EUROMET Project 369

Interlaboratory comparison

Diameter calibration of cylindrical artefacts with nominal diameters of 2,5 mm

Final Report

PTB, September 2000, F. Lüdicke

1. Introduction

The EUROMET comparison measurements of project 369 were first proposed in May 1995. At that time, the last comparison measurements on cylindrical artefacts were the BCR “Intercomparison of Measurements of Internal Diameter”. These comparison measurements had been carried out between 1983 and 1987 on 4 setting ring gauges with diameters from 3 mm to 100 mm. Five national metrology institutes had participated in this intercomparison: SBM (Service de la Métrologie Belge, BE), PTB (DE), LNE (FR), NPL (GB, pilot laboratory), and IMGC (IT). The synthesis report EUR 11949 EN showed differences of the diameter measurement results of about 0,3 µm and more, in spite of given uncertainties of 0,1 µm. In view of these differences which were not acceptable, a new intercomparison was urgently required.

The peg for new comparison measurements of diameters on cylindrical artefacts was a CCM intercomparison concerning a new definition of the pressure. One of the main topics of that CCM project was the dimensional measurement of the piston/cylinder transfer standard used. The number of participants of the CCM project was reduced because of the narrow time frame. It was proposed to use that CCM intercomparison also as a EUROMET comparison measurement and to carry out within the framework of this EUROMET project additional diameter measurements on small cylindrical artefacts with nominal diameters of 2,5 mm. The small number of participants of the CCM intercomparison was the reason why the number of the participants of the proposed overlapping EUROMET project 369 was reduced as well.

Topics of the EUROMET project were the calibration of diameters and form deviations of the piston/cylinder system as described in the guidelines of the CCM project, and diameter calibrations of two 2,5 mm ferrules (cylindrical plugs) and two 2,5 mm sleeves (internal cylinders) used as fibre optic connectors in the data communication technique.

2. Participants, Time Schedule

Participants of the CCM project were
FR (LNE), GB (NPL), IT (IMGC), USA (NIST), and DE (PTB),
Topics were comparison measurements concerning the
dimensional calibration of the piston/cylinder system and
pressure measurements.

Participants of EUROMET project 369 were (see table 1)
CH (OFMET), DE (PTB), FR (LNE), GB (NPL), IT (IMGC), NL (NMi), SE (SP), USA (NIST).
Topics were comparison measurements concerning the
dimensional calibration of the piston/cylinder system,
only PTB, LNE, IMGC, and NIST, and
diameter calibration of the 2,5 mm ferrules and sleeves,
except NPL.

In the end, the combination of the two project parts was abandoned for practical reasons. At the EUROMET meeting it was decided to separate both parts and to write a report excluding the CCM part. This is why this report presents only the comparison measurement results for the 2,5 mm artefacts. For the results of dimensional measurements of the piston/cylinder system please refer to: G. F. Molinar, B. Rebaglia, A. Sacconi, J. C. Legras, G. P. Vailleau, J. W. Schmidt, J. Stoup, D. Flack, W. Sabuga, O. Jusko, ”Dimensional Measurements and Calculation of the Effective Area. Phase A1 of the CCM Key Comparison in the Pressure Range 0,05 to 1 MPa (gas medium, gauge mode)”, Metrologia 36(6), 2000.

The comparison measurements on the 2,5 mm artefacts started in May 1996 and were finished in October 1996. The list of participants is given in Table 1.

Time schedule:

May	1996	PTB (former calibrations: 1992 ...1994)
June	1996:	SP
July	1996	NMi
August	1996	OFMET
September	1996	LNE
October	1996	IMGC
November	1996	NIST

Laboratory Code	Country Code	Contact person, Laboratory	Phone, Fax, email
EAM / OFMET	CH	Ruedi Thalmann Swiss Federal Office of Metrology Lindenweg 50 CH-3003 Bern - Wabern Switzerland	Phone +41 31 323 33 85 Fax +41 31 323 3210 rudolf.thalmann@eam.admin.ch
BNM/LNE	FR	Georges Vailleau Laboratoire National d'Essais 1, rue Gaston Boissier F-75015 Paris France	Phone +33 1 40 43 3847 Fax +33 1 40 43 3737 georges.vailleau@lne.fr
IMGC	IT	Bruno I. Rebaglia Istituto di Metrologia G. Colonnetti Strada delle Cacce 73 I-10135 Torino Italy	Phone +39 011 3977 466 Fax +39 011 3977 459 rebaglia@imgc.to.cnr.it
NMi	NL	Gerard Kotte, Han Haitjema NMi Van Swinden Laboratorium Postbus 654 NL-2600 AR Delft Netherlands	Phone +31 152 691 641 Fax +31 152 612 971 GKotte@nmi.nl
SP	SE	Mikael Frennberg Swedish National Testing and Research Institute P.O. Box 857 S-50115 Boras Sweden	Phone +46 33 165496 Fax +46 33 106973 Mikael.Frennberg@sp.se
NIST	USA	John R. Stoup National Institute of Standards and Technology Gaithersburg, Maryland 20899 United States of America	Phone: +1 301-975-3476 Fax +1 301-869-0822 John.Stoup@nist.com
Coordinator:			
PTB	DE	Frank Lüdicke Physikalisch-Technische Bundesanstalt Postfach 3345 D-38023 Braunschweig Germany	Phone +49 531 592 5310 Fax +49 531 592 5305 frank.luedicke@ptb.de

Table 1 List of participants and contact persons of EUROMET project 369, part covering diameter calibrations of 2,5 mm artefacts

3. Standards

Four cylindrical standards were circulated, two ferrules (external cylinder artefacts with internal holes) with an external diameter of about 2,5 mm and two sleeves with an internal diameter of 2,5 mm. The cylindrical standards had an axial length of about 15 mm. An engraved mark helped to position the artefact for the diameter measurements, see Fig. 1.

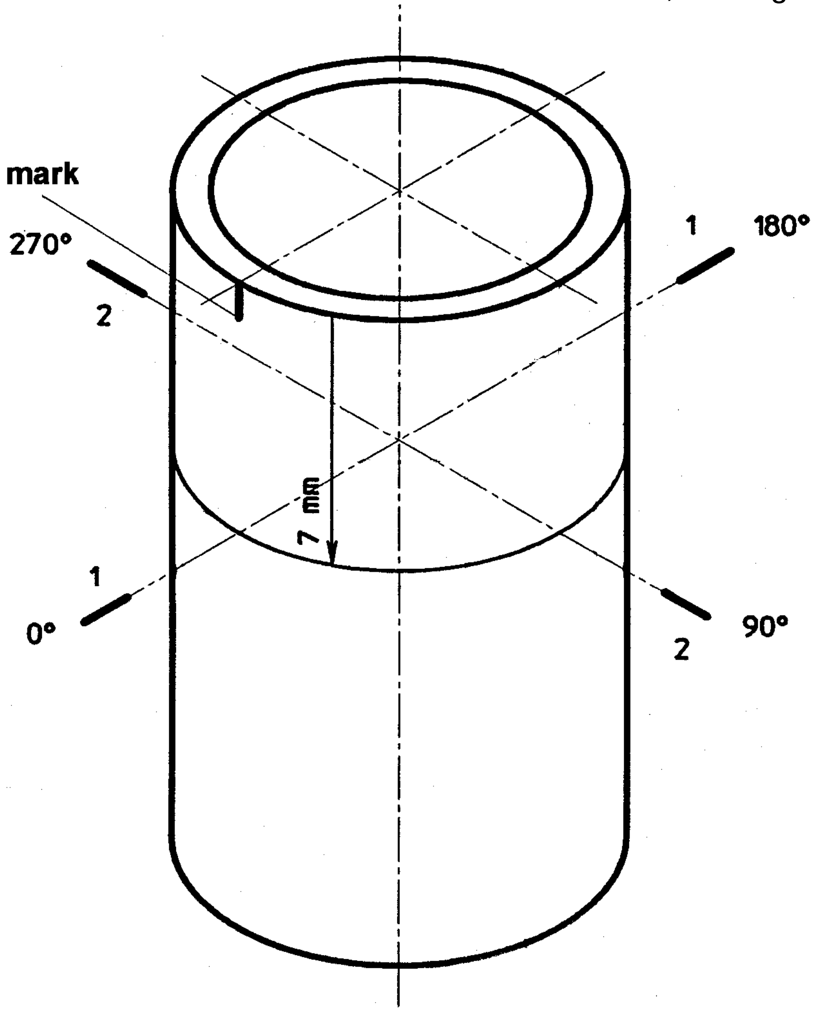

Fig. 1 Ferrules and sleeves to be calibrated
1, 2: positions of the diameter measurements

The artefacts were made of tungsten carbide. They were polished and showed very small form deviations.

The form calibration of the standards was carried out by the PTB (coordinator), and the standards were then sent to the participants. The results of the form calibration were to be used by them to calculate the influence of form deviations on the uncertainty of their diameter measurements. Figs. 2, 3, 4, and 5 show the calibrated form profiles of the artefacts used. The uncertainty of these form measurement results is smaller than 0,1 µm.

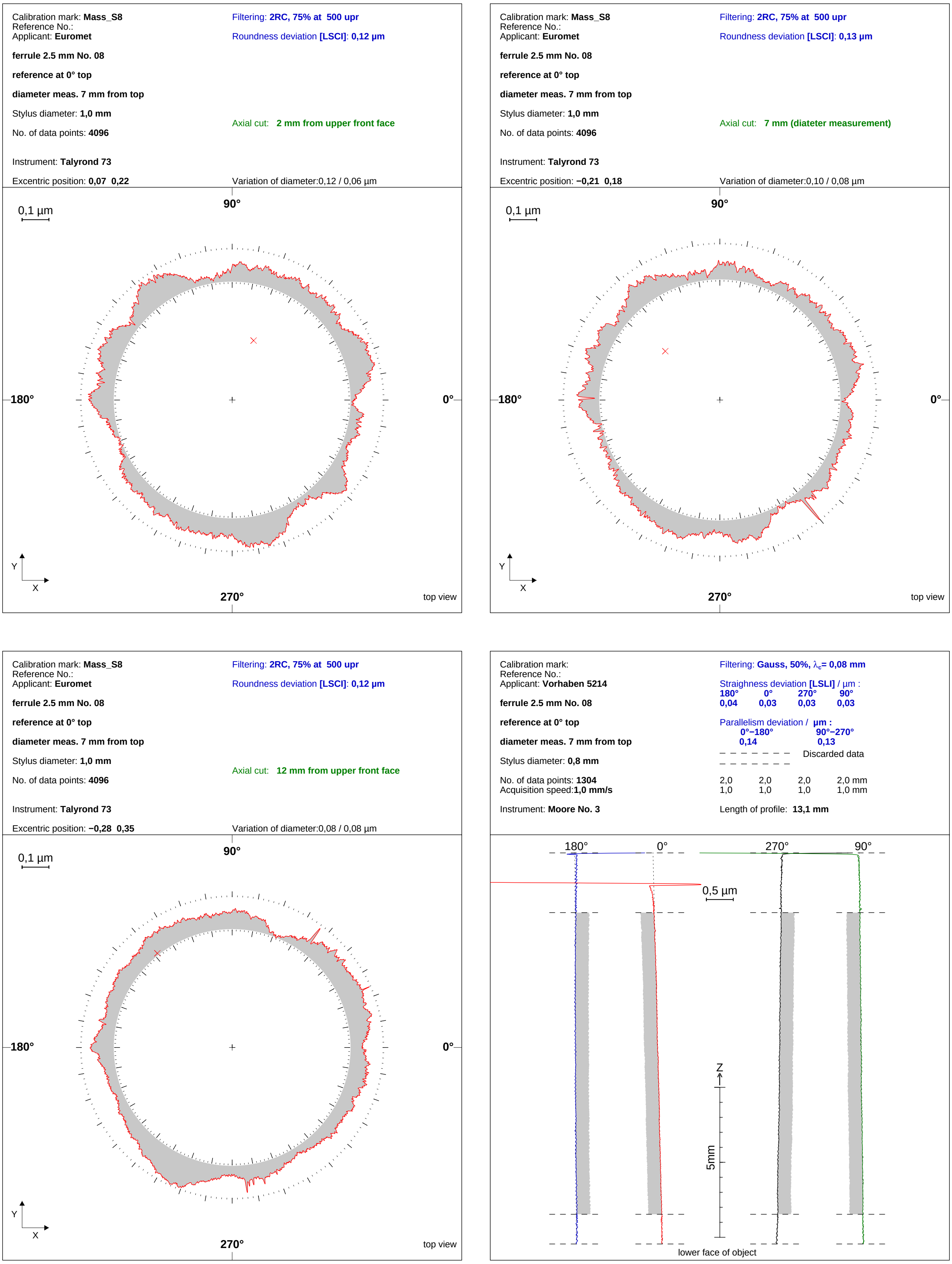

Fig. 2 Results of form calibrations of ferrule S65 (No. 8) carried out by the PTB and sent to the participants (here presented in a new layout)

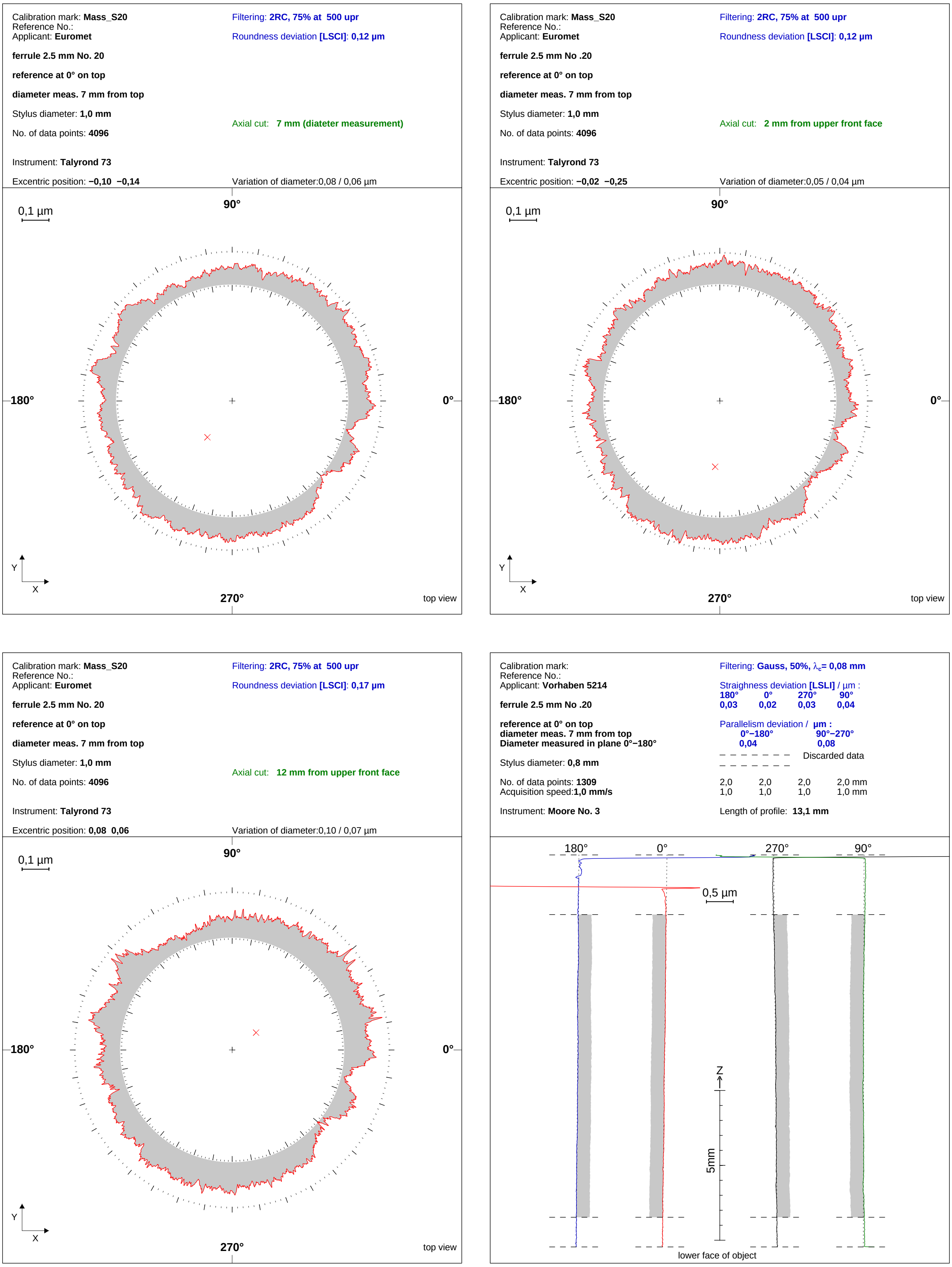

Fig. 3 Results of form calibrations of ferrule S141 (No. 20) carried out by the PTB and sent to the participants (here presented in a new layout)

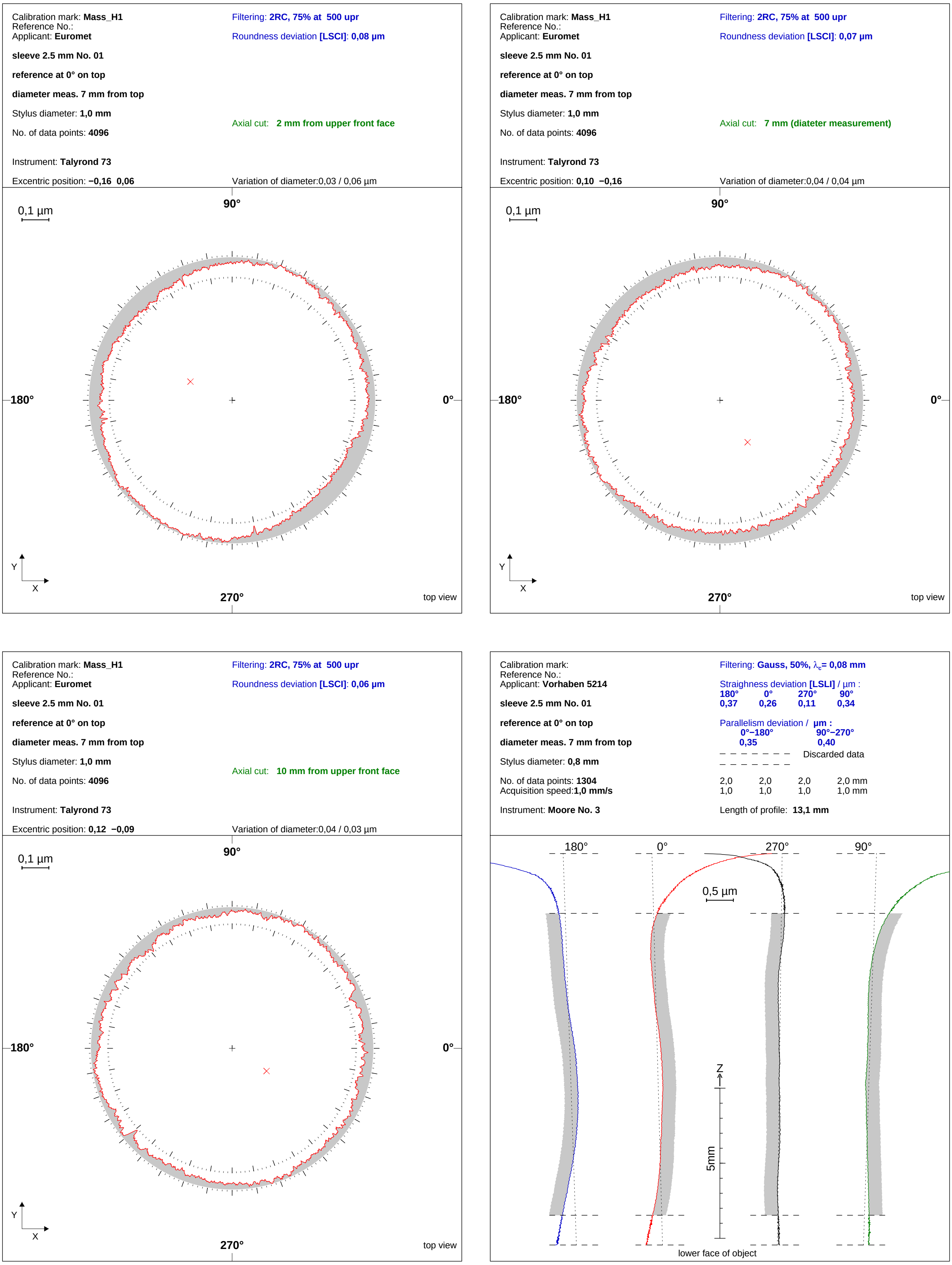

Fig. 4 Results of form calibrations of sleeve H25 (No. 1) carried out by the PTB and sent to the participants (here presented in a new layout)

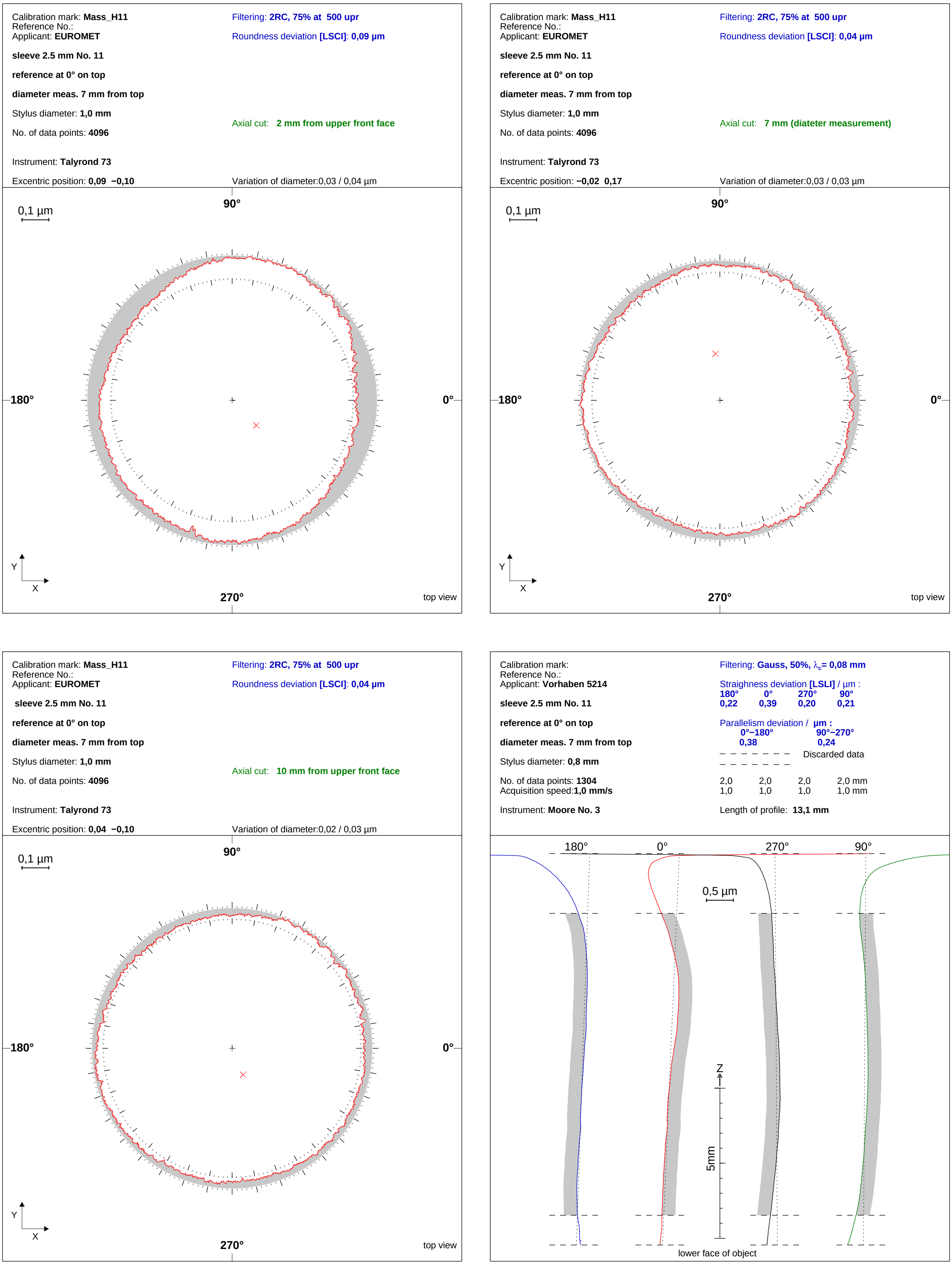

Fig. 5 Results of form calibrations of sleeve H61 (No. 11) carried out by the PTB and sent to the participants (here presented in a new layout)

4. Procedure of Circulation and Measurements

The small artefacts were sent by air mail letter. For identification, the standards were provided with identity numbers hanging on a small pin fastened on the face opposite to the marked face. The diameter calibrations were to be carried out at a distance of 7 mm from the marked front face as well as in the 0°-180° direction and in the 90°-270° direction (see Fig. 1). Only comparison measurements of the diameters were to be carried out.

Each participant was asked to carry out the calibration by his own method and to give some comments. A questionnaire was to be filled in by hand and sent to the PTB. Table 2 shows the questionnaire to be filled in.

A) Institute

B) Artefact no.

C) Diameter in the direction 0°-180°

D) Uncertainty

E) Number of repeat measurements

F) Number of specimen settings

G) Diameter in the direction 90°-270°

H) Uncertainty

I) Number of repeat measurements

J) Number of specimen settings

K) Measuring direction, vertical or horizontal

L) Form of the contacting element (e.g. ball)

M) Diameter of the contacting element

N) How has the diameter of the contacting element been calibrated, e.g. with a gauge block

O) Material of the contacting element:

P) Contacting force

Q) Contacting force corrected to zero

R) Length standard (laser, line scale, ...)

S) Date of this diameter calibration

T) Do you agree that all other participants will be informed about your results when we will publish them in the report

U) Comments e.g. concerning the measuring method

Table 2 Questionnaire to be filled in by the participants

5. Answers Given in the Questionnaire

Table 3 below the remarks made in by the pilot laboratory.

Plug measurements:

A)	PTB	PTB	PTB	PTB
B)	S65 (No.08)	S65 (No.08)	S141 (No.20)	S141 (No.20)
C)	2,49840 mm	2,49835 mm	2,49965 mm	2,49966 mm
D)	0,10 µm	0,10 µm	0,10 µm	0,10 µm
E)	3	1	3	1
F)	1	1	1	1
G)	2,49838 mm		2,49964 mm	
H)	0,10 µm		0,10 µm	
I)	3		3	
J)	1		1	
K)	horizontal	horizontal	horizontal	horizontal
L)	ball	ball	ball	ball
M)	5 mm	5 mm	5 mm	5 mm
N)	------------ three-body method, see “Participants’ Comments” ---------------------			
O)	ruby	ruby	ruby	ruby
P)	0,2 ... 1,4 mN	0,2 ... 1,4 mN	0,2 ... 1,4 mN	0,2 ... 1,4 mN
Q)	yes, extrap. to 0	yes, extrap. to 0	yes, extrap. to 0	yes, extrap. to 0
R)	laser interferom.	Cd spectral lamp	Cd spectral lamp	Cd spectral lamp
S)	Nov./Dec. 1992	May 1996	March 1994	May 1996
T)	yes	yes	yes	yes
U)	----------------- see “Participants’ comments” ----------------------------------			

Sleeve measurements:

A)	PTB	PTB	PTB	PTB
B)	H25 (No.01)	H25 (No.01)	H61 (No.11)	H61 (No.11)
C)	2,49961 mm	2,49961 mm	2,50025 mm	2,50023 mm
D)	0,10 µm	0,10 µm	0,10 µm	0,10 µm
E)	4	2	3	2
F)	3	1	1	1
G)	2,49970 mm	2,49961 mm	2,50024 mm	
H)	0,10 µm	0,10 µm	0,10 µm	
I)	5	4	3	
J)	2	1	1	
K)	horizontal	horizontal	horizontal	horizontal
L)	ball	ball	ball	ball
M)	1,35 mm /1,5 mm	1,35 mm	1,35 mm	1,35 mm
N)	------------ three-body method, see “Participants’ Comments” ---------------------			
O)	ruby/silicon nitride	ruby	ruby	ruby
P)	0,2 ... 1,4 mN	0,2 ... 1,4 mN	0,2 ... 1,4 mN	0,2 ... 1,4 mN
Q)	yes, extrap. to 0	yes, extrap. to 0	yes, extrap. to 0	yes, extrap. to 0
R)	laser i. / Cd lamp	Cd spectral lamp	laser interferom.	Cd spectral lamp
S)	Feb./Mar. 1992	May 1996	March 1993	May 1996
T)	yes	yes	yes	yes
U)	----------------- see “Participants’ comments” ----------------------------------			

Table 3 PTB’s remarks on questionnaire

The following Tables 4a, 4b, 4c, and 4d show the data filled in by the participants, except for the pilot laboratory (PTB).

Calibration of ferrule S65 (No.08)

A)	EAM / OFMET	LNE	IMGC
B)	S65 (No.08)	S65 (No.08)	S65 (No.08)
C)	2,49832 mm	2,4983 mm	2,49837 mm
D)	0,06 µm	0,1 µm	0,1 µm
E)	10	4	5
F)	2	4	2
G)	2,49833 mm	2,4983 mm	2,49835 mm
H)	0,06 µm	0,1 µm	0,10 µm
I)	15	4	5
J)	2	4	2
K)	hor., specimen vertical	vertical	vertical
L)	ball	ball	sphere
M)	4 mm	1,2 mm	0,8 mm
N)	gauge block	gauge block	gauge block
O)	ruby	ruby	ruby
P)	5 forces: 0 ... 0,02 N	0,005 N	<0,01 N
Q)	yes, by extrapolation	no	no
R)	HeNe laser	laser	laser interferometer
S)	September 1996	October 1996	November 1996
T)	yes	yes	yes
U)	s. Participants' comments	no comment	s. Participants' comments

Calibration of ferrule S141 (No.20)

A)	EAM / OFMET	LNE	IMGC
B)	S141 (No.20)	S141 (No.20)	S141 (No.20)
C)	2,49961 mm	2,4995 mm	2,49964 mm
D)	0,06 µm	0,1 µm	0,1 µm
E)	15	4	5
F)	2	4	2
G)	2,49958 mm	2,4996 mm	2,50024 mm
H)	0,06 µm	0,1 µm	0,1 µm
I)	15	4	5
J)	2	4	2
K)	hor., specimen vertical	vertical	vertical
L)	ball	ball	sphere
M)	4 mm	1,2 mm	0,8 mm
N)	gauge block	gauge block	gauge block
O)	ruby	ruby	ruby
P)	5 forces: 0 ... 0,02 N	0,005 N	<0,01 N
Q)	yes, by extrapolation	no	no
R)	HeNe laser	laser	laser interferometer
S)	September 1996	October 1996	Nov. / Dec. 1996
T)	yes	yes	yes
U)	s. Participants' comments	no comment	s. Participants' comments

Table 4a OFMET's, LNE's, and IMGC's replies to questionnaire for their calibrations of the ferrules

Calibration of ferrule S65 (No.08)

A)	NMi (instrument 1)	NMi (instrument 2)	SP	NIST
B)	S65 (No.08)	S65 (No. 08)	S65 (No.08)	S65 (No.08)
C)	2,4985 mm	2,49841 mm	2,4983 mm	2,498366 mm
D)	0,2 µm	0,17 µm	0,3 µm	0,040 µm
E)	2	no answer	6	5 per cont. force
F)	1	no answer	6	5
G)	2,4985 mm	2,49841 mm	2,4983 mm	2,498371 mm
H)	0,2 µm	0,17 µm	0,3 µm	0,040µm
I)	3	7	6	5 per cont. force
J)	1	1	6	5
K)	horizontal	vertical	vertical	horizontal
L)	ball	parall. gauge block	plain	4mmflat/100mmcyl
M)	3 mm	-	5 mm	-
N)	gauge block	interf. method	no answer	NA
O)	ruby	steel	tungsten carbide	tungsten carbide
P)	0,2 N	0,06 N	1 N	(191, ... ,1040) mN
Q)	eliminated in calibr.	no	no	no answer
R)	laser	laser	las., gauge b. 2,5mm	HP displ. interfer.
S)	August 1996	July 1996	June 1996	April 1997
T)	no answer	no answer	yes	yes
U)	no comment	s. Participants' co.	no comment	no comments

Calibration of ferrule S141 (No.20)

A)	NMi (instrument 1)	NMi (instrument 2)	SP	NIST
B)	S141 (No.20)	S141 (No.20)	H141 (No.21)	S141 (No.20)
C)	2,4998 mm	2,49966 mm	2,4996 mm	2,499649
D)	0,2 µm	0,17 µm	0,3 µm	0,040 µm
E)	4	no answer	6	5 per cont. force
F)	1	no answer	6	5
G)	2,4998 mm	2,49966 mm	2,4996 mm	2,499659 mm
H)	0,2 µm	0,17 µm	0,3 µm	0,040 µm
I)	2	5	6	5 per cont. force
J)	1	1	6	5
K)	horizontal	vertical	vertical	horizontal
L)	ball	parall. gauge block	plain	4mmflat/100mmcyl
M)	3 mm	-	5 mm	-
N)	gauge block	interf. method	no answer	NA
O)	ruby	steel	tungsten carbide	tungsten carbide
P)	0,2 N	0,06	1 N	(191, ... ,1040) mN
Q)	eliminated in calibr.	no	no	no answer
R)	laser	laser	las., gauge b. 2,5mm	HP displ. Interfer.
S)	August 1996	July 1996	June 1996	April 1997
T)	yes	no answer	yes	yes
U)	no comment	no comment	no comment	no comment

Table 4b NMi's, SP's, and NIST's replies to questionnaire for their calibrations of the ferrules

Calibration of sleeve H25 (No.01)

A)	EAM / OFMET	LNE	IMGC
B)	H25 (No.01)	H25 (No. 01)	H25 (No.01)
C)	2,49962 mm	2,4995 mm	2,49966 mm
D)	0,06 µm	0,1 µm	0,1 µm
E)	15	6	5
F)	2	6	2
G)	2,49960 mm	2,4995 mm	2,49964 mm
H)	0,06 µm	0,1	0,1 µm
I)	25	6	5
J)	4	6	2
K)	hor., specimen vertical	vertical	vertical
L)	ball	ball	sphere
M)	1,5 mm	1,2 / 1,0 mm	0,8 mm
N)	gauge block	gauge block bridge	gauge block
O)	ruby	ruby	ruby
P)	5 forces: 0 ... 0,02 N	about 0,005 N	<0,01 N
Q)	yes, extrapolation to 0	no	no
R)	HeNe laser	laser	laser interferometer
S)	Aug. / Sept. 1996	October 1996	December 1996
T)	yes	yes	yes
U)	s. Participants' comments	no comment	s. Participants' comments

Calibration of sleeve H61 (No.11)

A)	EAM / OFMET	LNE	IMGC
B)	H61 (No.11)	H61 (No.11)	H61 (No.11)
C)	2,50021 mm	2,5001 mm	2,50019 mm
D)	0,06 µm	0,1 µm	0,1 µm
E)	15	4	5
F)	2	4	2
G)	2,50022 mm	2,5001 mm	2,50028 mm
H)	0,06 µm	0,1 µm	0,1 µm
I)	15	4	5
J)	2	4	2
K)	hor., specimen vertical	vertical	vertical
L)	ball	ball	sphere
M)	1,5 mm	1 and 2 mm	0,8 mm
N)	gauge block	gauge block bridge	gauge block
O)	ruby	ruby	ruby
P)	5 forces: 0 ... 0,02 N	about 0,005 N	<0,01
Q)	yes, extrapolation to 0	no	yes
R)	HeNe laser	laser	laser interferometer
S)	Aug. / Sept. 1996	November 1996	December 1996
T)	yes	yes	yes
U)	s. Participants' comments	no comment	s. Participants' comments

Table 4c OFMET's, LNE's, and IMGC's replies to questionnaire for their calibrations of the sleeves

Calibration of sleeve H25 (No.01)

A)	NMi (instrument 1)	NMi (instrument 2)	SP	NIST
B)	H25 (No.01)	H25 (No.01)	H25 (No.01)	H25 (No.01)
C)	no measurements	no measurements	2,4997 mm	no measurements
D)			0,5 µm	
E)			12	
F)			1	
G)			2,4997 mm	
H)			0,5 µm	
I)			12	
J)			1	
K)			horizontal	
L)			ball	
M)			1,2 mm	
N)			gauge block 2,5 mm	
O)			steel	
P)			0,2 N	
Q)			no	
R)			laser	
S)			June 1996	
T)			yes	
U)			no comment	

Calibration of sleeve H61 (No.11)

A)	NMi (instrument 1)	NMi (instrument 2)	SP	NIST
B)	H61 (No.11)	H61 (No.11)	H61 (No.11)	H61 (No.11)
C)	no measurements	no measurements	2,5001 mm	no measurements
D)			0,5 µm	
E)			9	
F)			1	
G)			2,5001 mm	
H)			0,5 µm	
I)			15	
J)			2	
K)			horizontal	
L)			ball	
M)			1,2 mm	
N)			gauge block 2,5 mm	
O)			steel	
P)			0,2 N	
Q)			no	
R)			laser	
S)			June 1996	
T)			yes	
U)			no comment	

Table 4d NMi's, SP's, and NIST's replies to questionnaire for their calibrations of the sleeves

Participants' comments to their measurements

EAM / OFMET
Length measuring machine, specially designed for calibrating cylindrical standards and other 1-dim. Length standards. Using inductive probe (Cary 1-Dim) at different deflections and plane mirror interferometer.

BNM/LNE
(no comment)

IMGC
Measurements have been made automatically on a Moore n.3 measuring machine under full computer control; the probe system was a Cary Unidim type, resolution 0,01 µm, whose scale was calibrated against the laser interferometer

NMi
Comment for measurements with instrument II:
Interferometric measuring method, performed for the first time and not compared to other measurements.

Set A (instrument I) is performed with a laser interferometer on a 3D-CMM, and set B (instrument II) is performed with help of two end gauges and an optical flat in an end gauge interferometer. ... see the result of set B as an experiment, for we performed this kind of measurement for the first time.

SP
(no comment)

NIST
These artifacts have been measured using a contact micrometer combined with a laser displacement interferometer. The process employs a stabilized HeNe laser as the length standard. NIST control standards are present throughout the measurement to maintain process control and to develop statistical long term reproducibility data for the measurement system. Each artifact is measured multiple times at various applied forces to generate short term repeatability data and to characterize variations in deformation, bending, and two-point diameter measurements. The statistical data provides continuous measurement assurance of the process.

The average deviation from the nominal diameter of each artifact is given at the location described in the EUROMET Projecct No. 369 procedures. All values are reported at undeformed conditions. All measurements are reported at 20 degrees Celsius.

The uncertainty of the measurements was calculated according to NIST Technical Note 1297, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results", which is considered to be a part of this report. The expanded uncertainty, U, using a coverage factor of k = 2, is $\pm$0.000 040 millimeters.

PTB

The calibration was carried out with PTB's one-dimensional interference comparators, either with the comparator using a laser interferometer or with the comparator using a cadmium spectral lamp.

The calibration of the sphere diameter was carried out by the PTB's three-body method: two balls and 1 gauge block were calibrated together. Three displacements measurements d_i were carried out:

diameter of ball 1 + length of gauge block = d_1,
diameter of ball 2 + length of gauge block = d_2,
diameter of ball 1 + diameter of ball 2 = d_3

Three equations with three unknowns result. Both, the sphere diameters and the gauge block length were calculated.

The uncertainty of measurement stated is the expanded uncertainty which is obtained from the standard uncertainty of measurement by multiplication by the expansion factor $k = 2$. It was determined in accordance with the Guide to the Expression of Uncertainty in Measurement (ISO, 1995). The value of the measurand normally lies with a probability of approximately 95% in the interval of values assigned.

6. Measurement Results

The measurement results and the deviations from the mean value are compiled in Table 5. In the diagrams of Fig. 6 and Fig. 7, the measurement results are plotted and may be visually compared.

For the comparison of the measured diameters d_i, two different average values (*means*) were determined. The arithmetic mean, *mean1*, is non-weighted by the uncertainties given by the participants:

$$mean1 = \frac{1}{n} \cdot \sum_{i=1}^{n} d_i$$

with its standard uncertainty

$$u\,(mean1) = \left(\frac{1}{n \cdot (n-1)} \cdot \sum_{i=1}^{n} (d_i \text{ - } mean1)\right)^{1/2} \quad .$$

It is common practice to compare measured values with their weighted mean, weighted by the inverse square of their standard uncertainties $u(d_i)$:

$$mean2 = \frac{\sum_{i=1}^{n} (d_i \cdot (u(d_i))^{-2})}{\sum_{i=1}^{n} (u(d_i))^{-2}}$$

with its standard uncertainty

$$u\,(mean2) = \left(\sum_{i=1}^{n} (u(d_i))^{-2}\right)^{-1/2} \quad .$$

For each measurement result d_i , an *En* value is calculated from *mean2* and its standard deviation:

$$En = 0{,}5 \cdot \frac{d_i - mean2}{\sqrt{(u(d_i))^2 - (u(mean2))^2}}$$

An *En* value with an amount greater than 1 shows that this measured value is not comparable with the other measurement results. That is the reason why one value for the ferrule and one for the sleeve measurement results have been excluded from the calculation of the *mean2* values. Their *En* values are smaller than -1. For these diameter measurement results the deviations from the corrected *mean2* and the corrected *En* values have been marked in table 5.

	Participant	OFMET		IMGC		LNE		NIST		NMi I		NMi II		PTB		SP		*mean 1/2*	
		d	*U*	*d*	*U*	*d*	*U*	*d*	*U*	*d*	*U*	*d*	*U*	*d*	*U*	*d*	*U*	*d*	u_{ref}
Object		in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm	in µm
	0°-180°	2498,320	0,06	2498,370	0,1	2498,300	0,1	2498,366	0,040	2498,500	0,2	2498,410	0,17	2498,380	0,1	2498,300	0,3		
	dev. from *mean1*	-0,048		0,002		-0,068		-0,002		0,132		0,042		0,012		-0,068		2498,368	0,023
	dev. from *mean2*	-0,035		0,015		-0,055		0,011		0,145		0,055		0,025		-0,055		2498,355	0,014
S65	*En (mean2)*	-0,668		0,152		-0,578		0,370		0,730		0,325		0,256		-0,186			
(ferrule)	90°-270°	2498,330	0,06	2498,350	0,1	2498,300	0,1	2498,371	0,040	2498,500	0,2	2498,410	0,17	2498,380	0,1	2498,300	0,3		
No. 8	dev. from *mean1*	-0,038		-0,018		-0,068		0,003		0,132		0,042		0,012		-0,068		2498,368	0,023
	dev. from *mean2*	-0,029		-0,009		-0,059		0,012		0,141		0,051		0,021		-0,059		2498,359	0,014
	En (mean2)	-0,537		-0,089		-0,610		0,437		0,714		0,307		0,224		-0,196			
	0°-180°	2499,610	0,06	2499,640	0,1	2499,500	0,1	2499,649	0,040	2499,800	0,2	2499,660	0,17	2499,660	0,1	2499,600	0,3		
	dev. from *mean1*	-0,050		-0,020		-0,160		-0,011		0,140		0,000		0,000		-0,060		2499,660	0,030
	dev. from *mean2*	-0,033		-0,003		-0,143		0,006		0,157		0,017		0,017		-0,043		2499,643	0,015
S141	*En (mean2)*	-0,630		-0,032		-1,495		0,219		0,793		0,101		0,178		-0,144			
(ferrule)	90°-270°	2499,580	0,06	2499,570	0,1	2499,600	0,1	2499,659	0,040	2499,800	0,2	2499,660	0,17	2499,640	0,1	2499,600	0,3		
No. 20	dev. from *mean1*	-0,059		-0,069		-0,039		0,020		0,161		0,021		0,001		-0,039		2499,639	0,026
	dev. from *mean2*	-0,051		-0,061		-0,031		0,028		0,169		0,029		0,009		-0,031		2499,631	0,014
	En (mean2)	-0,960		-0,635		-0,322		0,983		0,854		0,173		0,094		-0,104			
	0°-180°	2499,620	0,06	2499,660	0,1	2499,500	0,1	-	-	-	-	-	-	2499,610	0,1	2499,700	0,5		
	dev. from *mean1*	0,002		0,042		-0,118		-		-		-		-0,008		0,082		2499,618	0,034
	dev. from *mean2*	0,015		0,055		-0,105		-		-		-		0,005		0,095		2499,605	0,021
H25	*En (mean2)*	0,344		0,604		-1,155		-		-		-		0,054		0,190			
(sleeve)	90°-270°	2499,600	0,06	2499,640	0,1	2499,500	0,1	-	-	-	-	-	-	2499,650	0,1	2499,700	0,5		
No. 1	dev. from *mean1*	-0,018		0,022		-0,118		-		-		-		0,032		0,082		2499,618	0,034
	dev. from *mean2*	0,001		0,041		-0,099		-		-		-		0,051		0,101		2499,599	0,021
	En (mean2)	0,024		0,451		-1,088		-		-		-		0,561		0,203			
	0°-180°	2500,210	0,06	2500,190	0,1	2500,100	0,1	-	-	-	-	-	-	2500,230	0,1	2500,100	0,5		
	dev. from *mean1*	0,044		0,024		-0,066		-		-		-		0,064		-0,066		2500,166	0,028
	dev. from *mean2*	0,020		0,000		-0,090		-		-		-		0,040		-0,090		2500,190	0,021
H61	*En (mean2)*	0,453		-0,004		-0,993		-		-		-		0,436		-0,181			
(sleeve)	90°-270°	2500,220	0,06	2500,280	0,1	2500,100	0,1	-	-	-	-	-	-	2500,240	0,1	2500,100	0,5		
No. 11	dev. from *mean1*	0,010		0,070		-0,110		-		-		-		0,030		-0,110		2500,210	0,039
	dev. from *mean2*	-0,016		0,044		-0,136		-		-		-		0,004		-0,136		2500,236	0,023
	En (mean2)	-0,400		0,499		-1,523		-		-		-		0,049		-0,272			

Table 5 Measurement results of EUROMET intercomparison project 369
d diameter determined, *U* expanded measurement uncertainty (k=2),
u_{ref} standard reference uncertainty of *mean1* (non-weighted) and *mean2* (weighted), see chapter 6

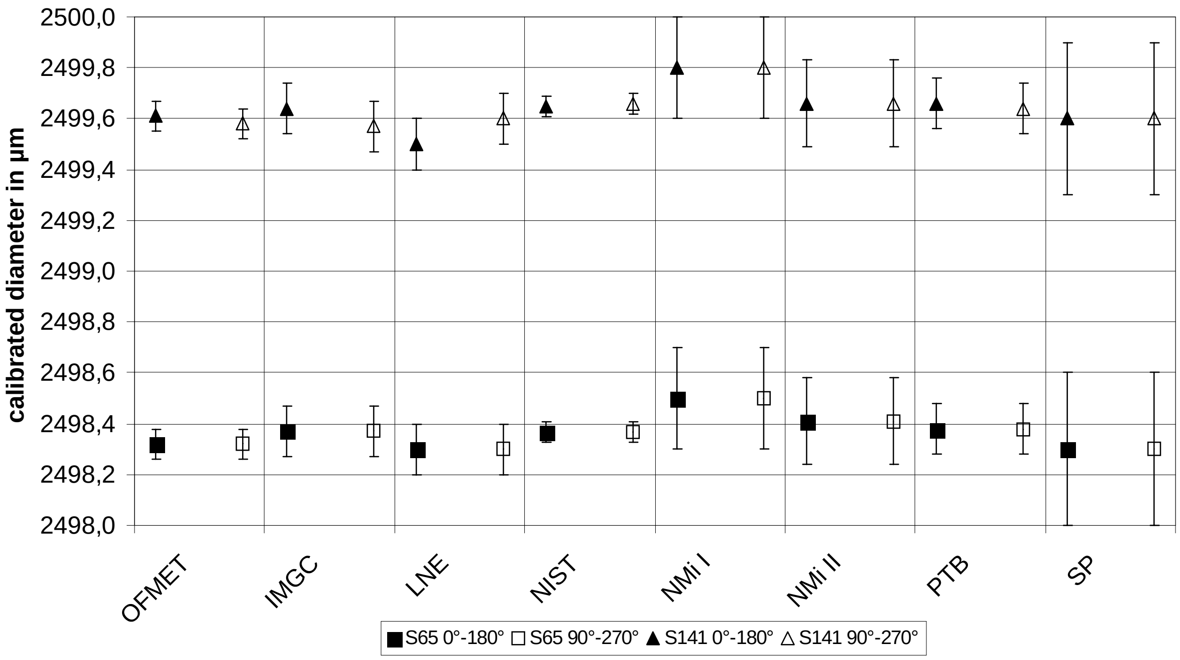

Fig. 6 Calibrated diameter of the ferrules and expanded uncertainty (*k*=2) determined by the participants

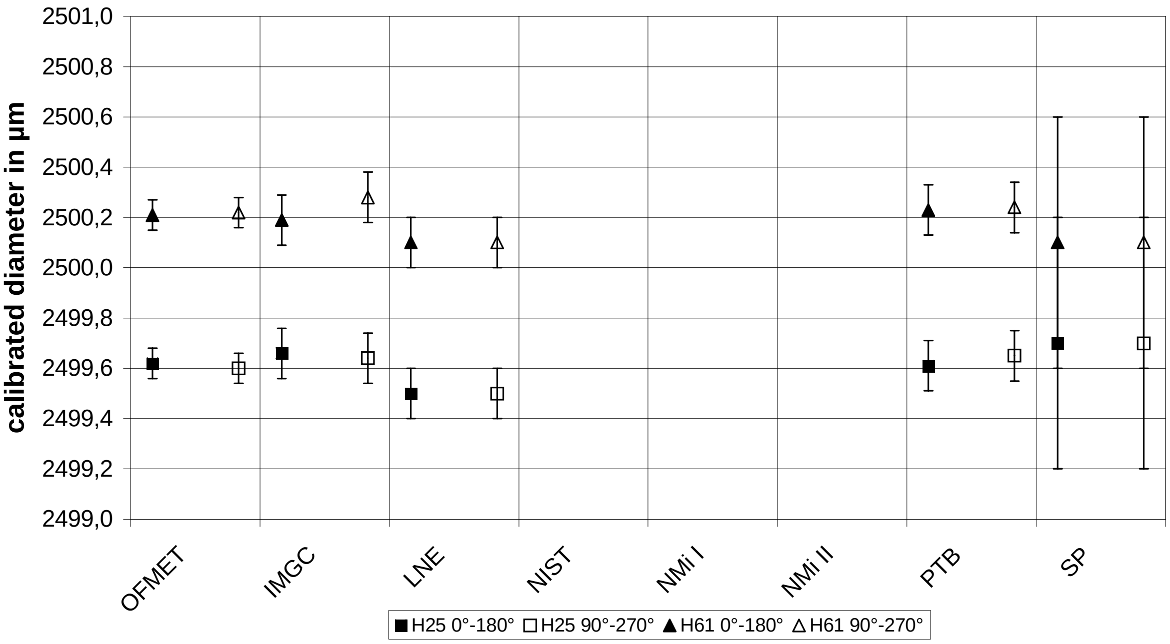

Fig. 7 Calibrated diameter of the sleeves and expanded uncertainty (*k*=2) determined by the participants

7. Conclusions

The measurement results of EUROMET project 369 concerning the part of the external (ferrules) and internal (sleeves) 2,5 mm cylinders show very good agreement. The participating national metrology institutes furnished measurement results with maximum deviations from one another in the range of the uncertainties given by them, if it is taken into account that a given uncertainty of 0,1 µm includes, for example, the deviation in the rounding frame of ± 0,15 µm (here max. dev. –0,143 µm).

The deviations are in the same range as documented for diameter measurements on the small artefacts of EUROMET comparison measurement project 384 (2,5 mm plug and 3 mm ring gauge).

Both, the external and the internal diameters measured by LNE tend to be smaller than those of the other participants (by up to 0,1 µm). The differences of the measured ferrule and sleeve diameters are, however, in the range of the overlapping uncertainties (see above).

The documentation of the form deviations of the ferrule and sleeve artefacts was made available by the pilot laboratory together with the guidelines. The uncertainty of the supplied form profiles was stated to be 0,1 µm (k=2). Today we know that PTB's uncertainty of the form measurement results was even smaller than 0,05 µm (k=2). The documentation of the roundness profiles of the ferrules shows local deviations which must influence a small uncertainty of the diameter calibration. It seems, however, that, for the diameter calibration of the ferrules, neither the form profiles documented by the pilot laboratory nor calibrations of the participants were taken into account.

The ferrules are slightly lobed, with nearly constant diameters. In spite of this property the small form variation (waviness) may somehow influence the diameter measurements, but this does not make itself felt in any variation and in the amount of the uncertainties given. For the diameter of the ferrules, two participants stated uncertainties similar to the local form deviations in a small angular variation around the position of the diameter measurement direction.

An uncertainty budget had not been requested by the guidelines (state of the art of intercomparisons at that time). It may, therefore, be supposed that not all uncertainties have been evaluated according to ISO-Guide.

The combination of the CCM project concerning artefacts for pressure measurements with the comparison measurements on the 2,5 mm ferrules and sleeves first impeded the progress in EUROMET project 369. The reduction of the number of participants was a prerequisite for the CCM project. Nevertheless, the results of the remaining project reduced to the comparison measurements on the 2,5 mm artefacts were satisfactory. The results have shown good harmonisation among the participating institutes, including the National Institute for Standardisation and Technology (NIST) of the United States of America. This is one of the first (and already successful) steps towards a harmonisation between the USA and Europe in the field of dimensional calibrations.