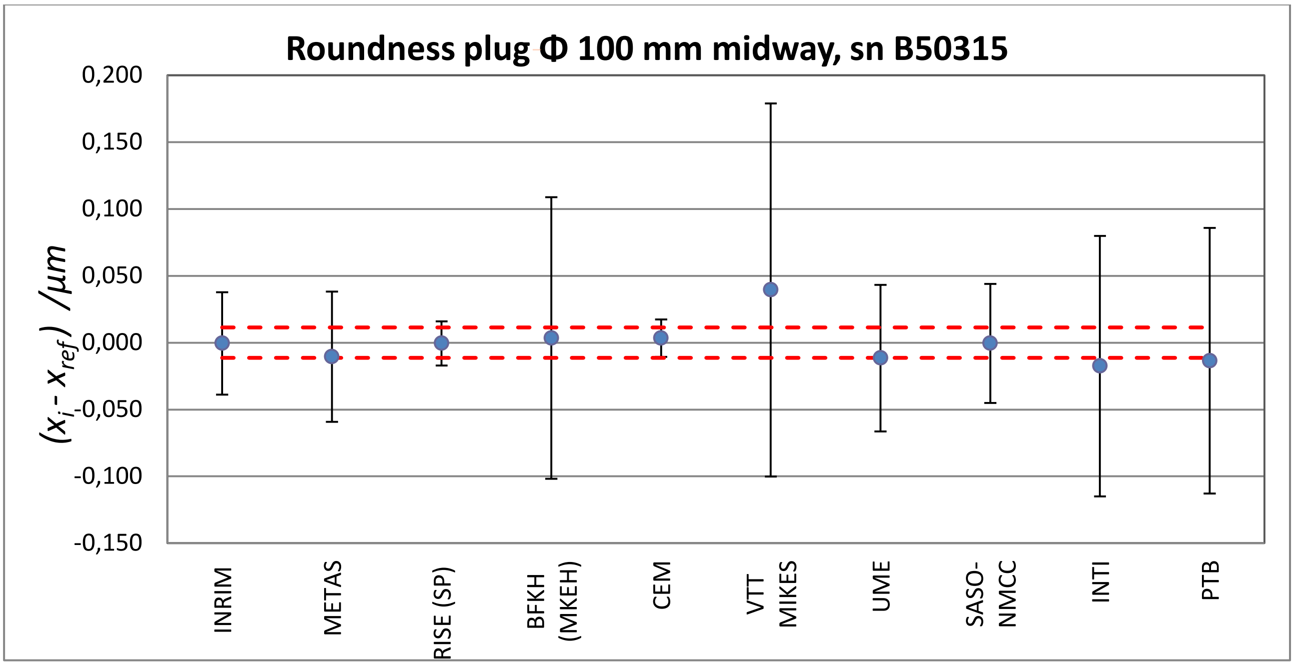
Laboratory	Roundness ring Φ 80 mm -8 mm, sn 1655174						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	$U(x_i$-$x_{ref})$ µm	En	w_i
METAS	0,230	0,025	1	-0,03	0,05	0,64	0,05
RISE (SP)	0,270	0,010	1	0,01	0,02	0,53	0,32
BFKH (MKEH)	0,261	0,053	1	0,00	0,11	0,00	0,01
CEM	0,258	0,009	1	0,00	0,01	0,24	0,40
VTT MIKES	0,250	0,070	1	-0,01	0,14	0,08	0,01
UME	0,257	0,028	1	0,00	0,05	0,08	0,04
SASO-NMCC	0,270	0,023	1	0,01	0,04	0,20	0,06
INTI	0,265	0,044	1	0,00	0,09	0,04	0,02
PTB	0,253	0,050	1	-0,01	0,10	0,08	0,01
INRIM	0,260	0,020	1	0,00	0,04	0,03	0,08

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,261	3,22E-05	0,006	0,003	0,55	1,39



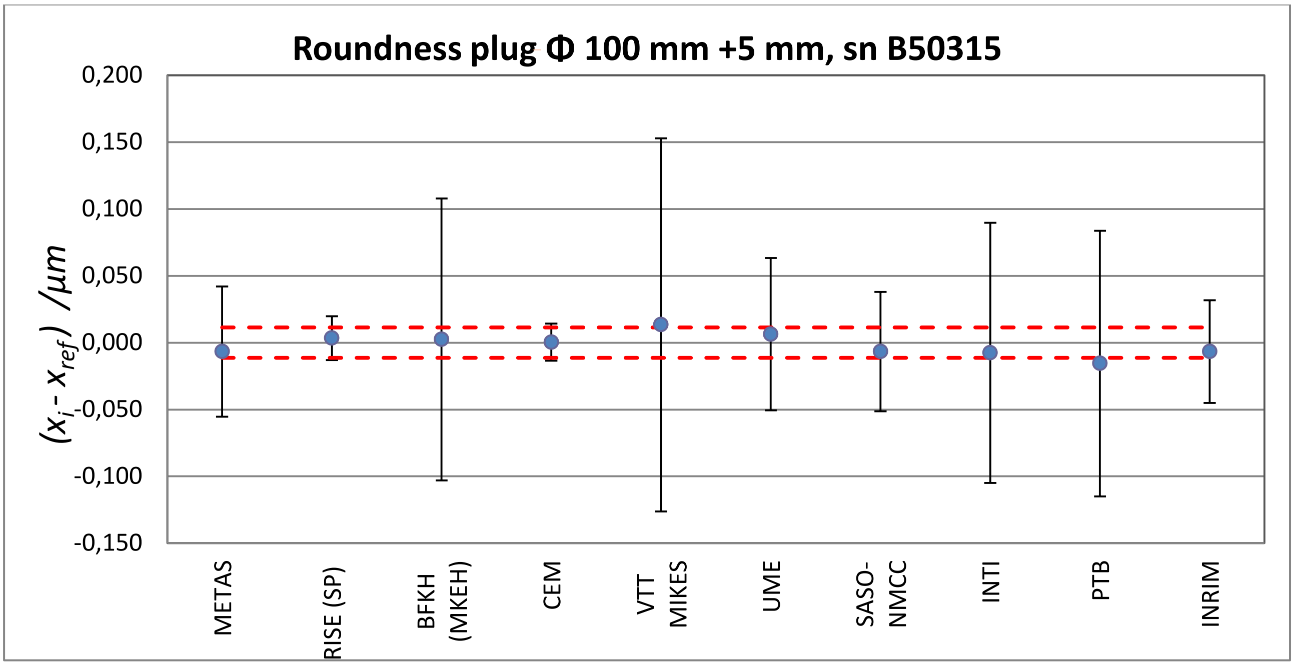
Laboratory	Roundness plug Φ 100 mm midway, sn B50315						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	$U(x_i$-$x_{ref})$ µm	En	w_i
INRIM	0,120	0,020	1	0,00	0,04	0,01	0,08
METAS	0,110	0,025	1	-0,01	0,05	0,22	0,05
RISE (SP)	0,120	0,010	1	0,00	0,02	0,03	0,32
BFKH (MKEH)	0,124	0,053	1	0,00	0,11	0,03	0,01
CEM	0,124	0,009	1	0,00	0,01	0,25	0,40
VTT MIKES	0,160	0,070	1	0,04	0,14	0,28	0,01
UME	0,109	0,028	1	-0,01	0,05	0,21	0,04
SASO-NMCC	0,120	0,023	1	0,00	0,04	0,01	0,06
INTI	0,103	0,049	1	-0,02	0,10	0,18	0,01
PTB	0,107	0,050	1	-0,01	0,10	0,14	0,01

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,121	3,23E-05	0,006	0,002	0,34	1,39



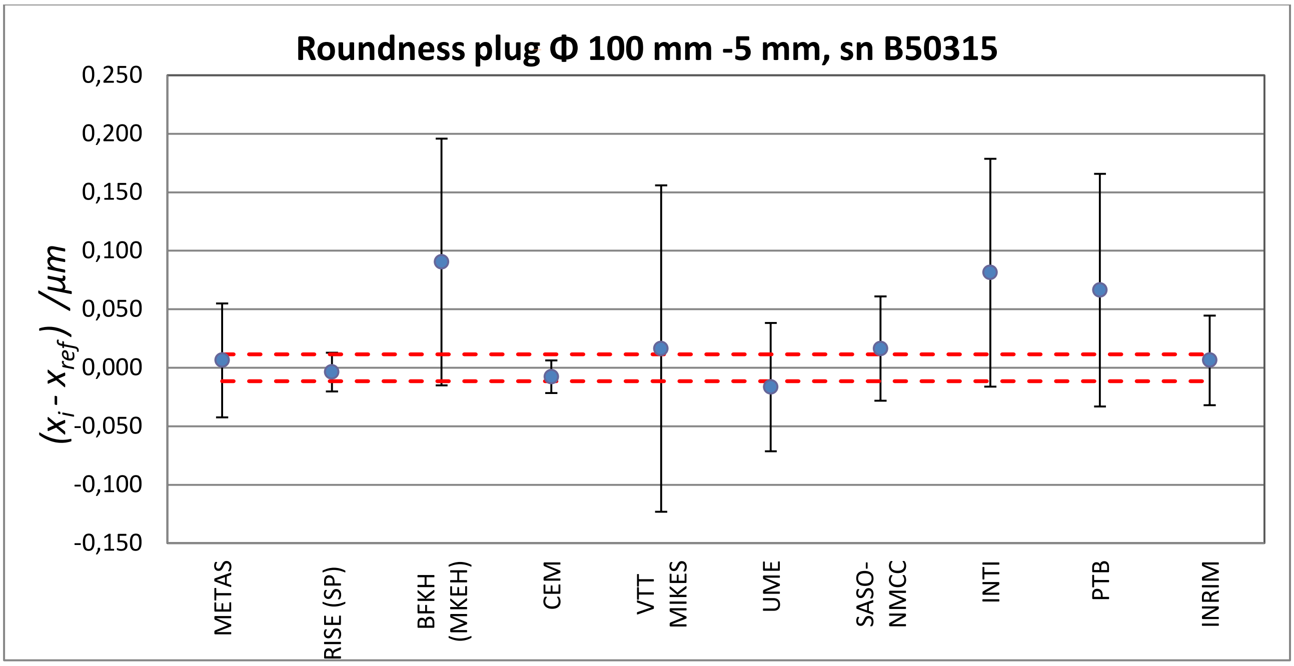
Laboratory	Roundness plug Φ 100 mm +5 mm, sn B50315						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
METAS	0,130	0,025	1	-0,01	0,05	0,14	0,05
RISE (SP)	0,140	0,010	1	0,00	0,02	0,20	0,32
BFKH (MKEH)	0,139	0,053	1	0,00	0,11	0,02	0,01
CEM	0,137	0,009	1	0,00	0,01	0,03	0,40
VTT MIKES	0,150	0,070	1	0,01	0,14	0,10	0,01
UME	0,143	0,029	1	0,01	0,06	0,11	0,04
SASO-NMCC	0,130	0,023	1	-0,01	0,04	0,15	0,06
INTI	0,129	0,049	1	-0,01	0,10	0,08	0,01
PTB	0,121	0,050	1	-0,02	0,10	0,16	0,01
INRIM	0,130	0,020	1	-0,01	0,04	0,17	0,08

Reference value				Consistency	
x_{ref}	C	u(x_{ref})	u_{ext}	R_B	Limit
µm	µm^2	µm	µm		
0,137	3,24E-05	0,006	0,001	0,26	1,39



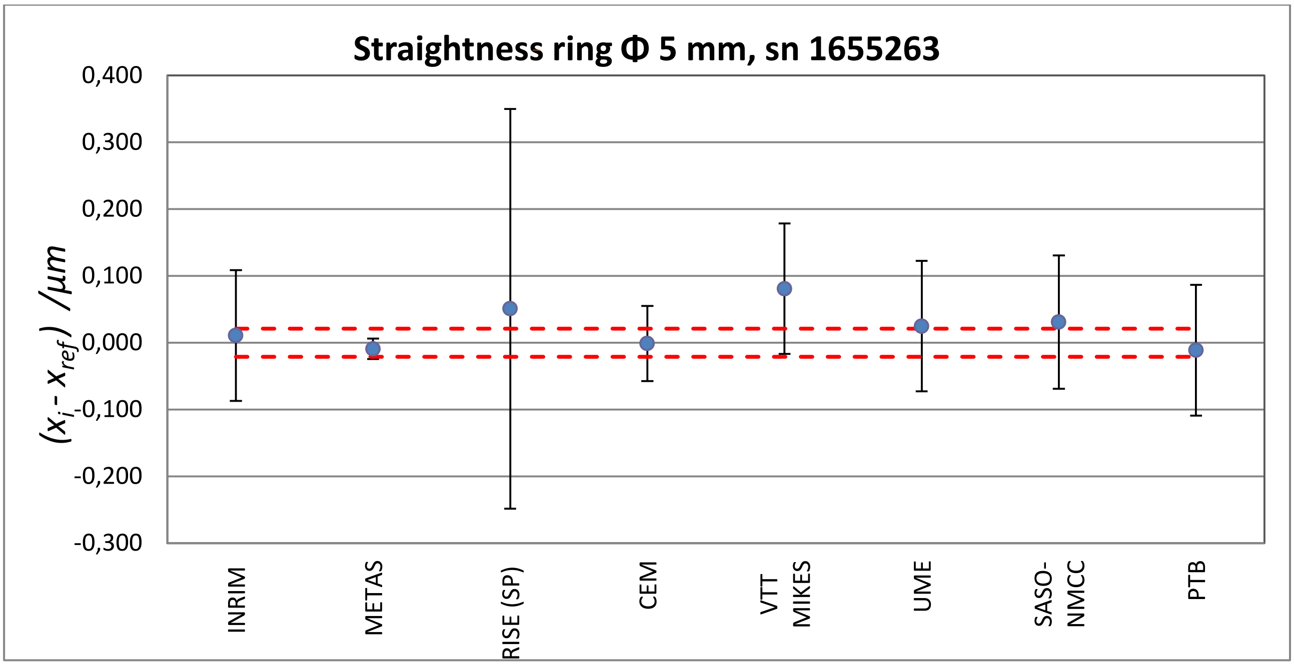
Laboratory	Roundness plug Φ 100 mm -5 mm, sn B50315						
	x_i - x_{nom} µm	u_i µm	on/off	$(x_i$-$x_{ref})$ µm	$U(x_i$-$x_{ref})$ µm	En	w_i
METAS	0,120	0,025	1	0,01	0,05	0,13	0,05
RISE (SP)	0,110	0,010	1	0,00	0,02	0,22	0,32
BFKH (MKEH)	0,204	0,053	1	0,09	0,11	0,86	0,01
CEM	0,106	0,009	1	-0,01	0,01	0,55	0,40
VTT MIKES	0,130	0,070	1	0,02	0,14	0,12	0,01
UME	0,097	0,028	1	-0,02	0,05	0,30	0,04
SASO-NMCC	0,130	0,023	1	0,02	0,04	0,37	0,06
INTI	0,195	0,049	1	0,08	0,10	0,84	0,01
PTB	0,180	0,050	1	0,07	0,10	0,67	0,01
INRIM	0,120	0,020	1	0,01	0,04	0,16	0,08

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,114	3,23E-05	0,006	0,006	1,02	1,39



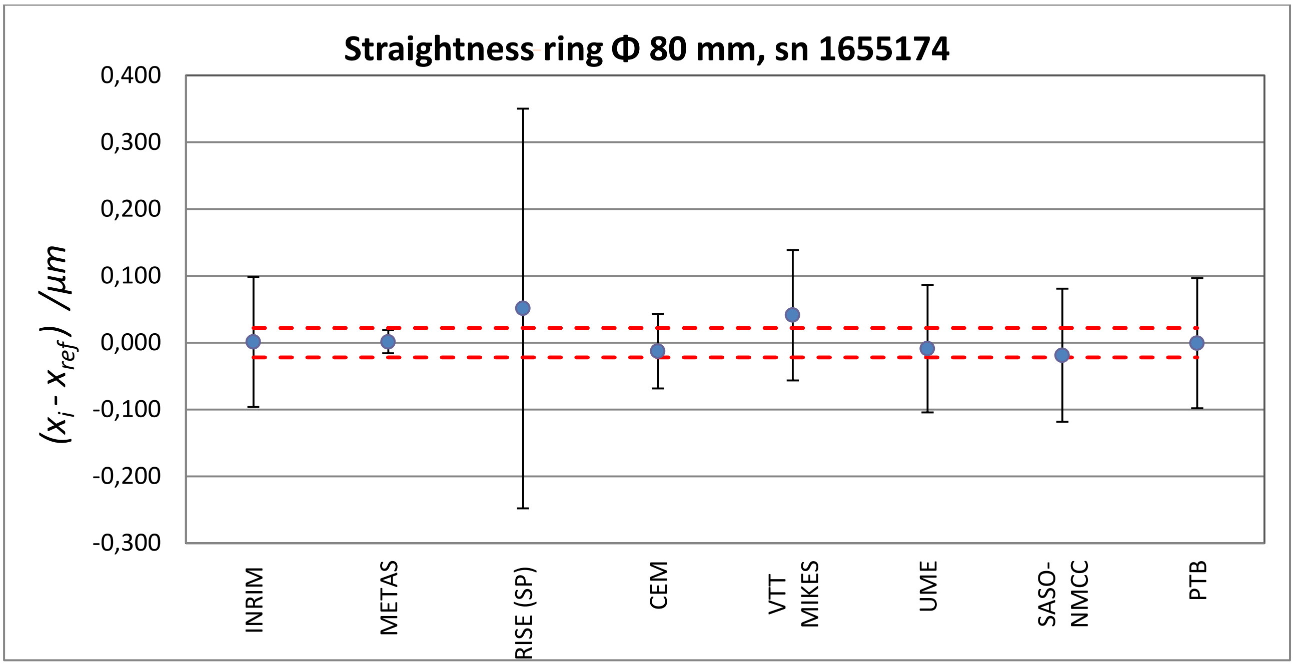
Laboratory	Straightness ring Φ 5 mm, sn 1655263						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,070	0,050	1	0,01	0,10	0,11	0,04
METAS	0,050	0,013	1	-0,01	0,02	0,60	0,65
RISE (SP)	0,110	0,150	1	0,05	0,30	0,17	0,00
CEM	0,058	0,030	1	0,00	0,06	0,02	0,12
VTT MIKES	0,140	0,050	1	0,08	0,10	0,83	0,04
UME	0,084	0,050	1	0,02	0,10	0,25	0,04
SASO-NMCC	0,090	0,051	1	0,03	0,10	0,31	0,04
PTB	0,048	0,050	1	-0,01	0,10	0,12	0,04

Reference value				Consistency	
x_{ref} µm	C µm^2	u(x_{ref}) µm	u_{ext} µm	R_B	Limit
0,059	0,00011	0,011	0,008	0,75	1,44



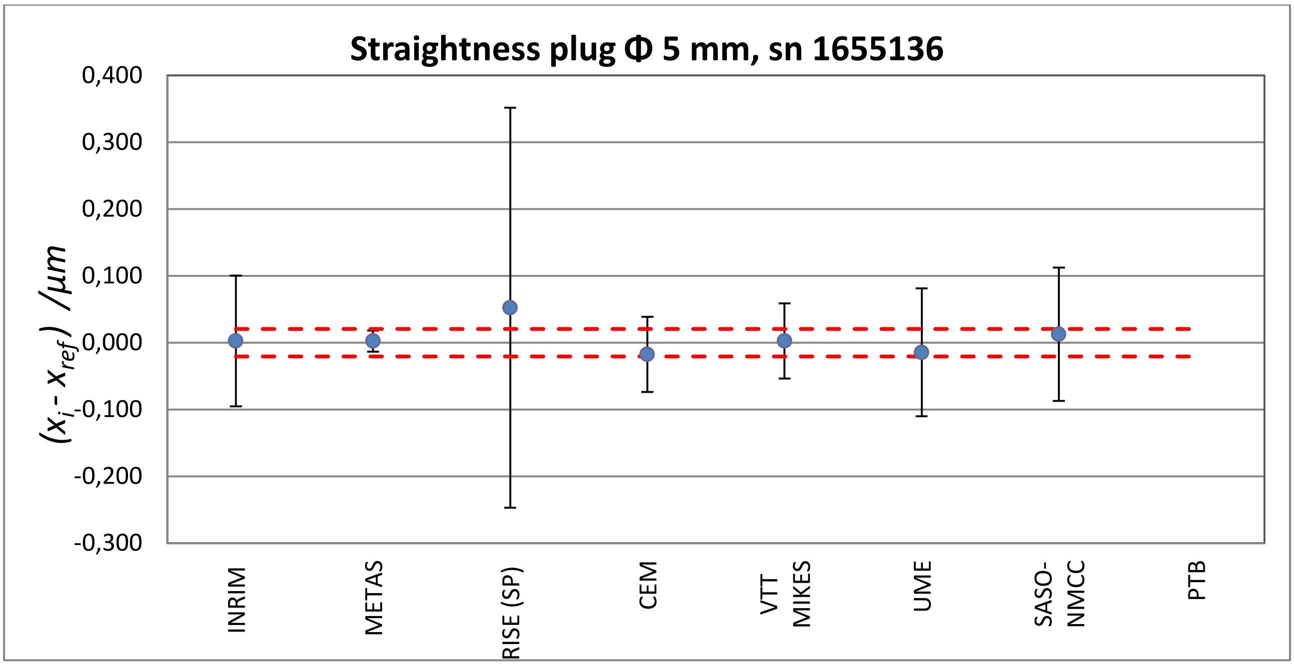
Laboratory	Straightness ring Φ 80 mm, sn 1655174						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,050	0,050	1	0,00	0,10	0,01	0,05
METAS	0,050	0,014	1	0,00	0,02	0,07	0,62
RISE (SP)	0,100	0,150	1	0,05	0,30	0,17	0,01
CEM	0,036	0,030	1	-0,01	0,06	0,23	0,13
VTT MIKES	0,090	0,050	1	0,04	0,10	0,42	0,05
UME	0,040	0,049	1	-0,01	0,10	0,09	0,05
SASO-NMCC	0,030	0,051	1	-0,02	0,10	0,19	0,05
PTB	0,048	0,050	1	0,00	0,10	0,01	0,05

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,049	0,00012	0,011	0,004	0,41	1,44



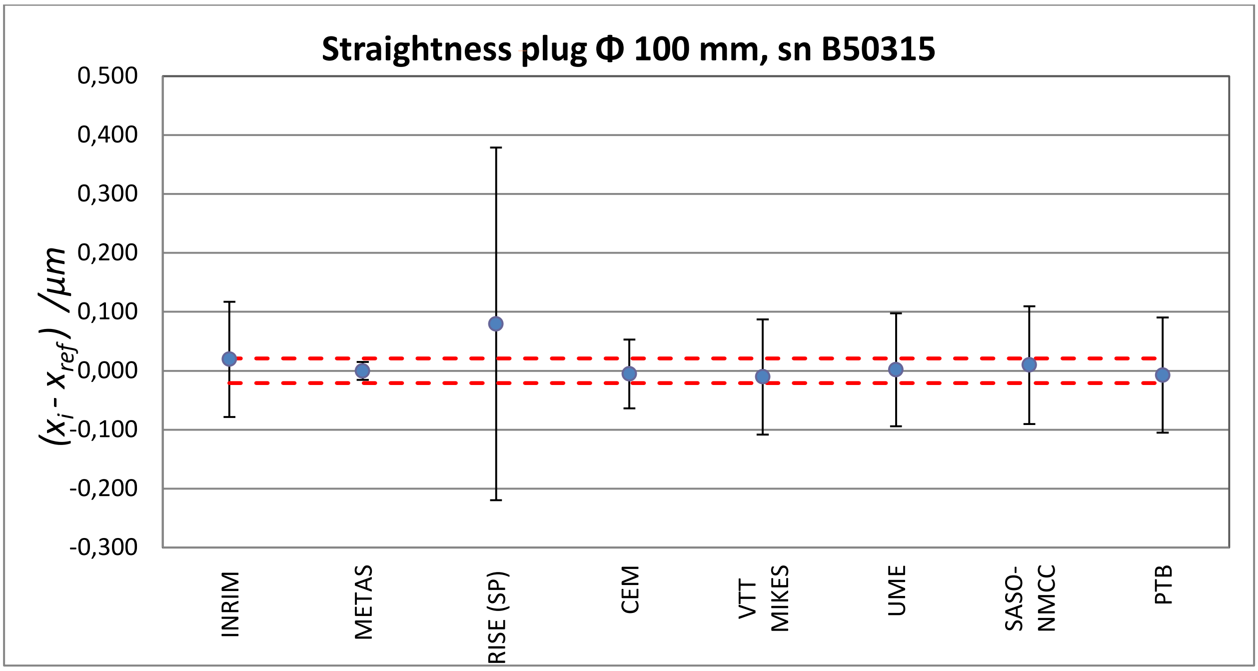
Laboratory	Straightness plug Φ 5 mm, sn 1655136						
	x_i - x_{nom} µm	u_i µm	on/off	(x_i-x_{ref}) µm	U(x_i-x_{ref}) µm	En	w_i
INRIM	0,050	0,050	1	0,00	0,10	0,03	0,04
METAS	0,050	0,013	1	0,00	0,02	0,16	0,63
RISE (SP)	0,100	0,150	1	0,05	0,30	0,18	0,00
CEM	0,030	0,030	1	-0,02	0,06	0,31	0,12
VTT MIKES	0,050	0,030	1	0,00	0,06	0,04	0,12
UME	0,033	0,049	1	-0,01	0,10	0,15	0,04
SASO-NMCC	0,060	0,051	1	0,01	0,10	0,12	0,04
PTB	-	-					

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,048	0,00011	0,010	0,003	0,31	1,44



Laboratory	Straightness plug Φ 100 mm, sn B50315						
	$x_i - x_{nom}$ µm	u_i µm	on/off	(x_i-x_{ref}) µm	$U(x_i-x_{ref})$ µm	En	w_i
INRIM	0,080	0,050	1	0,02	0,10	0,20	0,04
METAS	0,060	0,013	1	0,00	0,02	0,03	0,66
RISE (SP)	0,140	0,150	1	0,08	0,30	0,27	0,00
CEM	0,055	0,031	1	-0,01	0,06	0,09	0,12
VTT MIKES	0,050	0,050	1	-0,01	0,10	0,11	0,04
UME	0,062	0,049	1	0,00	0,10	0,02	0,05
SASO-NMCC	0,070	0,051	1	0,01	0,10	0,10	0,04
PTB	0,053	0,050	1	-0,01	0,10	0,08	0,04

Reference value				Consistency	
x_{ref} µm	C µm^2	$u(x_{ref})$ µm	u_{ext} µm	R_B	Limit
0,060	0,00011	0,011	0,003	0,28	1,44



10 Comparison with reference values

Although submitted results are corrected for systematic errors known by the laboratories any unknown bias may drive the Key Comparison Reference Values away from a reliable estimate of the measurand. Unknown bias is somewhat due to the changes in length over time, i.e., secular changes of the gauges.

The stability over time of the gauges was checked during the comparison with the measurements of the pilot laboratory. As shown in section **8**, an apparent change in length outside the uncertainty of pilot measurements was observed only with the two 100 mm plugs.

Therefore, in addition to the uncertainty of the laboratory and that of the reference value, an uncertainty related to the artefact is introduced with two 100 mm plugs to calculate the degree of equivalence of each participant. An uncertainty of 58 nm and of 70 nm was estimated for the two 100 mm plugs. It is worth noting that this approach follows from previous comparisons [2].

Due to correlations between results and reference value, the uncertainty of the deviation of each result *Xi* contributing to the weighted-mean Xw is

$$U(\Delta l) = 2\sqrt{u^2(Xi) - u^2(Xw) + u^2(Xartefact)} \quad ; \qquad (10)$$

while with "+" for the *Xi* not-contributing to the *W-mean*

$$U(\Delta l) = 2\sqrt{u^2(Xi) + u^2(Xw) + u^2(Xartefact)} \qquad (11)$$

With the exception of the diameter of the 100 mm plugs, the artefact-related uncertainty is assumed negligible for all other measurands and gauges.

Correlation between laboratories

Since the topic of this project is the comparison of primary measurements, correlations between the results of different NMIs are unlikely. Possible exceptions are from reference artefacts traceable to other NMIs in the two groups and from 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.

However, as reported in table 6, some labs declare traceability of their reference gauges from NMIs within the comparison. For the two groups, BEV, GUM, INM and UME declare traceability through reference ring and plug gauges traceable to METAS; DTI and NSAI trough reference ring gauges traceable to PTB; BFHK trough reference ring gauges traceable to LNE; SASO-NMCC trough reference ring gauges traceable to UME.

To estimate the effect of the correlation between the NMIs on the weighted mean of correlated quantities use was made of the mathematics, equations 27-29 within the section 3, in reference [5]. The correlation coefficient ($-1 \leq r \leq 1$) is assumed positive as the influence of the traceability is expected to bias in the same direction the results of the two laboratories correlated by the traceability chain. The correlation coefficient is calculated as in the equation (16) at page 70, providing the common uncertainty. On the basis of the correlation coefficients assumed for the laboratories linking the two groups, see section 10, correlation coefficients lower than or equal to 0,05 are calculated for each pair of traceability-related laboratories. As a test, the weighted mean and associated uncertainty of the diameter results of exemplary gauges (ring 80 mm and sphere 20 mm) in both groups were calculated using the mathematics in reference [5] including a pair of correlated results. The pairs with the highest correlation coefficient were selected to test the dataset of the two groups. Negligible changes (≤ 1 nm) were observed from the weighted mean calculated with and without the pair of correlated results. Hence, correlations are not considered in the analysis of this comparison.

Diameter - Group1

Laboratory	Ring Φ 5 mm, sn1655264	Ring Φ 80 mm, sn 1655173	Plug Φ 5 mm, sn 1655135	Plug Φ 100 mm, sn B49096	Sphere Φ 20 mm, sn S2813
	Δl ± U(Δl) *μm*	*Δl ± U(Δl)* *μm*	*Δl ± U(Δl)* *μm*	*Δl ± U(Δl)* *μm*	*Δl ± U(Δl)* *μm*
INRIM	-0,011 ± 0,092	0,005 ± 0,098	-0,003 ± 0,076	0,072 ± 0,147	-0,010 ± 0,057
BEV	0,239 ± 0,599	0,095 ± 0,296	-0,013 ± 0,194	-0,038 ± 0,338	-0,130 ± 0,277
CEM	0,239 ± 0,297	0,225 ± 0,296	-0,003 ± 0,142	-0,028 ± 0,184	0,200 ± 0,108
CMI	-0,061 ± 0,398	0,295 ± 0,457	-0,103 ± 0,397	0,022 ± 0,511	-0,120 ± 0,418
DTI	-0,111 ± 0,899	0,215 ± 1,199	-0,033 ± 0,518	-0,248 ± 0,906	-0,280 ± 0,599
FSB	-0,111 ± 0,759	0,615 ± 0,678	-0,133 ± 0,698	-0,148 ± 1,006	-0,180 ± 0,699
GUM	0,039 ± 0,539	-0,155 ± 0,377	0,647 ± 0,498	1,152 ± 0,535	0,380 ± 0,478
INM	-0,211 ± 0,519	0,365 ± 0,638	-0,223 ± 0,498	0,212 ± 0,688	-0,300 ± 0,458
LNE	0,089 ± 0,092	-0,105 ± 0,095	0,057 ± 0,088	0,162 ± 0,155	0,000 ± 0,091
METAS	-0,021 ± 0,031	0,025 ± 0,062	-0,023 ± 0,095	-0,058 ± 0,125	0,020 ± 0,054
VSL	-0,041 ± 0,196	-0,075 ± 0,214	-0,033 ± 0,194	-0,198 ± 0,245	0,090 ± 0,196
EIM	-0,031 ± 0,484	0,045 ± 0,507	-0,311 ± 0,343	-0,092 ± 0,418	-0,167 ± 0,346

Diameter - Group 2

Laboratory	Ring Φ 5 mm, sn 1655263	Ring Φ 80 mm, sn 1655174	Plug Φ 5 mm, sn 1655136	Plug Φ 100 mm, sn B50315	Sphere Φ 20 mm, sn S2812
	Δl ± U(Δl) *μm*	*Δl ± U(Δl)* *μm*	*Δl ± U(Δl)* *μm*	*Δl ± U(Δl)* *μm*	*Δl ± U(Δl)* *μm*
INRIM	0,011 ± 0,082	-0,069 ± 0,090	-0,029 ± 0,083	0,108 ± 0,171	0,007 ± 0,062
METAS	0,021 ± 0,052	0,031 ± 0,063	-0,009 ± 0,058	0,088 ± 0,166	0,017 ± 0,060
RISE (SP)	0,111 ± 0,135	0,081 ± 0,154	-0,139 ± 0,197	-0,062 ± 0,239	-0,063 ± 0,157
BFKH (MKEH)	-0,379 ± 0,243	-0,239 ± 0,277	0,241 ± 0,217	-0,092 ± 0,327	-0,343 ± 0,238
NSAI		-0,554 ± 0,879	-0,091 ± 0,148	-0,247 ± 0,281	-0,008 ± 0,165
CEM	1,031 ± 0,302	-0,059 ± 0,297	0,091 ± 0,146	-0,122 ± 0,199	0,057 ± 0,095
VTT MIKES	-0,169 ± 0,196	-0,039 ± 0,216	0,011 ± 0,197	-0,032 ± 0,256	-0,033 ± 0,146
UME	-0,119 ± 0,215	-0,259 ± 0,412	-0,059 ± 0,211	-0,192 ± 0,480	-0,193 ± 0,205
MBM		-0,289 ± 0,893	0,021 ± 0,693	0,168 ± 0,761	-0,223 ± 1,170
SASO-NMCC	-0,179 ± 0,322	-0,099 ± 0,428	0,031 ± 0,223	-0,082 ± 0,406	0,177 ± 0,234
INTI	0,001 ± 0,135	0,001 ± 0,175	0,051 ± 0,135	-0,072 ± 0,223	-0,013 ± 0,136
PTB	-0,019 ± 0,062	0,041 ± 0,070	0,011 ± 0,065	-0,012 ± 0,159	0,007 ± 0,064

Roundness

Group1

Laboratory	Sphere Φ 20 mm, sn S2813	Ring Φ 80 mm, sn 1655173			Plug Φ 100 mm, sn B49096		
		midway	"+8 mm	" -8 mm	midway	" +5 mm	" -5 mm
	ΔR ± U(ΔR) *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*
INRIM	-0,003 ± 0,004	-0,006 ± 0,038	0,025 ± 0,039	0,007 ± 0,039	-0,021 ± 0,038	-0,023 ± 0,039	-0,008 ± 0,039
CEM	0,001 ± 0,019	-0,003 ± 0,013	-0,004 ± 0,015	0,003 ± 0,015	-0,004 ± 0,013	0,005 ± 0,015	-0,002 ± 0,015
CMI	-0,001 ± 0,025	0,001 ± 0,027	0,010 ± 0,028	0,016 ± 0,028	0,014 ± 0,027	-0,003 ± 0,039	0,015 ± 0,028
DTI	0,032 ± 0,084	0,014 ± 0,089	0,015 ± 0,090	0,007 ± 0,090	0,019 ± 0,085	0,017 ± 0,087	0,032 ± 0,085
FSB	0,091 ± 0,090	-0,059 ± 0,109	-0,023 ± 0,110	-0,061 ± 0,110	0,028 ± 0,109	-0,008 ± 0,110	0,011 ± 0,110
GUM	0,056 ± 0,072	-0,001 ± 0,069	-0,013 ± 0,069	-0,007 ± 0,071	0,017 ± 0,069	-0,013 ± 0,069	0,044 ± 0,069
INM	0,017 ± 0,080	-0,068 ± 0,079	-0,081 ± 0,079	-0,093 ± 0,079	-0,021 ± 0,079	-0,033 ± 0,079	0,020 ± 0,079
LNE	0,012 ± 0,050	0,021 ± 0,048	0,000 ± 0,049	0,027 ± 0,049	-0,003 ± 0,048	-0,016 ± 0,049	-0,010 ± 0,049
METAS	-0,007 ± 0,029	0,024 ± 0,048	-0,005 ± 0,049	0,027 ± 0,049	0,009 ± 0,048	0,017 ± 0,049	0,012 ± 0,049
VSL	0,019 ± 0,039	0,160 ± 0,025	-0,002 ± 0,010	-0,008 ± 0,010	0,047 ± 0,019	0,001 ± 0,010	-0,005 ± 0,010
EIM	0,038 ± 0,140	0,178 ± 0,139	0,185 ± 0,140	0,138 ± 0,140	0,027 ± 0,139	0,010 ± 0,140	0,037 ± 0,140

Group 2

Laboratory	Sphere Φ 20 mm at 50 UPR	Ring Φ 80 mm, sn 1655174			Plug Φ 100 mm, sn B50315		
		midway	"+8 mm	" -8 mm	midway	" +5 mm	" -5 mm
	ΔR ± U(ΔR) *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*	*ΔR ± U(ΔR)* *µm*
INRIM	0,003 ± 0,007	-0,031 ± 0,038	-0,001 ± 0,038	-0,001 ± 0,038	-0,001 ± 0,038	-0,007 ± 0,038	0,006 ± 0,038
METAS	-0,004 ± 0,020	-0,021 ± 0,049	-0,021 ± 0,049	-0,031 ± 0,049	-0,011 ± 0,049	-0,007 ± 0,049	0,006 ± 0,049
RISE (SP)	-0,001 ± 0,002	-0,001 ± 0,016	0,009 ± 0,016	0,009 ± 0,016	-0,001 ± 0,016	0,003 ± 0,016	-0,004 ± 0,016
BFKH (MKEH)	0,024 ± 0,104	-0,006 ± 0,105	0,032 ± 0,105	0,000 ± 0,105	0,003 ± 0,105	0,002 ± 0,105	0,090 ± 0,105
CEM	0,017 ± 0,020	0,008 ± 0,014	-0,005 ± 0,014	-0,003 ± 0,014	0,003 ± 0,014	0,000 ± 0,014	-0,008 ± 0,014
VTT MIKES	0,082 ± 0,140	0,029 ± 0,140	-0,011 ± 0,140	-0,011 ± 0,140	0,039 ± 0,140	0,013 ± 0,140	0,016 ± 0,140
UME	0,014 ± 0,052	-0,006 ± 0,055	-0,009 ± 0,055	-0,004 ± 0,055	-0,012 ± 0,055	0,006 ± 0,057	-0,017 ± 0,055
SASO-NMCC	0,012 ± 0,046	0,009 ± 0,045	-0,001 ± 0,045	0,009 ± 0,045	-0,001 ± 0,045	-0,007 ± 0,045	0,016 ± 0,045
INTI	0,019 ± 0,070	0,001 ± 0,087	-0,001 ± 0,087	0,004 ± 0,087	-0,018 ± 0,097	-0,008 ± 0,097	0,081 ± 0,097
PTB	0,016 ± 0,100	0,026 ± 0,099	0,014 ± 0,099	-0,008 ± 0,099	-0,014 ± 0,099	-0,016 ± 0,099	0,066 ± 0,099

Straightness

Group 1

Laboratory	Ring Φ 5 mm, sn1655264	Ring Φ 80 mm, sn 1655173	Plug Φ 5 mm, sn 1655135	Plug Φ 100 mm, sn B49096
	ΔStr ± U(ΔStr) *µm*	*ΔStr ± U(ΔStr)* *µm*	*ΔStr ± U(ΔStr)* *µm*	*ΔStr ± U(ΔStr)* *µm*
INRIM	0,016 ± 0,098	0,042 ± 0,099	-0,004 ± 0,098	0,019 ± 0,099
CEM	0,007 ± 0,059	-0,001 ± 0,060	-0,005 ± 0,062	-0,011 ± 0,058
CMI	0,066 ± 0,199	0,062 ± 0,199	0,011 ± 0,199	0,084 ± 0,199
DTI	-0,004 ± 0,080	-0,008 ± 0,081	-0,019 ± 0,080	0,004 ± 0,083
GUM		-0,017 ± 0,400	-0,025 ± 0,400	-0,006 ± 0,400
INM	0,098 ± 0,159	0,057 ± 0,159	0,084 ± 0,159	0,119 ± 0,159
LNE	0,019 ± 0,109	0,041 ± 0,109	0,054 ± 0,109	0,049 ± 0,109
METAS	-0,004 ± 0,031	-0,008 ± 0,016	0,011 ± 0,031	0,004 ± 0,014
VSL	-0,004 ± 0,016	0,003 ± 0,019	-0,007 ± 0,016	-0,013 ± 0,019
EIM	0,006 ± 0,119	0,022 ± 0,159	0,001 ± 0,119	0,014 ± 0,119

Group 2

Laboratory	Ring Φ 5 mm, sn 1655263	Ring Φ 80 mm, sn 1655174	Plug Φ 5 mm, sn 1655136	Plug Φ 100 mm, sn B50315
	ΔStr ± U(ΔStr) *µm*	*ΔStr ± U(ΔStr)* *µm*	*ΔStr ± U(ΔStr)* *µm*	*ΔStr ± U(ΔStr)* *µm*
INRIM	0,011 ± 0,098	0,001 ± 0,098	0,002 ± 0,098	0,020 ± 0,098
METAS	-0,009 ± 0,015	0,001 ± 0,017	0,002 ± 0,016	0,000 ± 0,015
RISE (SP)	0,051 ± 0,299	0,051 ± 0,299	0,052 ± 0,299	0,080 ± 0,299
CEM	-0,001 ± 0,056	-0,013 ± 0,056	-0,018 ± 0,056	-0,005 ± 0,058
VTT MIKES	0,081 ± 0,098	0,041 ± 0,098	0,002 ± 0,056	-0,010 ± 0,098
UME	0,025 ± 0,098	-0,009 ± 0,095	-0,015 ± 0,096	0,002 ± 0,096
SASO-NMCC	0,031 ± 0,100	-0,019 ± 0,100	0,012 ± 0,100	0,010 ± 0,100
PTB	-0,011 ± 0,098	-0,001 ± 0,098		-0,007 ± 0,098

11 Linking the two groups

To establish a numerical link between the two groups use is made of the mathematics given in reference [4]. It was used for linking two loops in a recent comparison [3].
For a better readability of this report, the mathematical formulas from the references 3 and 4 are copied here for the reference values, their uncertainties and the parameters for the linking.
It is worth noting that the subscripts 1 and 2 in these formulas represent the two groups of this comparison.

Key Comparison Reference Values (KCRVs)

$$x_{ref,1} = \frac{b \cdot S_1 + c \cdot S_2}{a \cdot b - c^2} \quad ; \quad x_{ref,2} = \frac{c \cdot S_1 + a \cdot S_2}{a \cdot b - c^2} \tag{12}$$

Standard uncertainties of the KCRVs

$$u(x_{ref,1}) = \sqrt{\frac{b}{a \cdot b - c^2}} \;; u(x_{ref,2}) = \sqrt{\frac{a}{a \cdot b - c^2}} \tag{13}$$

Covariance of the KCRVs

$$u(x_{ref,1}\,,\ x_{ref,2}) = \frac{c}{a \cdot b - c^2} \tag{14}$$

Parameters (15)

$$a = \sum\nolimits_{1\backslash 2} \frac{1}{u^2(x_{1,i})} + \sum\nolimits_{1\cap 2} \frac{u^2(x_{2,i})}{u^2(x_{1,i})\, u^2(x_{2,i}) - u^2(x_{1,i}, x_{2,i})}$$

$$b = \sum\nolimits_{2\backslash 1} \frac{1}{u^2(x_{2,i})} + \sum\nolimits_{1\cap 2} \frac{u^2(x_{1,i})}{u^2(x_{1,i})\, u^2(x_{2,i}) - u^2(x_{1,i}, x_{2,i})}$$

$$c = \sum\nolimits_{1\cap 2} \frac{1}{u^2(x_{1,i})} + \sum\nolimits_{1\cap 2} \frac{u(x_{1,i}, x_{2,i})}{u^2(x_{1,i})\, u^2(x_{2,i}) - u^2(x_{1,i}, x_{2,i})}$$

$$S_1 = \sum\nolimits_{1\backslash 2} \frac{x_{1,i}}{u^2(x_{1,i})} + \sum\nolimits_{1\cap 2} \frac{u^2(x_{2,i})\, x_{1,i} - u^2(x_{1,i}, x_{2,i})\, x_{2,i}}{u^2(x_{1,i})\, u^2(x_{2,i}) - u^2(x_{1,i}, x_{2,i})}$$

$$S_2 = \sum\nolimits_{2\backslash 1} \frac{x_{2,i}}{u^2(x_{2,i})} + \sum\nolimits_{1\cap 2} \frac{u^2(x_{1,i})\, x_{2,i} - u^2(x_{1,i}, x_{2,i})\, x_{1,i}}{u^2(x_{1,i})\, u^2(x_{2,i}) - u^2(x_{1,i}, x_{2,i})}$$

The covariances are replaced by the correlation coefficients ***r*** in the above formulas**.**

$$r_{12,i} = \frac{u(x_{1,i}, x_{2,i})}{u(x_{1,i})\, u(x_{2,i})} \tag{16}$$

A conformity test is introduced in [4] to check the overall set of results of the twin artefacts and measurands.

$$\frac{q^2}{N-2} \leq 1 \quad ; \tag{17}$$

where N represents the total number of measured data and 2 are the estimated reference values for each set of data.

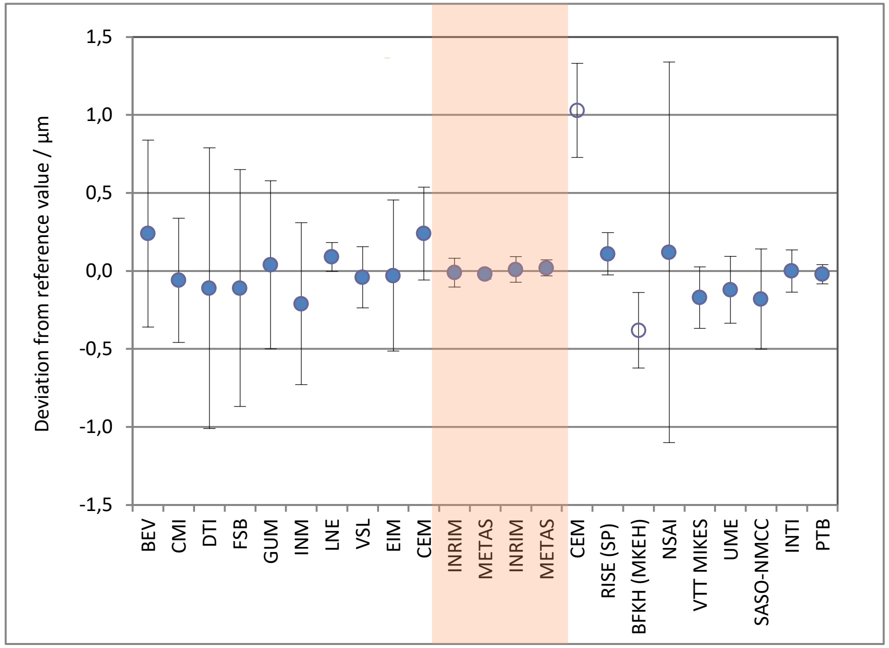
A detailed analysis of the uncertainty components is required to estimate the correlation coefficients ($r \leq 1$). They are expected to be positive assuming that measurements from the same laboratory in the two groups are affected in the same direction by systematic errors.

At this stage of the analysis, correlations coefficients of r = 0,1 are assumed for the three linking laboratories (CEM, INRIM, and METAS) in the two groups. With the exception of the 100 mm plugs, the linked reference values and their uncertainties show minor changes from those calculated for the independent groups, and conformity tests are consistent (≤ 1).

Again, this is not the case of the 100 mm plugs, thus demonstrating that results suffer from systematic deviations more possibly due to the apparent changes of length of these gauges during the circulation, as estimated from the pilot measurements. A slightly larger correlation coefficient (r=0,3) is estimated for INRIM to take into account a possibly larger systematic deviation being INRIM always at the beginning of the circulation of the two 100 mm plugs.
No correction is made for the apparent changes of length of the 100 mm plugs while an uncertainty related to the artefact is introduced for comparison with the reference value according to the equations (10, 11). With the 100 mm plugs, an artefact-related uncertainty of 58 nm and of 70 was estimated from the pilot measurements.
The linking results are shown on the following pages for the diameter of rings and plugs, and for the departure of roundness of the sphere. All quantity values are in micrometers. The subscript “R” stands for reference values while “i” for the i-th laboratory.

Ring 5 mm

Measurement results	/µm			Degrees of equivalence		
Institute	x_i - x_{nom}	u_i	on/off	x_i-x_R	$U(x_i$-$x_R)$	E_n
BEV	-1,250	0,300	1	0,240	0,599	0,4
CMI	-1,550	0,200	1	-0,060	0,398	0,2
DTI	-1,600	0,450	1	-0,110	0,899	0,1
FSB	-1,600	0,380	1	-0,110	0,759	0,1
GUM	-1,450	0,270	1	0,040	0,539	0,1
INM	-1,700	0,260	1	-0,210	0,519	0,4
LNE	-1,400	0,050	1	0,090	0,092	1,0
VSL	-1,530	0,100	1	-0,040	0,196	0,2
EIM	-1,520	0,243	1	-0,030	0,484	0,1
CEM	-1,250	0,150	1	0,240	0,297	0,8
INRIM	-1,500	0,050	1	-0,010	0,092	0,1
METAS	-1,510	0,025	1	-0,020	0,031	0,6
INRIM	-1,570	0,045	1	0,010	0,082	0,1
METAS	-1,560	0,032	1	0,020	0,052	0,4
CEM	-0,550	0,150	0	1,030	0,302	3,4
RISE (SP)	-1,470	0,070	1	0,110	0,135	0,8
BFKH (MKEH)	-1,960	0,120	0	-0,380	0,243	1,6
NSAI	-1,460	0,610	1	0,120	1,219	0,1
VTT MIKES	-1,750	0,100	1	-0,170	0,196	0,9
UME	-1,700	0,109	1	-0,120	0,215	0,6
SASO-NMCC	-1,760	0,162	1	-0,180	0,322	0,6
INTI	-1,580	0,070	1	0,000	0,135	0,0
PTB	-1,600	0,036	1	-0,020	0,062	0,3



Parameter	
a	2,66E+03
b	2,89E+03
c	1,71E+02
S_1	-3,69E+03
S_2	-4,31E+03
q^2	1,69E+01
$u(x_{1,A},x_{2,A})$	2,25E-04
$u(x_{1,B},x_{2,B})$	8,00E-05
$r_{12,A}$	0,1
$r_{12,B}$	0,1
$u_{ext,1}$	0,017
$u_{ext,2}$	0,019
$u_{int,1}$	0,019
$u_{int,2}$	0,018

Reference values

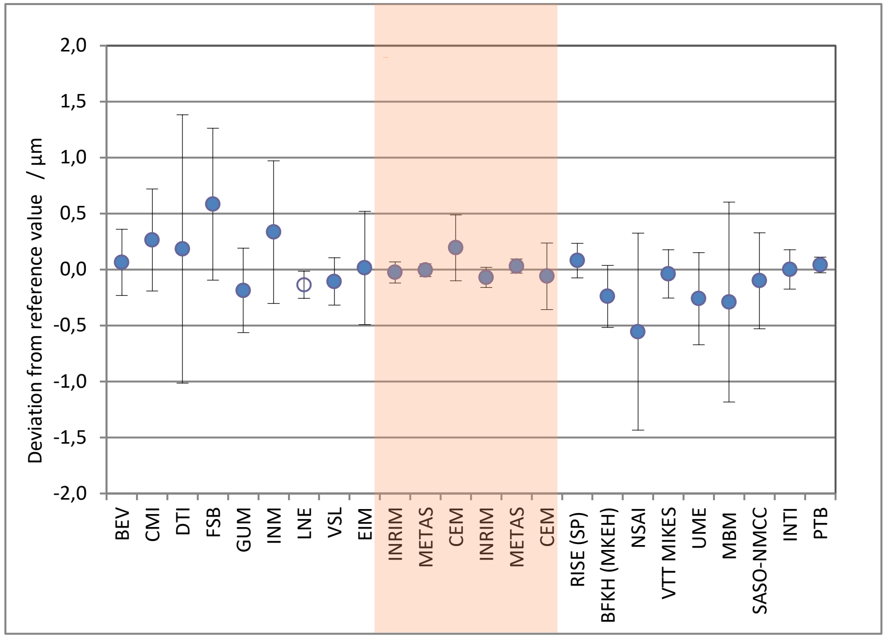
	x_R	u_R	N	χ^2 Test	R_B	R_B limit
Group 1	-1,490	0,019	12	passed	0,86	1,36
Group 2	-1,580	0,019	9	passed	1,06	1,41
Conformity	0,89					
Covariance	2,24E-05					

Reference values by separate groups

	x_R	u_R
Group 1	-1,489	0,019
Group 2	-1,581	0,019

Ring 80 mm

Measurement results		/µm		Degrees of equivalence		
Institute	x_i - x_{nom}	u_i	on/off	x_i - x_R	$U(x_i$-$x_R)$	E_n
BEV	-0,520	0,150	1	0,064	0,294	0,2
CMI	-0,320	0,230	1	0,264	0,456	0,6
DTI	-0,400	0,600	1	0,184	1,199	0,2
FSB	0,000	0,340	1	0,584	0,678	0,9
GUM	-0,770	0,190	1	-0,186	0,376	0,5
INM	-0,250	0,320	1	0,334	0,637	0,5
LNE	-0,720	0,054	0	-0,136	0,122	1,1
VSL	-0,690	0,110	1	-0,106	0,212	0,5
EIM	-0,570	0,255	1	0,014	0,507	0,0
INRIM	-0,610	0,055	1	-0,026	0,094	0,3
METAS	-0,590	0,040	1	-0,006	0,056	0,1
CEM	-0,390	0,150	1	0,194	0,294	0,7
INRIM	0,210	0,050	1	-0,069	0,090	0,8
METAS	0,310	0,038	1	0,031	0,063	0,5
CEM	0,220	0,150	1	-0,059	0,297	0,2
RISE (SP)	0,360	0,080	1	0,081	0,154	0,5
BFKH (MKEH)	0,040	0,140	1	-0,239	0,277	0,9
NSAI	-0,275	0,440	1	-0,554	0,879	0,6
VTT MIKES	0,240	0,110	1	-0,039	0,216	0,2
UME	0,020	0,207	1	-0,259	0,412	0,6
MBM	-0,010	0,447	1	-0,289	0,893	0,3
SASO-NMCC	0,180	0,215	1	-0,099	0,428	0,2
INTI	0,280	0,090	1	0,001	0,175	0,0
PTB	0,320	0,041	1	0,041	0,070	0,6



Parameter	
a	1,22E+03
b	2,21E+03
c	1,08E+02
S_1	-7,43E+02
S_2	6,81E+02
q^2	2,11E+01
$u(x_{1,A},x_{2,A})$	2,75E-04
$u(x_{1,B},x_{2,B})$	1,52E-04
$u(x_{1,C},x_{2,C})$	2,25E-03
$r_{12,A}$	0,1
$r_{12,B}$	0,1
$r_{12,C}$	0,1
$u_{ext,1}$	0,028
$u_{ext,2}$	0,022
$u_{int,1}$	0,025
$u_{int,2}$	0,021

Reference values

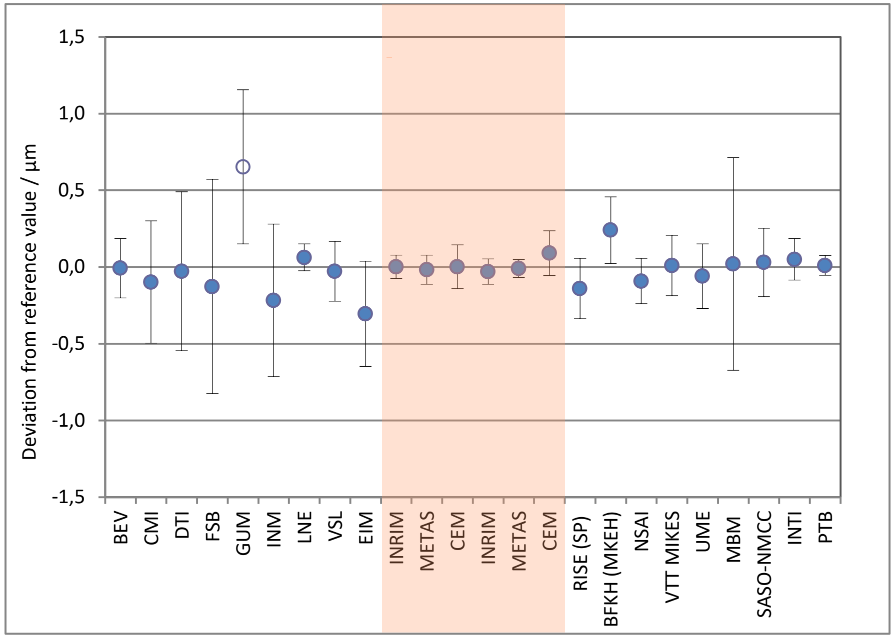
	x_R	u_R	N	χ^2 Test	R_B	R_B limit
Group 1	-0,584	0,029	11	passed	1,10	1,38
Group 2	0,279	0,021	12	passed	1,03	1,36
Conformity	1,00					
Covariance	4,01E-05					

Reference values by separate groups

	x_R	u_R
Group 1	-0,615	0,025
Group 2	0,279	0,021

Plug 5 mm

Measurement results	/µm			Degrees of equivalence		
Institute	x_i - x_{nom}	u_i	on/off	x_i - x_R	$U(x_i$-$x_R)$	E_n
BEV	-0,580	0,100	1	-0,007	0,194	0,0
CMI	-0,670	0,200	1	-0,097	0,397	0,2
DTI	-0,600	0,260	1	-0,027	0,518	0,1
FSB	-0,700	0,350	1	-0,127	0,698	0,2
GUM	0,080	0,250	0	0,653	0,502	1,3
INM	-0,790	0,250	1	-0,217	0,498	0,4
LNE	-0,510	0,050	1	0,063	0,088	0,7
VSL	-0,600	0,100	1	-0,027	0,194	0,1
EIM	-0,878	0,173	1	-0,305	0,343	0,9
INRIM	-0,570	0,045	1	0,003	0,076	0,0
METAS	-0,590	0,053	1	-0,017	0,094	0,2
CEM	-0,570	0,075	1	0,003	0,142	0,0
INRIM	-0,210	0,045	1	-0,030	0,083	0,4
METAS	-0,190	0,034	1	-0,010	0,058	0,2
CEM	-0,090	0,075	1	0,090	0,146	0,6
RISE (SP)	-0,320	0,100	1	-0,140	0,197	0,7
BFKH (MKEH)	0,060	0,110	1	0,240	0,217	1,1
NSAI	-0,272	0,076	1	-0,092	0,148	0,6
VTT MIKES	-0,170	0,100	1	0,010	0,197	0,1
UME	-0,240	0,107	1	-0,060	0,211	0,3
MBM	-0,160	0,347	1	0,020	0,693	0,0
SASO-NMCC	-0,150	0,113	1	0,030	0,223	0,1
INTI	-0,130	0,070	1	0,050	0,135	0,4
PTB	-0,170	0,037	1	0,010	0,065	0,2



Parameter	
a	1,74E+03
b	3,12E+03
c	1,24E+02
S_1	-9,71E+02
S_2	-4,91E+02
q^2	1,72E+01
$u(x_{1,A},x_{2,A})$	2,03E-04
$u(x_{1,B},x_{2,B})$	1,80E-04
$u(x_{1,C},x_{2,C})$	5,63E-04
$r_{12,A}$	0,1
$r_{12,B}$	0,1
$r_{12,C}$	0,1
$u_{ext,1}$	0,019
$u_{ext,2}$	0,018
$u_{int,1}$	0,024
$u_{int,2}$	0,018

Reference values

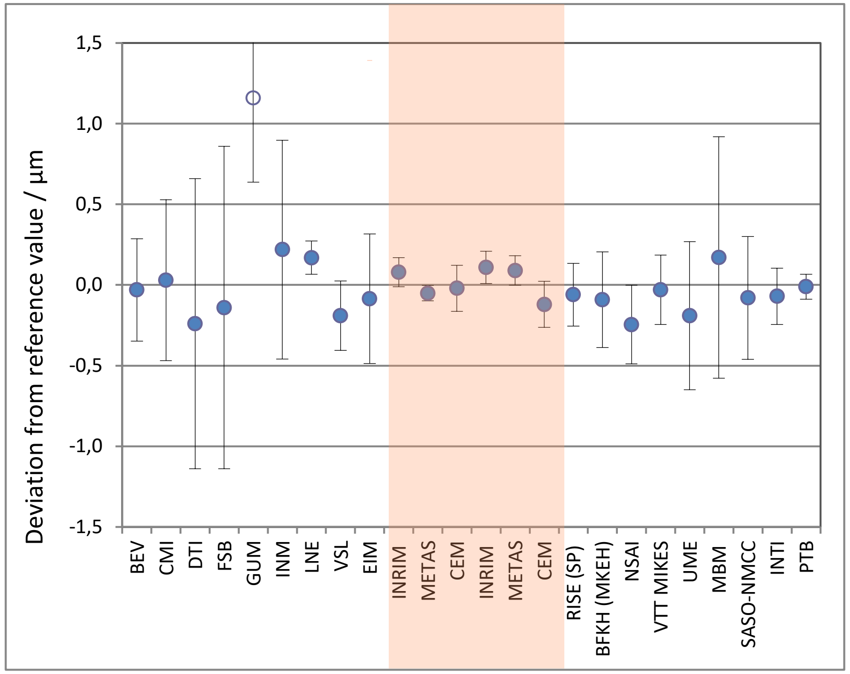
	x_R	u_R	N	χ² Test	R_B	R_B limit
Group 1	-0,573	0,024	11	passed	0,78	1,38
Group 2	-0,180	0,018	12	passed	1,01	1,36
Conformity	0,82					
Covariance	2,30E-05					

Reference values by separate groups

	x_R	u_R
Group 1	-0,567	0,024
Group 2	-0,181	0,018

Plug 100 mm

Measurement results		/µm		Degrees of equivalence			U(Δl) see equations (10,11)
Institute	x_i - x_{nom}	u_i	on/off	x_i - x_R	$U(x_i$-$x_R)$	E_n	$U(\Delta l)$
BEV	58,710	0,160	1	-0,031	0,317	0,1	0,338
CMI	58,770	0,250	1	0,029	0,498	0,1	0,511
DTI	58,500	0,450	1	-0,241	0,899	0,3	0,906
FSB	58,600	0,500	1	-0,141	0,999	0,1	1,006
GUM	59,900	0,260	0	1,159	0,522	2,2	0,535
INM	58,960	0,340	1	0,219	0,679	0,3	0,688
LNE	58,910	0,056	1	0,169	0,103	1,6	0,155
VSL	58,550	0,110	1	-0,191	0,216	0,9	0,245
EIM	58,656	0,202	1	-0,085	0,402	0,2	0,418
INRIM	58,820	0,050	1	0,079	0,090	0,9	0,147
METAS	58,690	0,032	1	-0,051	0,047	1,1	0,125
CEM	58,720	0,075	1	-0,021	0,143	0,1	0,184
INRIM	36,390	0,055	1	0,110	0,100	1,1	0,171
METAS	36,370	0,051	1	0,090	0,091	1,0	0,166
CEM	36,160	0,075	1	-0,120	0,143	0,8	0,199
RISE (SP)	36,220	0,100	1	-0,060	0,195	0,3	0,239
BFKH (MKEH)	36,190	0,150	1	-0,090	0,296	0,3	0,327
NSAI	36,035	0,124	1	-0,245	0,244	1,0	0,281
VTT MIKES	36,250	0,110	1	-0,030	0,215	0,1	0,256
UME	36,090	0,231	1	-0,190	0,460	0,4	0,480
MBM	36,450	0,375	1	0,170	0,749	0,2	0,761
SASO-NMCC	36,200	0,192	1	-0,080	0,381	0,2	0,406
INTI	36,210	0,090	1	-0,070	0,174	0,4	0,223
PTB	36,270	0,045	1	-0,010	0,077	0,1	0,159



Parameter	
a	2,10E+03
b	1,89E+03
c	2,00E+02
S_1	1,16E+05
S_2	5,70E+04
q^2	3,34E+01
$u(x_{1,A},x_{2,A})$	8,25E-04
$u(x_{1,B},x_{2,B})$	1,63E-04
$u(x_{1,C},x_{2,C})$	5,63E-04
$r_{12,A}$	0,3
$r_{12,B}$	0,1
$r_{12,C}$	0,1
$u_{ext,1}$	0,030
$u_{ext,2}$	0,028
$u_{int,1}$	0,022
$u_{int,2}$	0,023

Reference values

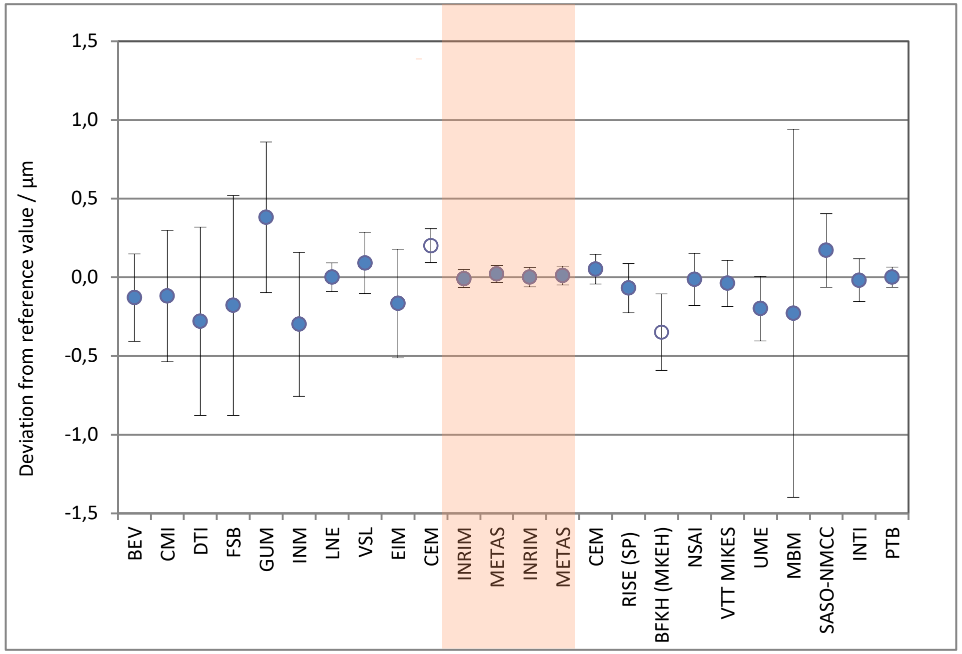
	x_R	u_R	N	χ^2 Test	R_B	R_B limit
Group 1	58,741	0,022	11	passed	1,36	1,38
Group 2	36,280	0,023	12	passed	1,21	1,36
Conformity	1,59					
Covariance	5,06E-05					

Reference values by separate groups

	x_R	u_R	$u_{xartefact}$
Group 1	58,748	0,022	0,058
Group 2	36,282	0,023	0,070

Ceramic sphere 20 mm

Measurement results	/µm			Degrees of equivalence		
Institute	x_i - x_{nom}	u_i	on/off	x_i - x_R	$U(x_i$-$x_R)$	E_n
BEV	-23,350	0,140	1	-0,129	0,277	0,5
CMI	-23,340	0,210	1	-0,119	0,418	0,3
DTI	-23,500	0,300	1	-0,279	0,599	0,5
FSB	-23,400	0,350	1	-0,179	0,699	0,3
GUM	-22,840	0,240	1	0,381	0,478	0,8
INM	-23,520	0,230	1	-0,299	0,458	0,7
LNE	-23,220	0,050	1	0,001	0,091	0,0
VSL	-23,130	0,100	1	0,091	0,196	0,5
EIM	-23,387	0,174	1	-0,166	0,346	0,5
CEM	-23,020	0,050	0	0,201	0,108	1,9
INRIM	-23,230	0,035	1	-0,009	0,057	0,2
METAS	-23,200	0,034	1	0,021	0,054	0,4
INRIM	-21,680	0,035	1	0,001	0,062	0,0
METAS	-21,670	0,034	1	0,011	0,060	0,2
CEM	-21,630	0,050	1	0,051	0,094	0,5
RISE (SP)	-21,750	0,080	1	-0,069	0,157	0,4
BFKH (MKEH)	-22,030	0,120	0	-0,349	0,242	1,4
NSAI	-21,695	0,084	1	-0,014	0,165	0,1
VTT MIKES	-21,720	0,075	1	-0,039	0,146	0,3
UME	-21,880	0,104	1	-0,199	0,205	1,0
MBM	-21,910	0,585	1	-0,229	1,170	0,2
SASO-NMCC	-21,510	0,118	1	0,171	0,234	0,7
INTI	-21,700	0,070	1	-0,019	0,136	0,1
PTB	-21,680	0,036	1	0,001	0,064	0,0



Parameter	
a	2,36E+03
b	3,72E+03
c	1,70E+02
S_1	-5,11E+04
S_2	-7,66E+04
q^2	1,68E+01
$u(x_{1,A},x_{2,A})$	1,23E-04
$u(x_{1,B},x_{2,B})$	1,16E-04
$r_{12,A}$	0,1
$r_{12,B}$	0,1
$u_{ext,1}$	0,019
$u_{ext,2}$	0,015
$u_{int,1}$	0,019
$u_{int,2}$	0,016

Reference values

	x_R	u_R	N	χ^2 Test	R_B	R_B limit
Group 1	-23,221	0,021	11	passed	1,01	1,38
Group 2	-21,681	0,016	11	passed	0,91	1,38
Conformity	0,84					
Covariance	1,94E-05					

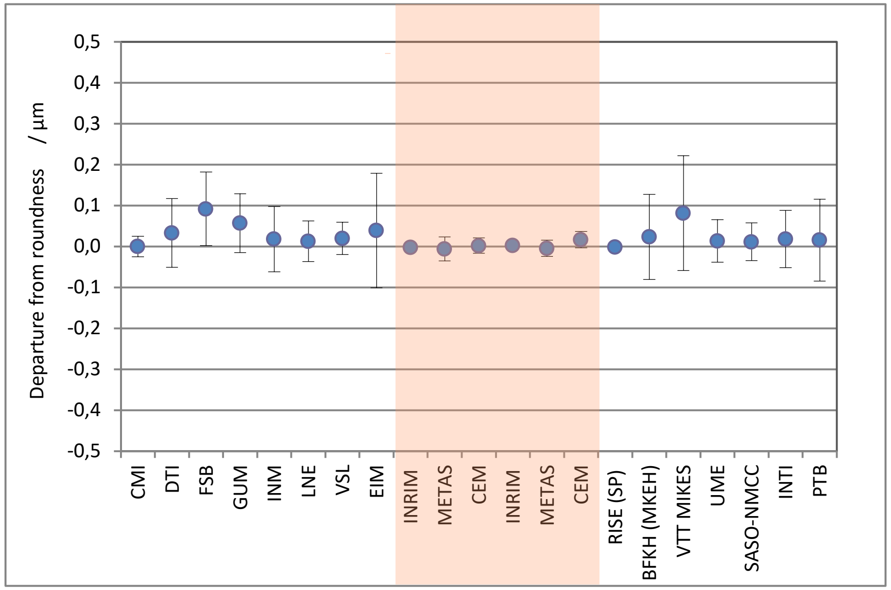
Reference values by separate groups

	x_R	u_R
Group 1	-23,220	0,021
Group 2	-21,687	0,016

Ceramic sphere 20 mm roundness

Measurement results /µm **Degrees of equivalence**

Institute	x_i	u_i	on/off	x_i-x_R	$U(x_i$-$x_R)$	E_n
CMI	0,027	0,013	1	0,000	0,025	0,0
DTI	0,060	0,042	1	0,033	0,084	0,4
FSB	0,119	0,045	1	0,092	0,090	1,0
GUM	0,084	0,036	1	0,057	0,072	0,8
INM	0,045	0,040	1	0,018	0,080	0,2
LNE	0,040	0,025	1	0,013	0,050	0,3
VSL	0,047	0,020	1	0,020	0,039	0,5
EIM	0,066	0,070	1	0,039	0,140	0,3
INRIM	0,025	0,004	1	-0,002	0,005	0,5
METAS	0,021	0,015	1	-0,006	0,029	0,2
CEM	0,029	0,010	1	0,002	0,019	0,1
INRIM	0,021	0,004	1	0,002	0,007	0,3
METAS	0,014	0,010	1	-0,005	0,020	0,2
CEM	0,035	0,010	1	0,016	0,020	0,8
RISE (SP)	0,017	0,002	1	-0,002	0,002	0,8
BFKH (MKEH)	0,042	0,052	1	0,023	0,104	0,2
VTT MIKES	0,100	0,070	1	0,081	0,140	0,6
UME	0,032	0,026	1	0,013	0,052	0,3
SASO-NMCC	0,030	0,023	1	0,011	0,046	0,2
INTI	0,037	0,035	1	0,018	0,070	0,3
PTB	0,034	0,050	1	0,015	0,100	0,2



Parameter

a	9,39E+04
b	3,42E+05
c	1,77E+04
S_1	2,22E+03
S_2	5,88E+03
q^2	1,59E+01
$u(x_{1,A},x_{2,A})$	4,00E-06
$u(x_{1,B},x_{2,B})$	1,50E-05
$u(x_{1,C},x_{2,C})$	4,00E-06
$r_{12,A}$	0,1
$r_{12,B}$	0,1
$r_{12,C}$	0,1
$u_{ext,1}$	0,003
$u_{ext,2}$	0,001
$u_{int,1}$	0,003
$u_{int,2}$	0,002

Reference values

	x_R	u_R	N	χ^2 Test	R_B	R_B limit
Group 1	0,027	0,003	11	passed	0,98	1,38
Group 2	0,019	0,002	10	passed	0,84	1,39
Conformity	0,83					
Covariance	5,58E-07					

Reference values by separate groups

	x_R	u_R
Group 1	0,028	0,003
Group 2	0,018	0,002

12 Linking of results 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.

The comparison will be linked to CCL-K4.2015 through the linking labs INRIM, CEM and METAS. They participated in both comparisons, CCL-K4.2015 and EURAMET.L-K4.2015.

The comparison followed the protocol of the comparison CCL-K4 as closely as possible. To what extent the two comparisons can be linked to each other, and whether this brings any added value, needs to be investigated by the CCL Task Group on comparison linking (TG-L) once the final reports of the comparisons are available.

13 Comments by partners

13.1 Comments before draft A

According to the Key-comparison guidelines, after the initial overview of the submitted results with calculation of reference values, En values, and Birge ratio, the NMIs having En values > 1 were asked by the pilot to check their results for numerical errors. Here below are copied the NMI's comment submitted with the revised report, if any.

GUM comment from October 12th, 2018

"We have reviewed our measurement results and found out that the uncertainty we have used for the ball and plug gauges is different from the ones we use for the usual calibrations for customers (we have sent the wrong values by mistake). The uncertainty for plug gauges that we have sent comes from CMC table. We have recently come to a conclusion that the value is too low and we are going to change the CMC claims. The uncertainty used for the ball was the same as for plug gauges (all were measured using the length measuring machine) and it is also too low. The correct value of uncertainty for the plug gauges and ball standard should be: Q[0.4; 4.0 *L*] µm, *L* in m. "

VSL comment from December 20th, 2018

"We discovered that our CMM has some previously unknown, but significant, pitch movements in the area where the measurements for L-K4 were performed. This affects all diameter measurements that were part of L-K4 due to the Abbe offset in our measurement setup. Since we do not record the absolute position of the standards that are measurement by CMM we could not accurately link the pitch angle curve to the position of the standards during the L-K4 measurements. We therefore decided to take a broad margin for the position of the standards and estimated what the Abbe error would have been from the pitch curve and the Abbe offset. This value (0.06 um) was added to the uncertainty budgets for all diameter measurements. "

As a result of a comment from the pilot laboratory (INRIM) about the VSL results for the diameter of the 100 mm plug gauge, an investigation was started to find the origin for the comment. Initially a typing error was found in the reported value: 10.05855 mm should have been 100.05855 mm. This was, however, not the reason VSL was informed about a problem with the initial result. Further investigation

led to the finding that the measurements were performed in section of the CMM where unexpectedly large pitch movements of the CMM were observed. Since absolute positions of the standards measured by the CMM are not recorded, we could not could accurately link the measured pitch curve to the exact position of the plug within the CMM during the measurements for L-K4. We therefore used a broad position margin to estimate the Abbe error from the measured pitch angle and the Abbe offset as a function of the CMM probe position. An uncorrected Abbe error of 0.06 µm was finally estimated and added to the uncertainty budget as a standard uncertainty.
Since the Abbe error was not considered and corrected for in all CMM measurements for L-K4, the uncertainty for all diameter measurements has been corrected by including the Abbe error.

Additionally, we found that the relative standard uncertainty component b as stated in the original document 'Appendix E2 Functional Uncertainty Report Form for Diameter Measurements.docx' was erroneously reported as an expanded uncertainty of 1·10-6. The relative standard uncertainty component b is now stated correctly as 5·10-7".

UME comment from June 25th, 2019

"After checking the raw data of our measurement results, we realized that we accidentally misprint (typo) the result in "Appendix D1 - Results Report Form" on page 12. Instead of the correct value of "4.9983 mm" in our measurement data, we have written the wrong value "4.99983 mm", writing an extra 9 after the comma.
The error was made when filling out the form. It was not the measurement process itself.
Therefore, UME does not need to make any corrective action on the measurement process. However, we decided that the measurement results and raw data forms should be rechecked by a third person before sending them out."

RISE comment from July 10th, 2019

"We have now looked into our records regarding the intercomparison Euramet.L-K4.2015.
We found that two sets of data exist for the 5 mm plug gauge. The first set of measurements, using spherical measuring tips, relate to our normal procedure for this type of objects, which also is the base for our CMC claim. The second set of measurements has been made with an experimental method, using flat measuring anvils, which has not been fully validated. The disadvantage with flat anvils is that the contact area is substantially wider than with spherical tips and therefore not comparable to results measured 4 mm from the end.
For some reason our colleague has chosen to report the result of this second set of measurements. However, we cannot provide an explanation why this choice was made.
We also found that the uncertainty regarding the 5 mm plug gauge has been underestimated, because a couple of uncertainty components are missing."

SASO-NMCC comment from July 1st, 2019

"We've reviewed all the results and found copy paste error in roundness results of the sphere.
Actually, we have copied result of 100 mm plug gauge to get the same formatting but unfortunately, we adjusted the last digit and forgot to remove number (1) and put (0) instead.
So, the correct results is 0.03 instead of 0.13 and 0.04 instead of 0.14."

13.2 Comments after draft A and draft B

At their request, some gauges have been remeasured by LNE (plug 100 mm sn B49096) and by CEM (sphere 20 mm, s/n S2813; ring 5 mm, s/n 1655263) after draft A.

LNE comments from October 21st, 2019 and February 26th, 2021

"After Draft A issue we ask for remeasurement of the 100 mm plug sn B49096. These measurement were done in February 2019. During these measurements it appeared, that we may have encounter a cleaning procedure problem: our technician did some measurements that gave a result similar to the reported, but noticed that find finding the turning point was not very clear. I did a second cleaning of the plug and probe more carefully. After this procedure, finding the turning point was easy and the results of several series of measurement gave the following diameter 100.05875 mm.
For the ring 80 mm sn 1655173 we found no errors or reason that could explained the difference.
However, since we found that we had certainly a cleaning issue for the 100 mm plug, we are wondering if it may be the same problem for the ring. Therefore, we ask INRIM for the possibility of doing some control measurement on this ring to check the hypothesis."

CEM comments from October 28th, 2019 and February 23rd, 2021

A report (attached separately) on gauge measurements after draft A has been submitted by CEM.
Comments and findings by CEM are summarized below.

"Sphere sn 2813 - Second measurements by CEM (April-May 2019)
After a previous analysis of the possible causes of the discrepancies observed in the values of the diameter of the sphere, it was decided to measure again the sphere in the one-coordinate measuring machine used in the first measurements, but adding to the standard an additional cylindrical holder to the small base support of the sphere, since an unstable fixation to the table of the measuring machine could have influenced the high value obtained for En.
A diameter of 19.976 82 mm with a standard uncertainty u_c 0.10 µm, fully compatible (En = 0.46) with the rest of the participants in the comparison was measured with the sphere fixed with an additional holder"

"Ring sn 1655263 - Second measurements by CEM (October 2019)
After a previous analysis of the possible causes of the discrepancies observed in the values of the inner diameter, it was decided to measure again the standard in the three-coordinate measuring machine used in the first measurements, but fixing the standards with two tweezers, instead of using modelling clay, since it is one of the variables that could have influenced the high value obtained for En.
A diameter of 4.998 31 mm with a standard uncertainty u_c 0.30 µm, fully compatible (En = 0.36) with the rest of the participants in the comparison was measured with the ring fixed with tweezers".

GUM comments from February 27th, 2021

"Due to our unsatisfactory results of plug gauge calibration in EURAMET.L-K4.2015 comparison, we started activities to determine the causes of non-compliance:

1. We took several measurements of the reference plug gauge used in the comparisons and other length and diameter standards on the 1-D length measuring machine using different measuring tips (spherical and flat). The results has been compared with measurement results obtained using other interferometers and 3-D coordinate machine in Laboratory.
2. The operation of the temperature measurement path was checked (the problem with non-contacting link in Keithley's multimeter was fixed) - no relation was found with the results obtained during comparisons.

3. The parallelism of the surfaces of flat measuring tips used in the comparisons of the plug gauges was checked - the inspection showed that the faces of flat tips are in good condition.
4. The calibration records have been carefully investigated once again.

The above attempts finally provide us with the answer about the reasons for non-compliance during the comparison. After analysing the measurements, it turned out that the results of measurements on our new 3-D coordinate machine and on a 1-D length measuring machine using a laser interferometer are slightly different (from 0.1 µm to 0.3 µm), whereas the results on the 1-D machine using the incremental scales are sometimes different significantly (from 0.6 µm to even 1.0 µm). Future measurements showed that calibration results on the 1-D length measuring machine with the use of an incremental scales were sometimes higher than the results obtained on a 1-D machine using a laser interferometer and 3-D coordinate machine. Due to the fact that no errors were previously observed when using the incremental scales, the measurement results with this standard were used as equally good in EURAMET.L-K4.2015 comparison. Now we have noticed that from time to time some errors occurs when we use it as a standard. In addition, we have seen an increasingly frequent error message popping up on an incremental scales. We decided to give up the use of the incremental scales in a 1-D length measuring machine and limit the measurements only to those with the laser interferometer. It turns out that if the results obtained for plug gauges using a laser interferometer were included in our EURAMET.L-K4.2015 report, they would easily fit in the criteria for acceptance."

MBM comments from March 2nd, 2021

"We send you slightly modified results of measurement uncertainties that take into account linearization and rounding. Attached I am sending you uncertainties (excel files) so you can clearly see the way the measurement uncertainties were calculated."
ring Φ80 mm: 0.896 (0.894) ;
plug Φ100 mm: 0,770 (0.750) ; plug Φ5 mm: 0.704 (0.694) ; sphere: 1.212 (1.17)

14 Conclusions

Twelve laboratories from EURAMET participated in group 1, while eleven laboratories from EURAMET and two laboratories from other RMOs participated in group 2 of this comparison on diameter standards. CEM, INRIM and METAS participated in both groups to link them.
The comparison was driven according to Key Comparison Guidelines. Some delays in circulation occurred in both groups, mainly due to minor changes in schedule, shipping and customs operations. Measurements reports have been submitted by all the NMIs and DIs. Unfortunately, EMI (UAE) has withdrawn.

No significant drifts due to secular changes of the gauges were observed with most of the gauges, while an apparent change in length outside the k = 2 uncertainty of the pilot laboratory was observed with the two plugs 100 mm, leading to an apparent shrinkage drift of these gauges during the circulation.
Some scratches and minor damages 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 milliNewton to the Newton range. The participants were asked to report diameter, roundness and straightness of the gauges.

In primis, the KCRV was calculated on a gauge-per-gauge basis as the weighted mean of the submitted results of the diameter, roundness and straightness measurements. If not consistent, the KCRV was

recomputed by zero weighting the result with larger En and the process iterated until a consistent Birge ratio was achieved.
With group 1, En ≥ 1 gave a number of 6 for diameter and 7 for roundness, while with group 2 a number of 6 for diameter. These numbers are mostly reflected in the comparison with reference values, while it is worth noting that with the plugs 100 mm a decrement of 3 inconsistent results is achieved by introducing an uncertainty contribution related to the apparent change of length of these gauges.

In secundis, the KCRV was calculated by linking the two groups according to the mathematics in reference [4]. Results of the linking are calculated for the diameter of all the twin gauges and for the roundness of the twin spheres. When compared to those calculated independently for each group, minor changes of the KCRVs and associated uncertainties are observed from linking the groups. Consistency checks are satisfied for most of the gauges with the exception of the plugs 100 mm, which suffer from an apparent change in length during the circulation.
With the linking, En ≥ 1 gave a number of 12 for diameter and 1 for roundness of the sphere.

In conclusion, the comparison shows a generally good constancy of results either for diameter, departure from roundness and straightness measurements.

Acknowledgments

The pilot laboratory would like to thank all colleagues from INRIM, participating laboratories and NMIs for their work and support in measuring and circulating the diameter gauges.

15 References

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