EURAMET.L-K3.01
Key Comparison
Calibration of Angle Standards

Technical protocol

(rev4 – July 2021)

Istituto Nazionale di Ricerca Metrologica

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10135 Torino, Italy

Turin, 01 July 2021

Contents

1 Document control

Version Draft A1 Issued on 22 April 2021;
Version Draft A2 Issued on 31 May 2021;
Version Draft A3 Issued on 17 June 2021;
Version Draft A4 Issued on 01 July 2021;

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 (RMOs) in collaboration with the Consultative Committees.

At its meeting in October 2018, the EURAMET Technical Committee for Length, EURAMET TC-L, decided upon a key comparison on angle measurements with INRIM as the pilot laboratory. The comparison was registered in March 2021, artefact circulation will start in June 2021 and will be completed in August 2022.

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

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

By their declared intention to participate in this key comparison, laboratories accept the general instructions and to strictly follow the technical protocol of this document. Due to the large number of participants, it is very important that participating NMIs perform their measurements during assigned dates. Participants should keep in mind that the allocated time period is not only for measurements, but for 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.

RMO	Laboratory Code	Contact person, Laboratory	Phone, email
EURAMET	INRIM (Pilot)	Milena Astrua, Marco Pisani INRiM, Istituto Nazionale di Ricerca Metrologica, Div. Applied Metrology and Engineering strada delle Cacce, 91 - 10135 - Torino - Italy	Phone: +39 011 3919 966 m.astrua@inrim.it m.pisani@inrim.it
	BIM	Denita Tamakyarska, Valentin Vasilev Bulgarian Institute of Metrology GD National Center of Metrology 52B, G.M. Dimitrov Blvd 1797 Sofia - Bulgaria	Phone: +359 9702 719 d.tamakjarska@bim.government.bg v.vasilev@bim.government.bg
	CEM	Emilio Prieto, Mª Mar Pérez CENTRO ESPAÑOL DE METROLOGÍA C/ del Alfar, 2 Tres Cantos – 28760 Madrid - Spain	Phone: +34 91 8074 801 eprieto@cem.es mmperezh@cem.es
	CMI	František Dvořáček CMI OI Liberec Slunecná 23 460 01 Liberec - Czech Republic	Phone: fdvoracek@cmi.cz

	DMDM	Slobodan Zelenika Directorate of Measures and Precious Metals Mike Alasa 14 11000 Belgrade - Serbia	Phone: +381 11 2024 421 zelenika@dmdm.rs
	EIM	Christos Bantis Hellenic Institute of Metrology (EIM) Industrial Area of Thessaloniki, Block 45 57022 Sindos, Thessaloniki – Greece	Phone: +302310569952 bantis@eim.gr
	GUM	Dariusz Czułek, Piotr Sosinowski Central Office of Measures (GUM) ul. Elektoralna 2, 00-139 Warsaw – Poland	Phone: +48 22 581 9543 d.czulek@gum.gov.pl piotr.sosinowski@gum.gov.pl
	IPQ	Fernanda Saraiva Instituto Português da Qualidade Rua António Gião, 2 Almada 2829-513 CAPARICA – Portugal	Phone: +351 212 948 460 Fsaraiva@ipq.pt
	LNE	José Salgado LNE 23 Avenue Albert Bartholomé - 75015 Paris – France	Phone: +33 1 40 43 39 57 +33 1 40 43 37 37 Jose-Antonio.Salgado@lne.fr
	NPL	Steve Mortimer NPL Room F3-A6 Engineering Measurement Division Hampton Road, Teddington TW11 0LW - United Kingdom	Phone: +44 2089436373 steve.mortimer@npl.co.uk
	VSL	Richard Koops VSL Thijsseweg 11, 2629 JA Delft, The Netherlands	Phone: +31 15 2691500 +31 6 31119917 rkoops@vsl.nl
	VTT – MIKES	Antti Lassila Centre for Metrology and Accreditation P.O. box 9 (Tekniikantie 1) 02151 Espoo – Finland	Phone: +358 40 7678584 Antti.Lassila@vtt.fi
APMP	CMS/ITRI	Tsung-Han Hsieh, Po-Er Hsu Bldg. 8, 321, Sec. 2, Kuang-Fu Rd., Hsinchu City, 30011 Taiwan, R.O.C.	Phone: +886 3 5743762 HenryHsieh@itri.org.tw
	NIMT	Ketsaya Vacharanukul 3-4/5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120 Thailand	Phone: +66 25775100 ext. 1216 ketsaya@nimt.or.th
	NMIA	Peter Cox NMIA, 1/153 Bertie Street Port Melbourne VIC 3207 Australia	Phone: +61 3 9644 4906 Peter.Cox@measurement.gov.au
	NMIM	Razman Mohd Halim, Rafidah Rosli National Metrology Institute of Malaysia Lot PT 4803 Bandar Baru Salak Tinggi 43900 Sepang - Malaysia	Phone: +603-87781613 +603-87781616 razmanmh@sirim.my rafidahr@sirim.my
	NPL-I	Rina Sharma, Arifsanjid Arifsanjid LENGTH & DIMENSION STANDARDS National Physical Laboratory, Dr. K.S. Krishnan Road, New Delhi – 110012 - India	Phone: rina@nplindia.org sanjid@nplindia.org
	SCL	Henry Chiu, George Tang Standards and Calibration Laboratory 35/F Immigration Tower, 7 Gloucester Road Wanchai, Hong Kong, China	Phone: +852 2829 4839 +852 2829 4805 hklchiu@itc.gov.hk george.tang@itc.gov.hk
COOMET	RSE	Iskender Toleuov Kazakhstan Standardisation and Metrology Institute 010016, Nur-Sultan city, Left bank, Mangilik El avenue, 11 - Kazakhstan	Phone: e.toleuov@ksm.kz

	SE	Yuri Glushko , Anna Fursa SE "UKRMETRTESTSTANDART" Metrolohichna St, 4, Kyiv, Ukraine, 03143	Phone: +38 098 4239322 yygeom@gmail.com
GULFMET	SASO-NMCC	Faisal A. AlQahtani National Measurement and Calibration Center (Building No. 4) PO. B 3437 Riyadh 11471 Kingdom of Saudi Arabia	Phone: +966 5404 556 55 +966 1125 297 26 f.qahtany@saso.gov.sa

3.2 Schedule

The participating laboratories are asked to specify a preferred timetable slot for their own measurements. The timetable given in table 2 has been drawn up taking these preferences into account as much as possible. The programme is to start in June 2021 with measurement at the pilot laboratory. **Each laboratory has four weeks** that include customs clearance, calibration and transportation to the following participant.

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 the standard 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. The pilot laboratory will repeat measurements at the end of the schedule to check the stability of the artefacts.

Table 2. Draft schedule of the comparison – circulation of the polygons

Group 1 (inside EURAMET)

RMO	Laboratory	Starting date of measurement /group 1
EURAMET	INRIM (Pilot Lab)	June 2021
	EIM (Greece)	July 2021
	IPQ (Portugal)	August 2021
	VSL (Netherlands)	September 2021
	GUM (Poland)	October 2021
	LNE (France)	November 2021
	INRIM (Pilot Lab)	December 2021
	VTT-MIKES (Finland)	January 2022
	BIM (Bulgaria)	February 2022
	CEM (Spain)	March 2022
	CMI (Czech Republic)	April 2022
	INRIM (Pilot Lab)	May 2022
	DMDM (Serbia)	June 2022
	NPL (UK)	July 2022
	INRIM (Pilot Lab)	August 2022

Group 2 (outside EURAMET)

RMO	Laboratory	Starting date of measurement /group 2
	INRIM (Pilot Lab)	July 2021
APMP	NPL India	August 2021
	NIMT (Thailand)	September 2021
	SCL (Hong Kong)	October 2021
	CMS/ITRI (Taiwan)	November 2021
	NMIM (Malaysia)	December 2021
	NMIA (Australia)	January 2022
	INRIM (Pilot Lab)	February 2022
GULFMET	SASO-NMCC (Saudi Arabia)	March 2022
COOMET	RSE (Kazakhstan)	April 2022
	SE (Ukraine)	May 2022
	INRIM (Pilot Lab)	June 2022

3.3 Reception, transportation, insurance, costs

Each standard will circulate within a box together with a copy of this protocol and an ATA carnet in case of circulating outside Europe.

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 on the standards. The reception has to be confirmed immediately to the pilot with a copy to the former participant (sender), preferably using the form of Appendix A.

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

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

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

For group 2 and for the last loop of group 1, the package is accompanied by an ATA carnet. Outside EU the carnet shall always be shipped with the package, never inside the box, but apart. **Please be certain, that when receiving the package, you also receive the carnet!**

4 Artefacts

4.1 Description of artefacts

The artefacts to be calibrated are the following ones:

Table 3. List of artefacts.

Standard	Manufacturer	Model	Identification	Properties	Group
12-sided polygon	Moeller Wedel Optical		320	Face dimension: 25 mm diameter	Group 1
12-sided polygon	Matrix	STD.638	T4147	Face dimension: (16 x 16) mm	Group 2

Figure 1 – picture of angular standards

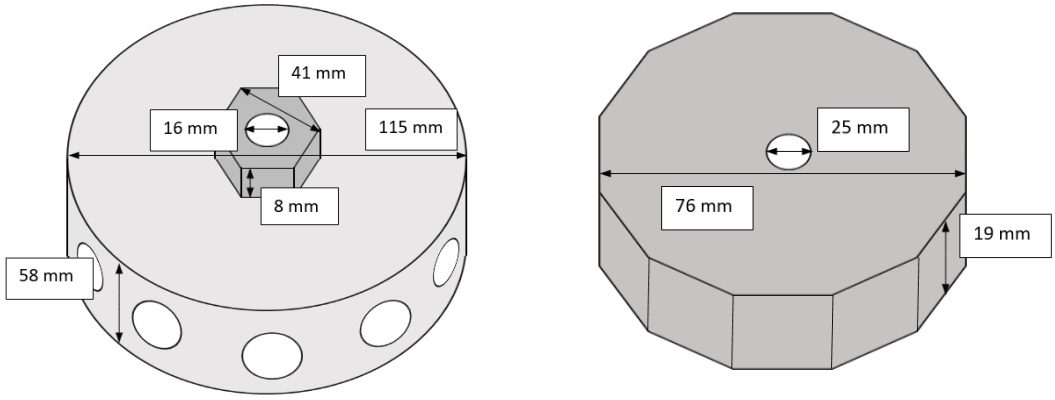

Figure 2 – dimensions of the two optical polygons

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, the polygons need to be checked to verify that their

measuring surfaces are not damaged and do not present severe scratches and/or rust that may affect the measurement result. The condition of the polygons before measurement should be registered in the form provided in Appendix A.

No participant shall try to re-finish measuring faces by burring, lapping, stoning, or whatsoever. No other measurements are to be attempted by the participants and the gauges should not be used for any purpose other than described in this document. The gauges may not be given to any party other than the participants in the comparison.

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

5.2 Mounting the artefact

The polygon shall be mounted by each laboratory's own usual method.
It has to be measured in the normal position: i.e. with the face indicated as the base downwards (please refer to Fig. 1 to see which is the upward face).
Moreover, the polygon must be adjusted for eccentricity and centered to the rotation axis of the rotary table.

5.3 Traceability

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

5.4 Measurand

The optical polygon has reflecting side faces which serve as measuring faces. In ideal conditions the individual measuring faces are perpendicular to the measuring plane. In practice, the measuring faces are not perpendicular to the measuring plane by small tilts referred to as pyramidal errors. In any case, the measuring plane is defined as the plane parallel to the base of the polygon.

The **pitch angles** α_i are the angles between the projections of two adjacent normals N_{i-1} and N_i in the measuring plane with the counting index (i=1,2,...,n). The deviations of the pitch angles from their nominal values of 360°/n are referred to as pitch angle deviations. The **measurand** is the deviation of the pitch angles from the nominal value.

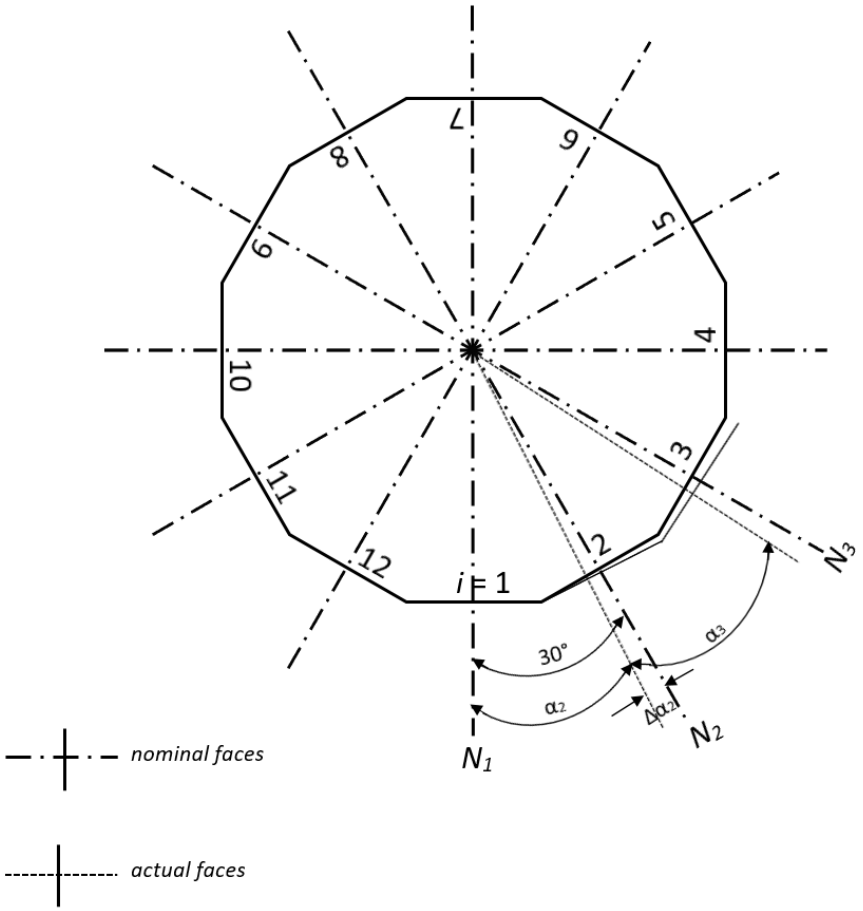

Figure 3 – drawing of optical polygon angles in case of polygon manufactured by Moeller Wedel

Measuring face index	$i = 1 \ldots n$	
Normals to the faces	N_i	
Pitch angles	α_i	(angles between $N_i - 1$ and N_i)
Pitch angle deviation	$\Delta\ \alpha_i = \alpha_i - \frac{360°}{n}$	(i = 2,3,…,n)

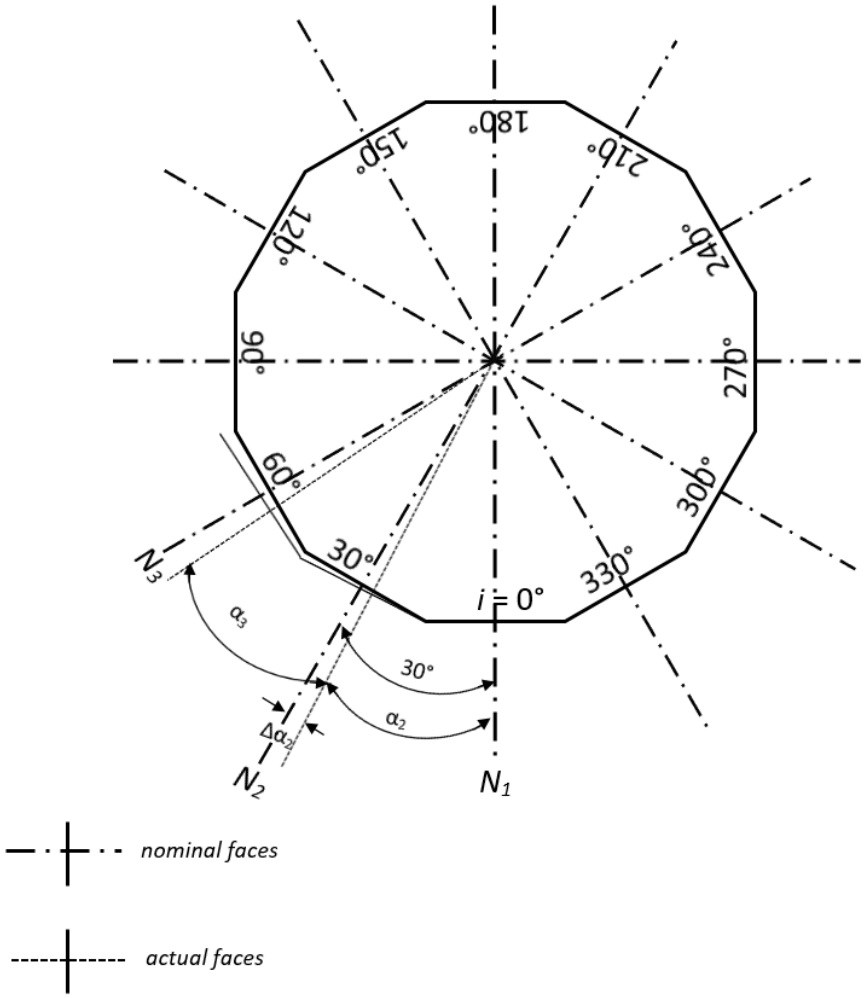

Figure 4 – drawing of optical polygon angles in case of polygon manufactured by Matrix

The positive count direction of the polygon angle corresponds to the count direction of the face (index i). Please, note that in polygon made by Moeller Wedel the positive count direction is counterclockwise (as in the drawing of figure 3), while in polygon made by Matrix the positive count direction is clockwise (as in the drawing of figure 4).

5.5 Measurement methods

The polygon must be adjusted for eccentricity and is to be measured only in the normal position.

The laboratory must measure the polygon according to its' internal procedure. The measurement method and the procedure should be described in Appendix B.

5.6 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. If appropriate, the corresponding effective degrees of freedom for each component should be stated by the participants. If

none is given, ∞ is assumed. For efficient evaluation and subsequent assessment of CMC claims an uncertainty statement in a functional form is preferred, with indication of the factor *k* used, typically 2, or the one corresponding to a level of confidence of a 95 %, in case it was different.

6 Reporting of results

6.1 Results and standard uncertainties as reported by participants

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

The measurement report forms in Appendix B of this document should be used. It would be appreciated if the report forms could be completed by computer and sent back electronically to the pilot laboratory. In any case, the signed report must also be sent in paper form by mail or electronically as a scanned pdf document. In case of any differences, the signed forms are considered to be the definitive version.

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

7 Analysis of results

7.1 Calculation of the KCRV

The key comparison reference value (KCRV) is calculated as the weighted mean of the participants results. The check for consistency of the comparison results with their associated uncertainties will be made based on Birge ratio. The degrees of equivalence for each laboratory with respect to the KCRV will be evaluated using E_n values, along the lines of the *WG-MRA-KC-report-template*. If necessary, artefact instability, correlations between institutes and the necessity for linking to another comparison will be taken into account.

7.2 Artefact instability

The instability of the standards must be determined in course of the comparison. For this check the measurements of the pilot laboratory are used exclusively, not that of the other participants.

In case of artefact stability, to avoid biasing the weighted mean, an average value of all sets of measurements from the pilot laboratory will be included in the reference value determination.

7.3 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 the foreseen CCL-K3 through the linking labs INRIM, CEM and NPL. These three labs agree to participate in both groups for linking the two loops.

Appendix A – Reception of Standards

To:	Milena Astrua Istituto Nazionale di Ricerca Metrologica (INRIM) Strada delle Cacce 91 10135 Torino Italy	Tel. +39 011 3919966 e-mail: m.astrua@inrim.it
From:	Date: NMI:	Name: Signature:

We confirm having received the standard for the EURAMET.L-K3.01 comparison on the date given above.

After a visual inspection:

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

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

Appendix B – Measurement Results

To:	Milena Astrua Istituto Nazionale di Ricerca Metrologica (INRIM) Strada delle Cacce 91 10135 Torino Italy	Tel. +39 011 3919966 e-mail: m.astrua@inrim.it
From:	Date: NMI:	Name: Signature:

Description of the measuring system and set-up

Description of the reference table

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Description of the method used

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Description of the procedure

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Environmental conditions

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CMC uncertainty for the service related to this comparison topic (if existing in the KCDB)

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(use additional pages as needed)

Measurement results

Table B2. **Results and uncertainties on polygon ref……..**

Faces Moeller Wedel	**Faces** Matrix	**Pitch angle deviation (arc sec)**	**Expanded uncertainty (*k* = 2)**
1-2	**0°-30°**		
2-3	**30°-60°**		
3-4	**60°-90°**		
4-5	**90°-120°**		
5-6	**120°-150°**		
6-7	**150°-180°**		
7-8	**180°-210°**		
8-9	**210°-240°**		
9-10	**240°-270°**		
10-11	**270°-300°**		
11-12	**300°-330°**		
12-1	**330°-0°**		

Please, choose the first or the second column according to the polygon you have calibrated

Appendix C – Uncertainty of measurement

Table B1. Uncertainty budget of measurement

x_i	$u(x_i)$	v_i	$c_i = \partial y/\partial x_i$	$u_i(y)$

Combined standard uncertainty: $u_c(R)$=

Expanded uncertainty: $U(R)$ (k =) =

$U(R) = Q[a, bR] = \sqrt{a^2 + (bR)^2}$ =