Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

EURAMET Key Comparison EURAMET.L-K8.2020
Calibration of surface roughness standards
(EURAMET project #1502)

Technical protocol

L. Jung-Albrecht (PTB)

Braunschweig, 2020-04-17

Contents

1 Document control

Version Draft 0.1	Issued on 2 October 2019
Version Draft 0.2	Issued on 9 October 2019 (changes introduction and time schedule)
Version Draft 0.3	Issued on 18 December 2019 (changes participants and schedule)
Version Draft 0.4	Issued on 16 January 2020 (changes contact address and schedule)
Version Draft final	Issued on 05 February 2020 (changes annex C, Text)
Version final	Issued on 17 April 2020 (changes schedule)

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 2018, the EURAMET Technical Committee for Length, EURAMET-TC-L, decided upon preparation of a key comparison on the calibration of surface roughness standards, with PTB as the pilot laboratory. PTB was asked to propose to Dr. Baker (DG8 moderator) the list of EURAMET laboratories that will take part in the planned EURAMET.L-K8 comparison and invite some participation from other regions. It turned out that there are also several NMI's from APMP who would need to join a roughness comparison soon and it was thus proposed to organize a comparison within EURAMET and another within APMP, which are linked by two common participants. The EURAMET.L-K8.2020 comparison was registered in November 2019. It is planned that the artefact circulation will start **April 2020** and will be completed **October 2021.**
The procedures outlined in this document cover the technical procedure to be followed during the measurements. A goal of the CCL key comparisons for topics in dimensional metrology is to demonstrate the equivalence of routine calibration services offered by NMIs to clients, as listed in Appendix C of the Mutual Recognition Agreement (MRA). To this end, participants in this comparison agree to use the same apparatus and methods as routinely applied to client artefacts.
By their declared intention to participate in this key comparison, laboratories accept the general instructions and to strictly follow the technical protocol of this document. To run the comparison in time, it is important that participating NMIs perform their measurements during assigned dates. Participants should keep in mind that the allocated time period is not only for measurements, but transportation and customs clearance as well. Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants.

3 Organization

3.1 Participants

Participants are listed in Table 1.

Table 1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
PTB (Pilot)	**Lena Jung-Albrecht** Physikalisch-Technische Bundesanstalt (PTB) Bundesallee 100 38116 Braunschweig Germany	Phone: +49 531 592 5124 Fax: +49 531 592 5105 E-Mail: lena.jung-albrecht@ptb.de
DFM	**Jørgen Garnæs** Danish Fundamental Metrology (DFM) Kogle Allé 5 2970 Hørsholm Denmark	Phone: + 45 2545 9018 E-Mail: jg@dfm.dk

CMI	**Jiří Borovský** Czech Metrology Institute (CMI) Laboratory of Fundamental Metrology V Botanice 4 150 72 Prague 5 Czech Republik	Phone: +420 257 288 319 Fax: +420 257 328 077 E-Mail: jborovsky@cmi.cz
FSB-LPMD	**Gorana Baršić** Faculty of Mechanical Engineering and Naval Architecture - Laboratory for Precise Measurement of Length Ivana Lucica 5 10002 Zagreb Croatia	Phone: +385 161 68 327 E-Mail: gorana.barsic@fsb.hr
NPL	**Dave Gunn** National Physical Laboratory (NPL) Hampton Road TW11 0LW Teddington, Middlesex United Kingdom	Phone: +44 2089436063 E-Mail: dave.gunn@npl.co.uk
INM-RO	**Alexandru Duta** National Institute of Metrology (INM-RO) Sos. Vitan-Bârzesti 11, Sector 4 042122 Bucuresti Romania	Phone: +40 21 334 5060 Fax: +40 21 335 533 E-Mail: alexandru.duta@inm.ro
CEM	**Laura Carcedo** Centro Español de Metrología (CEM) C/Alfar 2 28760 Tres Cantos (Madrid) SPAIN	Phone: +34 91 807 4801 Fax: +34 91 807 4829 E-Mail: lcarcedo@cem.es
METAS (linking lab)	**Felix Meli** Federal Institute of Metrology (METAS) Lindenweg 50 CH-3003-Bern-Wabern Switzerland	Phone: +41 58 387 0346 Fax: +41 58 387 0210 E-Mail: felix.meli@metas.ch
BEV	**Michael Matus** Bundesamt für Eich- und Vermessungswesen (BEV) Arltgasse 35 1160 Wien Austria	Phone: +43 1 21110 826540 Email: michael.matus@bev.gv.at
GUM	**Dariusz Czułek** Laboratory of Length Central Office of Measures (GUM) ul. Elektoralna 2, 00-139 Warszawa Poland	Phone: +48 22 581 95 43 Fax: +48 22 581 93 92 E-Mail: dariusz.czulek@gum.gov.pl
VNIIMS (COOMET)	**Vladimir Kosteev** All-Russian Research Institute of metrological Service (VNIIMS) Ozernaya str., b.46 Moscow, 119361 Russia	Phone: +7 (495) 781-86-53 Fax: + 7 (495) 437-34-29 E-Mail: vkosteev@vniims.ru
NMIA (linking lab)	**Andrew Baker** National Measurement Institute 1/153 Bertie St Port Melbourne VIC 3207 Australia	Phone: +61 3 9644 4902 E-Mail: andrew.baker@measurement.gov.au
NIM (linking lab)	**Yushu Shi** National Institute of Metrology, China	Phone: +86 10 64524920 Fax: +86 10 64524907

	No.18 Bei San Huan Dong Lu, Chaoyang District, Beijing China 100029 P. R. China	E-Mail: shiys@nim.ac.cn

3.2 Schedule

The participating laboratories were asked to specify a preferred timetable slot for their own measurements of the surface measurement standards – the timetable given in Table 2 has been drawn up taking these preferences into account. Each laboratory has four weeks (4) that include customs clearance, calibration and transportation to the following participant. Those from APMP region are allowed eight (8) weeks for measurement and transfer due to expected longer time for the transportation of artefacts. With its confirmation to participate, each laboratory is obliged to perform the measurements in the allocated period and to allow enough time in advance for transportation so that the following participant receives them in time. If a laboratory has technical problems to perform the measurements or customs clearance takes too long, the laboratory has to contact the pilot laboratory as soon as possible and, according to whatever it decides, it might eventually be obliged to send the standards directly to the next participant before completing the measurements or even without doing any measurements.

Table 2. Schedule of the comparison.

RMO	Laboratory	Starting date of measurement	Carnet
EURAMET	PTB	3-4 / 2020	
	METAS	5-6 / 2020[1]	yes
	BEV	7 / 2020	
	GUM	8 / 2020	
	CMI	9 / 2020	
	FSB-LPMD	10 / 2020	
	INM-RO	11 / 2020	
	PTB	12 / 2020-1 / 2021 control	
	CEM	2 / 2021	
	DFM	3 / 2021	
	NPL	4 /2021	yes
COOMET	VNIIMS	5 / 2021	yes
APMP	NIM	6 -7/ 2021	yes
	NMIA	8-9 / 2021	yes
EURAMET	PTB	10 / 2021 control	

3.3 Reception, transportation, insurance, costs

The standards will be transported in an aluminium case (size: length 33,5 cm x width 24,5 cm x height 16,5 cm) which contains boxes for each of the standards, see Figure 1 .Upon reception of the package, each laboratory has to check that the content is complete and that there is no apparent damage on the box or any of the standards. The reception has to be confirmed immediately to the pilot with a copy to the former participant, preferably using the template in Appendix A.

The organization costs will be covered by the pilot laboratory, which include the standards themselves, the Al-case and packaging.

Attention to the standards, because the pilot laboratory has no insurance for any loss or damage of the standards during the circulation.

[1] Longer period taking into account possible delays in shipment due to Corona pandemic.

Figure 1 - transporting case

Once the measurements have been completed, the package shall be sent to the following participant.

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

For shipment outside the EU the package is accompanied by an ATA carnet**. Outside EU the carnet has always be shipped with the documents of the package, never inside the box. Please be certain, that when receiving the package, you also receive the carnet!**

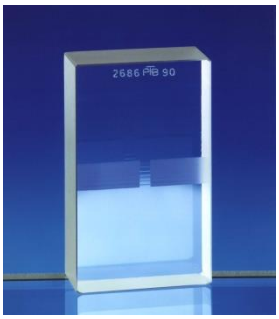
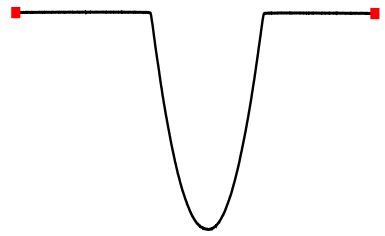
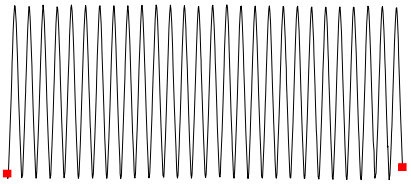
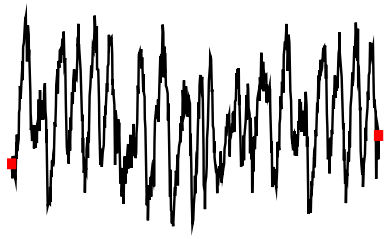
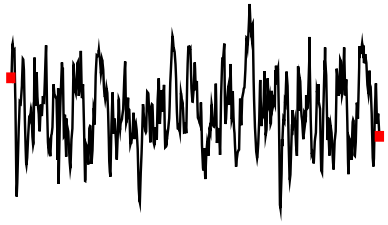
For shipment inside the EU the ATA carnet may be shipped inside the box.

4 Artefacts

4.1 Description of artefacts

The package contains four (4) ISO 5436-1 standards: one type A2, one type C3, one type D1 and one type D2. The standards are from different manufacturers and made from different materials and shown in Table 3.

Table 3. List of artefacts.

Identification	Description	Picture	Typical Profile
Type A2 Standard, Manufacturer: Halle Präzisions-Kalibriernormale GmbH, Germany, KNT 2060/01, No: 6891	Depth measurement standard, glass, 6 grooves with rounded bottoms, nominal values *d* 0.15 µm to 9.00 µm		
Type C3 standard, Manufacturer: Mahr GmbH, Germany, PGN-10, No: 7828	Wavelength measurement standard, glass, simulated sine wave groove, nominal values *Ra* 2.3 µm, *RSm* 200 µm		
Type D1 standard, Manufacturer: Halle Präzisions-Kalibriernormale GmbH, Germany, KNT 4058/01, No: 7377	Roughness measurement standard, steel, unidirectional irregular profile, nominal values *Ra* 0.5 µm, *Rz* 3µm		
Type D2 standard, Manufacturer: PTB, Germany, No: 11.3.030	Roughness measurement standard, copper nickel-plated, unidirectional irregular profile, nominal values *Ra* 80 nm, *Rz* 450 nm		

5 Measuring instructions

5.1 Handling the artefact

The standards should only be handled by authorized persons and stored in such a way as to prevent damage. Before making the measurements, each standard need to be checked to verify that its measuring surface is not damaged and do not present severe scratches that may affect the measurement results. The condition of the standards before measurement should be registered in the template provided in appendix B.

No other measurements are to be attempted by the participants and the standards should not be used for any purpose other than described in this document. The standards may not be given to any party other than the participants in the comparison.

The standards should be examined before despatch and any change in condition during the measurement at each laboratory should immediately be communicated to the pilot laboratory. Ensure that the content of the package is complete before shipment. Always use the original packaging.

5.2 Measuring instruments

The instruments (optical and tactile) used for the comparison have to be calibrated according to the ISO rules. For stylus instruments, please ensure that the stylus is of appropriate quality and not damaged. **Additionally, please check that the force is not too high, especially for type D2 standard.**

5.3 Measurands

The following parameters are to be determined:

Artefact	Parameters	Relevant standards
Type A2, No. 6891	*d*	ISO 5436-1
Type C3, No. 7828	*Ra*, *Rz*, *Rt*, *RSm*	ISO 4287, ISO 4288, ISO 16610-21
Type D1, No. 7377	*Ra*, *Rq*, *Rz*, *Rt*	ISO 4287, ISO 4288, ISO 16610-21
Type D2, No. 11.3.030	*Ra*, *Rq*, *Rz*, *Rt*	ISO 4287, ISO 4288, ISO 16610-21

5.3.1 Measurement and evaluation for type A2 artefact

Each groove is to be calibrated at the position c (centre of the groove), see Figure 2.

The measurement results are the average values of at least five intersection planes laying within a range of 50 µm around the nominal measuring positions.

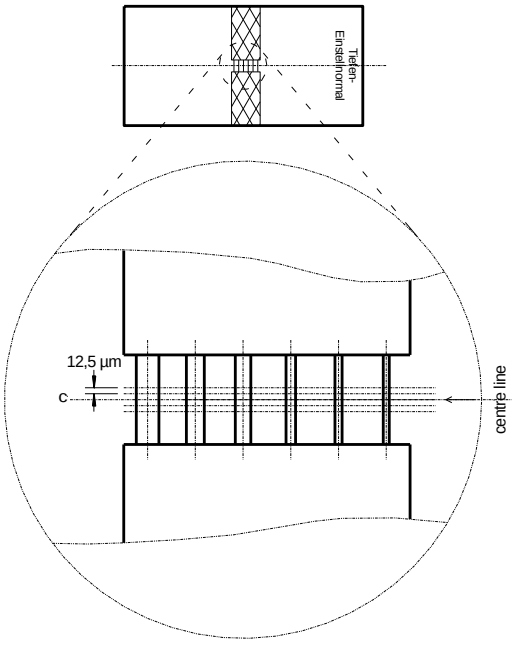


Figure 2

For stylus instruments the speed of traverse should be **slower than 0.2 mm/s**. The determination of the depth of the grooves ***d*** must be carried out according to the procedure described in ISO 5436-1. If this cannot be measured, calculate ***Pt*** according to ISO 4287 **for an approximation**. The evaluation length

for ***Pt*** should be limited to equivalent region for the calculation of ***d*** and profiles must be levelled according to partial adjustment ranges least squares method, see Figure 3. The application of short-wave filter λs must be specified and documented if done.
For some **non-contact optical** instruments, the results are an approximation of ***d***.

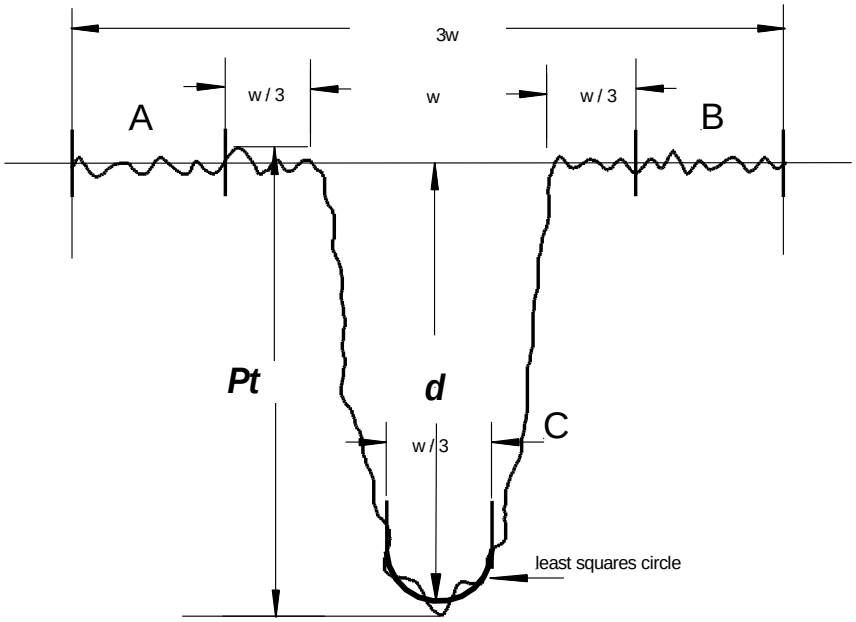


Figure 3

5.3.2 Measurement conditions for type C3 artefact

The measurements have to be carried out by means of a pick-up with independent datum. Twelve measurements should be done in points distributed over the whole area of measurement, see Figure Figure 4 and Figure 5. The mean value, maximum, minimum and standard deviation have to be determined and reported. A Gaussian filter according to ISO 16610-21 has to be applied to assessed profiles for evaluating the R-parameters. If other filter is applied, the type of the filter **must** be specified. The following measurement conditions must be respected:

Standard	Evaluation length (mm)	λc (µm)	λs (µm)	Measuring force (mN)	Traverse speed (mm/s)	Sampling spacing (µm)	Tip radius (µm)	Measurement area
Type C3	4.0	800	2.5	< 1	< 0.5	< 0.5	2	Figure 4
PGN-10	12.5	2500	8.0	< 1	< 0.5	< 0.5	2	Figure 5

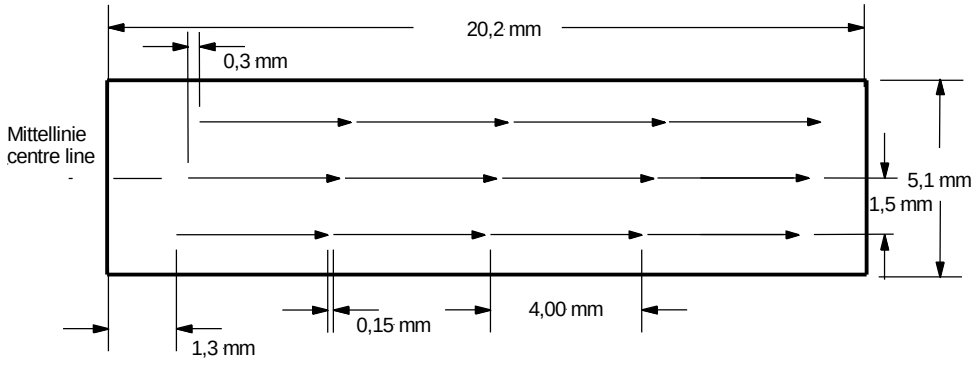


Figure 4 - The area of measurement shows the starting points of the respective evaluation lengths of **4.0 mm**.

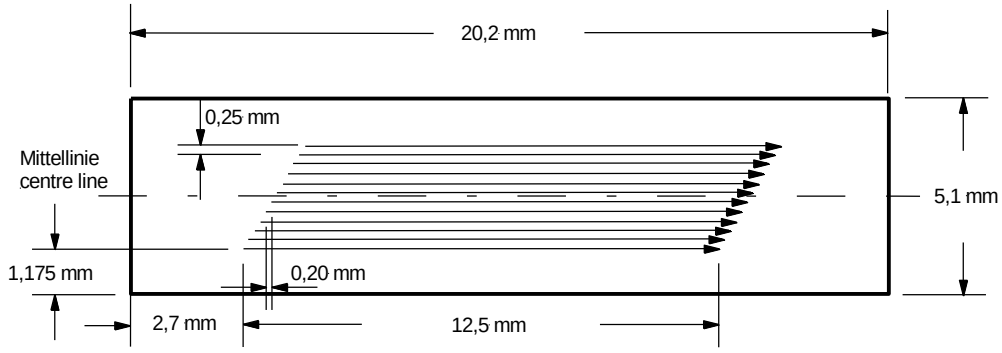


Figure 5- The area of measurement shows the starting points of the respective evaluation lengths of **12.5 mm**.

5.3.3 Measurement conditions for type D1 and D2 artefacts

The measurements have to be carried out by means of a pick-up with independent datum. Twelve measurements should be done in points distributed over the whole area of measurement, see Figure 6 and Figure 7. The mean value, maximum, minimum and standard deviation have to be determined and reported. A Gaussian filter according to ISO 16610-21 has to be applied to assessed profiles for evaluating the R-parameters. If other filter is applied, the type of the filter **must** be specified.
The following measurement conditions must be respected:

Standard	Evaluation length (mm)	λc (µm)	λs (µm)	Measuring force (mN)	Traverse speed (mm/s)	Sampling spacing (µm)	Tip radius (µm)	Measurement area
Type D1	4.0	800	2.5	< 1	< 0.5	< 0.5	2	Figure 6
Type D2	1.25	250	2.5	< 1	< 0.5	< 0.5	2	Figure 7

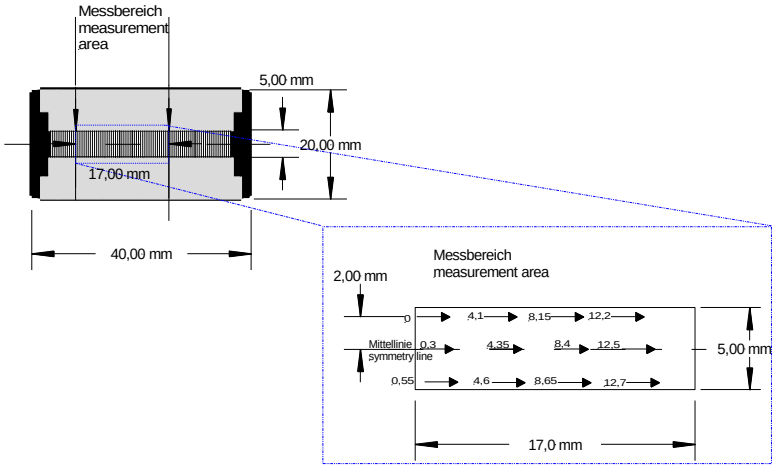


Figure 6 - The area of measurement shows the starting points and traversing direction of the respective traversing lengths of **5.6 mm**.

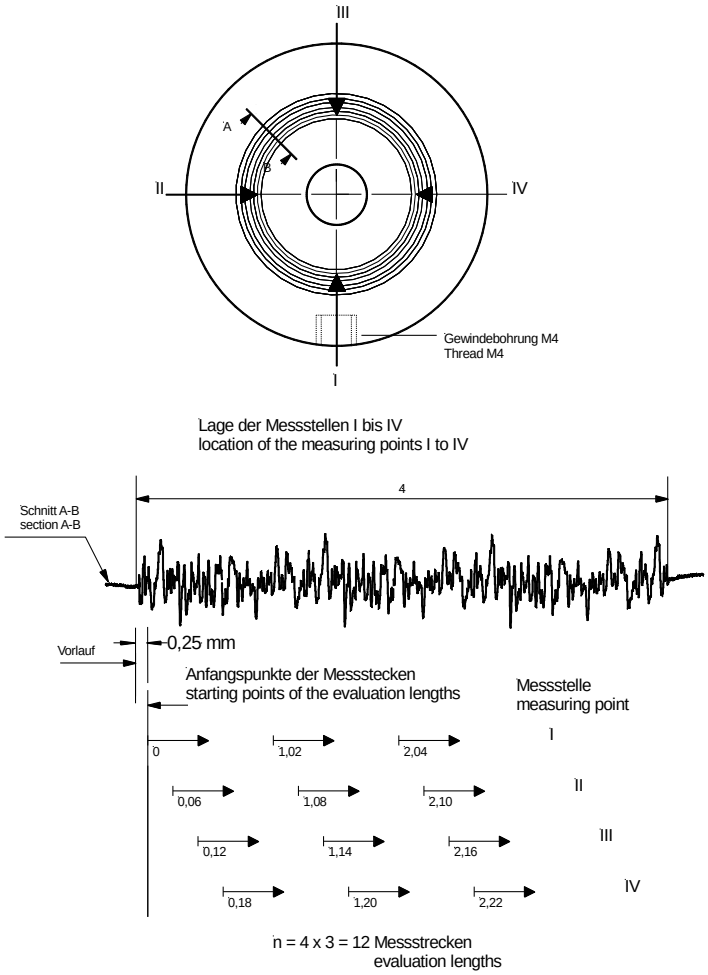


Figure 7 - The area of measurement shows the starting points and traversing direction of the respective evaluation lengths of **1.25 mm**.

5.4 Measurement uncertainty

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

All measurement uncertainties shall be stated as standard uncertainties and combined standard uncertainty $U(k=2)$. If appropriate the corresponding effective degree of freedom might be stated by the participants and can be used to calculate the combined uncertainty U. If none is given, ∞ is assumed.

6 Reporting of results

6.1 Results and uncertainties as reported by participants

As soon as possible after measurements have been completed, the results of each NMI should be communicated to the pilot laboratory **within four (4) weeks** at the latest.

The report templates in **appendix A, B, C and D** of this document will be sent from pilot by e-mail **as Word documents** to all participating laboratories. The report template in **appendix C** will also be provided **as Excel sheet.** The report templates should be completed by computer and sent back electronically to the pilot. **Please feel out the appendix D for measurement of each standard if the measurement conditions are changed.** In any case, the signed report must also be sent in paper form by mail or electronically as a

scanned pdf document. **In case of any differences, the signed forms are considered to be the definitive version.**

Each report will be checked by the pilot for consistency of results. In case of discrepancies the lab will be informed to check measurement results and uncertainty budget, but with no indication of size and direction of discrepancy.

Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare within **three (3) months** a first draft A.1 report on the comparison. This will be circulated to the participants for comments, additions and corrections.

7 Analysis of results

7.1 Calculation of the KCRV

When all measurements are completed, the reference value for each measured quantity is to be selected from either the arithmetic value or the weighted mean of the values x_i from each individual laboratory, as given by:

Arithmetic mean:

$$\bar{x} = \frac{1}{n}\sum_{i}^{N} x_i \qquad (1)$$

Weighted mean:

$$\bar{x}_w = \left[\sum_{i=1}^{N} x_i/u^2(x_i)\right] \Big/ \left[\sum_{i=1}^{N} 1/u^2(x_i)\right] \qquad (2)$$

Note: The two methods will be calculated for comparison only. The weighted mean will be used for the reference value.

The check for consistency of the comparison results of each laboratory for each measurand with their associated uncertainties will be made based on En criteria using E_n values, along the lines of the *WG-MRA-KC-report-template*, and on the Birge ratio.

Degree of equivalence ratio:

$$E_n = \frac{x_i - \bar{x}}{2\sqrt{u^2(x_i) - u^2(\bar{x}_w)}} \qquad (3)$$

where $u(x_{i)}$ is the standard uncertainty of the individual laboratory and $u(\bar{x}_w)$ is the standard uncertainty of the weighted mean.
Birge ratio:

$$u_I^2(\bar{x}_w) = \left[\sum_{i=1}^{N} 1/u^2(x_i)\right]^{-1} \qquad (4)$$

$$u_E^2(\bar{x}_w) = \left[\sum_{i=1}^{N} (x_i - \bar{x}_w)^2/u^2(x_i)\right] \Big/ \left[(N-1)\sum_{i=1}^{N} 1/u^2(x_i)\right] \qquad (5)$$

where $u_I(\bar{x}_w)$ is propagated (internal) uncertainty
$u_E(\bar{x}_w)$ is external uncertainty calculated from the standard deviation of the weighted mean

Birge criterion: $$R_B = \sqrt{1 + \sqrt{\frac{8}{N-1}}} \quad (6)$$

where N is the number of accepted measurements.

Appendix A – Reception of Standards

To:	Lena Jung-Albrecht, AG 5.15 PTB, Bundesallee 100, 38116 Braunschweig, Germany Fax: 0049 531 592 5105 E-mail: lena.jung-albrecht@ptb.de
From:	NMI: …… Name: …… Signature: …… Date: ……

We confirm having received the roughness standards for the EURAMET.L-K8.2020 comparison on the date given above.

After a visual inspection:

☐ There are no apparent damages; their precise state will be reported in the form provided in Annex B/C once inspected in the laboratory along with the measurement results.

☐ We have detected severe damages putting the measurement results at risk. Please indicate the damages, specifying every detail and, if possible, include photos. If it is necessary, use additional sheets to report it.

Appendix B – Conditions of measuring surfaces

To:	Lena Jung-Albrecht, AG 5.15 PTB, Bundesallee 100, 38116 Braunschweig, Germany Fax: 0049 531 592 5105 E-mail: lena.jung-albrecht@ptb.de
From:	NMI: …… Name: …… Signature: …… Date: ……

After detailed inspection of the measuring surfaces of the standards these are the results. Please mark significant surface faults (scratches, indentations, corrosion, etc.).

Pictures of measuring areas:

Appendix C – Results Report Form

To:	Lena Jung-Albrecht, AG 5.15 PTB, Bundesallee 100, 38116 Braunschweig, Germany Fax: 0049 531 592 5105 E-mail: lena.jung-albrecht@ptb.de
From:	NMI: …… Name: …… Signature: …… Date: ……

Type A2, No. 6891

Groove	λs (µm)	Parameter	Value (µm)	σ (µm)	*U (µm)*	u_c *(µm)*	*k*
R1, d_{nom} *0.2 µm*		*d*					
R2, d_{nom} *0.5 µm*		*d*					
R3, d_{nom} *0.9 µm*		*d*					
R4, d_{nom} *3.5 µm*		*d*					
R5, d_{nom} *6.5 µm*		*d*					
R6, d_{nom} *8.5 µm*		*d*					

σ: standard deviation
u_c: standard uncertainty
U: expanded uncertainty
k: coverage factor

Type C3, No.7828

Parameter	λc (µm)	λs (µm)	Value (µm)	MAX (µm)	MIN (µm)	σ (µm)	*U* (µm)	u_c *(µm)*	*k*
Ra	800	2.5							
Rz									
Rt									
RSm									
Ra	2500	8							
Rz									
Rt									
RSm									

σ: standard deviation
u_c: standard uncertainty
U: expanded uncertainty
k: coverage factor

Type D1, No. 7377

Parameter	λc (µm)	λs (µm)	Value (µm)	MAX (µm)	MIN (µm)	σ (µm)	*U* (µm)	u_c *(µm)*	*k*
Ra	800	2.5							
Rq									
Rz									
Rt									

σ: standard deviation
u_c: standard uncertainty
U: expanded uncertainty
k: coverage factor

Type D2, No. 11.3.030

Parameter	λc (µm)	λs (µm)	Value (µm)	MAX (µm)	MIN (µm)	σ (µm)	*U* (µm)	u_c *(µm)*	*k*
Ra	250	2.5							
Rq									
Rz									
Rt									

σ: standard deviation
u_c: standard uncertainty
U: expanded uncertainty
k: coverage factor

Appendix D – Description of the measurement instrument and measurement conditions

To:	Lena Jung-Albrecht, AG 5.15 PTB, Bundesallee 100, 38116 Braunschweig, Germany Fax: 0049 531 592 5105 E-mail: lena.jung-albrecht@ptb.de
From:	NMI: …… Name: …… Signature: …… Date: ……

Standard No.	
Groove	
Date of measurement	
Make and type of instrument	
Vertical measurement traceability	
Traverse measurement traceability	
Stylus type:	
Manufacturer	
Radius	
Angle	
Measuring force	
Measuring speed	
Sampling spacing	
Analysis software, version	
Software manufacturer	
Filter type (λc)	
Filter wave length (µm)	
Filter type (λs)	
Filter wave length (µm)	
Short description of the evaluation procedure	

* Please feel out the appendix D for measurement of each standard if the measurement conditions are changed.

CMCs in the CIPM MRA .....

Do you have CMCs published in KCDB? .....

If yes, please indicate below the service identifiers and the uncertainties related to the quantities measured in this comparison: .....

.....

(use additional pages as needed)