CCL K3 Key comparison

Calibration of Angle Standards
Technical Protocol (Final)
Prepared by NML

Contents

1. Introduction

1.1 Equivalence of National Metrology Institutes is becoming more and more important. This is established by key comparisons set out by the CIPM. Specific key comparisons are decided upon and organised by the Consultive Committee for a specific field, which, in this case is the Consultive Committee for Length (CCL).

1.2 At the last CCL meeting the key comparisons were decided upon; which included a comparison for the calibration of angle standards. At this meeting it was decided that a 12 sided polygon would be used. It was also decided, that the use of a 7 sided polygon would be investigated. Subsequently the 7 sided polygon was replaced with 4 angle blocks. It was felt that the 7 sided polygon was not representative of the calibrations performed at National Metrology Institutes.

1.3 A large number of National Metrology Institutes have shown great interest in this comparison, however, this would be quite impractical and the number of participants must be reduced. A regional comparison will help to reduce the number participating in the CCL intercomparison. Both the CCL and the Regional comparisons will establish equivalence with National Metrology Institutes throughout the world. The participating countries MUST participate in both the regional and CCL comparisons.

1.4 This technical protocol has been drawn up by a small working group comprising of members from the NML (South Africa), NRC (Canada), OFMET (Switzerland) and the PTB (Germany). The procedure, which follows the guidelines established by the BIPM[1], is based on the existing technical protocol document for the key comparison on gauge blocks[2] and the EUROMET comparison No. 371 for Angle calibration on a precision polygon[3].

1.5 The 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 BIPM Mutual Recognition Agreement (MRA). To this end, participants in this comparison agree to use the same apparatus and methods as is routinely applied when calibrating client artefacts.

[1] TJ Quinn, *Guidelines for CIPM key comparisons*, 1 March 1999, Paris

[2] R Thalmann, J Dekker, N Brown, *CCL Key comparison: Calibration of gauge blocks by interferometer*, April 1998

[3] R Probst, *Euromet Project No 371*, 1995

2. Organisation

2.1 Participant Requirements

2.1.1 As previously stated in the Introduction, the participating laboratories in the CCL comparison must also partake in the regional one.

2.1.2 Secondly, the laboratory must offer this capability as a calibration service.

2.1.3 Finally, uncertainty budgets: for example, gauge blocks' uncertainty budgets are cognate to all National Metrology Institutes. Whereas, the calculation of uncertainty budgets in the field of angle calibration, is not so well defined. However, the participants must be able to present a detailed uncertainty budget. One stipulation for taking part in this key comparison, is that the claimed best measurement capability for the participating laboratories should be 0,2 seconds.

2.1.4 By their declared intention to participate in this key comparison, the laboratory accepts the general instructions and technical protocols as stated in this document and commits themselves to follow the procedures rigorously.

2.2 Participants

2.2.1 With the help of the Regional Metrology Chairman, a list, tabled below, of participating laboratories was drafted.

Pilot Laboratory		
Mr O A Kruger	National Metrology Laboratory CSIR Meiring Naude road Pretoria 0001 SOUTH AFRICA	Tel: + 27 12 841 3005 Fax + 27 12 841 4458 e-mail: oakruger@csir.co.za
APMP		
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	JAPAN	
Dr. Tae Bong EOM	Principal Researcher, Length Group Division of Mechanical Metrology Korea Research Institute of Standards and Science P.O. Box 102, Yusong, Taejon 305-600, KOREA	Tel : +82 42 868 5108 Fax : +82 42 868 5012 e-mail: tbeom@kriss.re.kr
	EUROMET	
Dr Attilio Saconni	CNR – Istituto di Metrologia G. Colonnetti Stada delle Cacce 73 I-10135 Torino ITALY	Tel: + 39 011 3977 470 Fax: + 39 011 3977 459 e-mail: a.sacconi@imgc.to.cnr.it
Dr George Vailleau	BNM-LNE Laboratoire National d'essais Department Metrolgie at Instruments de mesure 1, rue Gaston Boissier 75724 Paris Cedex 15 FRANCE	Tel: + 33 1 40 43 37 00 Fax: + 33 1 40 43 37 37 e-mail: georges.vailleau@lne.fr
Dr Rudolf Thalman	Office Federal de Metrologie	Tel: + 41 31 323 33 85 Fax: + 41 31 323 32 10 e-mail: rudolf.thalmann@metas.admin.ch
Dr Reinhard Probst	Physikalish-Technische Bundesanstalt (PTB) Section 5.22, Graduations of Length and Angle Budesalle100 D-38116 Braunschweig, GERMANY	Tel: + 49 531 592 5220 Fax: + 49 531 592 5205 e-mail: reinhard.probst@ptb.de
	COOMET	
Dr Alexander N. Korolev	Head of Laboratory of Standards in the field length and angle measurements, nanometrology and laser metrology D.I. Mendelev Institute for Metrology 19, Moskovsky pr., 198005, St. Petersburg RUSSIA	Tel: + 812 251 86 38 Fax: + 812 113 01 14 e-mail: al_korolev@mail.ru
Dr Roma Fira	Slovak Institute of Metrology Laboratory of Length and Lasers Karloveska 63 842 55 Bratislava SLOVAKIA	Tel: + 421 7 602 94 284 Fax: + 421 7 654 29 592 e-mail: fira.smu@smu.gov.sk
Mr Miguel Viliesid	Jefe de Division, Metrologia Dimensional CENAM Apartado Postal 1-100 Centro 7600 Quetaro, Qro	Tel: 52 42 11 0574 Fax: 52 42 11 0577 e-mail: mviliesi@cenam.mx
Dr Theodore D. Doiron	National Institute of Standards and Technology Metrology (220) Room B118, 100 Bureau Drive, Stop 8211	Tel: 1 301 975 3472 Fax: 1 301 869 0822 e-mail theodore.doiron@nist.gov

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Dr Jim Pekelsky	Programme Leader, Dimensional Metrology Institute for National Measuring Standards National Research Council Canada Ottowa K1A OR6 CANADA	Tel: + 1 613 993 7578 Fax: + 1 613 952 1394 e-mail: jim.pekelsky@nrc.ca

2.3 Time Schedule

2.3.1 The comparison will commence with the CSIR/NML as the pilot laboratory followed by the APMP region. On completion of the comparison the artefacts will be returned to the pilot laboratory for verification of either drift or damage to the artefacts.

2.3.2 Each laboratory will have one month (4 weeks) in which to perform the calibration and a further 2 weeks to pass it on to the next laboratory. The schedule must be kept and no deviation from it will be allowed. Should a laboratory experience problems, be it in the measurements of the artefacts or with the customs of a country, the allotted time must be adhered to, even if it means not completing the measurements. Otherwise, the time schedule starts to run behind and it is very difficult to get back on track, which is unfair to the remaining laboratories.

2.3.3

Region	Laboratory	Start Date
Pilot laboratory		July 200
APMP	NIM KRISS NRLM	21 August 2000 2 October 2000 13 November 2000
Pilot laboratory		20 January 2001
COOMET	SMU	15 March 2001
EUROMET	PTB OFMET LNE IMGC	28 May 2001 9 July 2001 20 August 2001 1 October 2001
Pilot laboratory		12 December 2001
SIM	NIST NRC CENAM	28 January 2001 11 March 2002 22 April 2002
Pilot laboratory		3 June 2002

COOMET	VNIIM	24 June 2002
Pilot laboratory		August 2002

2.4 Handling of artefacts

2.4.1 The gauges should be examined immediately upon receipt. The condition of the gauges should be noted and communicated to the pilot laboratory. Please use the return form; appendix A4.

2.4.2 No re-lapping or re-furbishing of the artefacts should be attempted. Laboratories should attempt to measure all gauges/artefacts, unless in doing so would result in damage to their equipment.

2.4.3 The gauges should be inspected before being dispatched and any change in their condition during the measurements at the laboratory should be communicated to the pilot laboratory.

2.4.4 The laboratory must also inform the next laboratory via fax or e-mail when the artefacts are to be sent to them.

2.4.5 After the measurements, the artefacts must be packed in the original packaging before shipment to the next laboratory.

2.5 Transportation of artefacts

2.5.1 It is very important that the artefacts be packed and transported in the best possible manner, thus eliminating either damage, being lost or handled by unauthorised persons.

2.5.2 The artefacts should be accompanied by a suitable customs carnet (where appropriate) or documentation uniquely identifying the items. The packaging should be easily opened to enable inspection by custom officials.

2.5.3 Each laboratory must cover the cost of it’s own measurements; transportation to the next laboratory and any custom’s charges incurred. The laboratory is also responsible for any damages which may occur within the country during the measurements and transportation. The pilot laboratory has no insurance for any loss or damage to the artefacts during transportation.

3. Description of artefacts

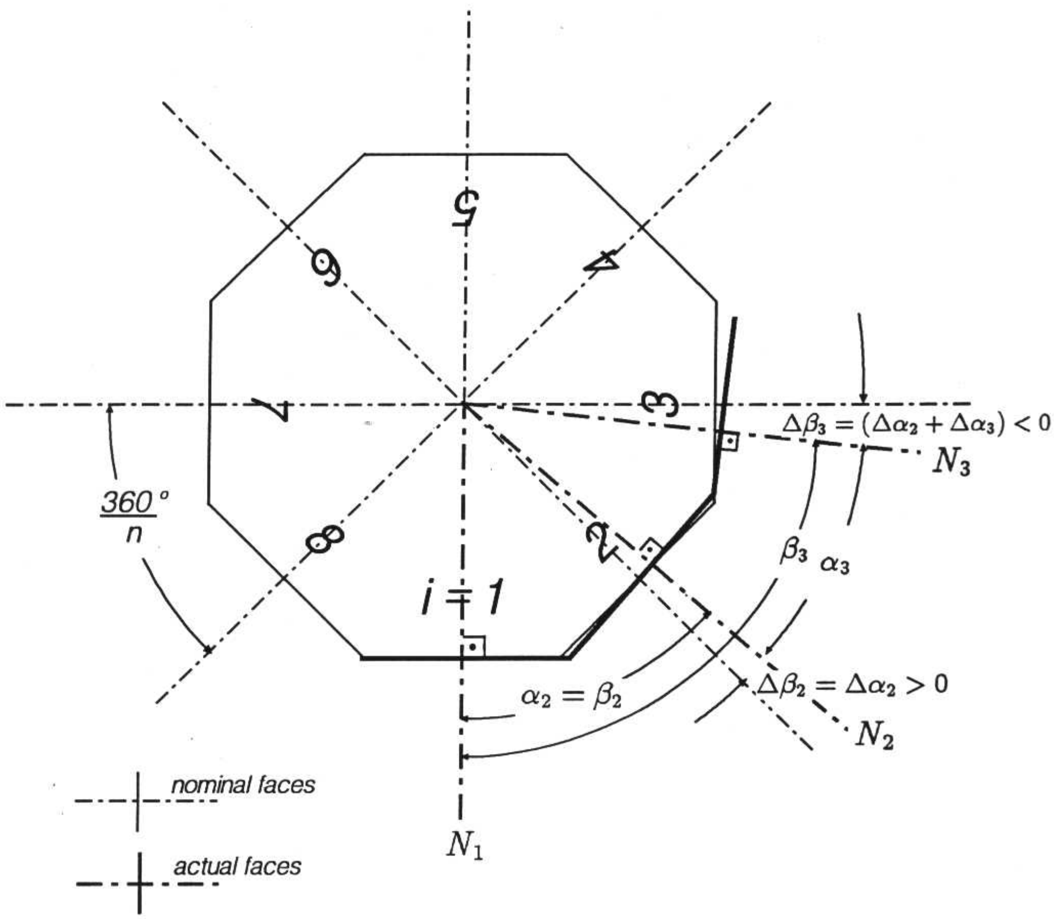
3.1 The artefacts to be measured consist of a 12 sided polygon and 4 angle blocks.

3.2 Four angle blocks, 5"; 30"; 5' and 5° will be used to test the calibration capabilities of the laboratory which are the extremes of their calibration range. The angle blocks will be Webber blocks with a material of chrome carbide with all the angle blocks having a serial number OGU6. The angle blocks have a measuring face of 50*25 mm.

3.3 The polygon, serial number 9.387OP7 is also manufactured by Webber and a material of chrome carbide; with a measuring face of 16*14 mm. The polygon has a centre hole of 25,4 mm for mounting purposes and a thickness of 18,5 mm.

3.4 The angle blocks must be measured using an aperture, which is 1mm less (on the edge) than the overall face.

3.5 Drawing:



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 deviations $\Delta\alpha_i = \alpha_i - \frac{360°}{n}$ $(i = 2,3,\ldots)$

4. Measurement Instructions

4.1 Definitions

4.1.1 The precision 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 that case, the measuring plane is defined; as the plane for which the sum of the squares of the pyramidal errors of all measuring faces is a minimum.

4.1.2 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.

$$\Delta \alpha_i = \alpha_i - \frac{360°}{n} \qquad (i = 2,3,\ldots,n) \qquad (1)$$

4.1.3 The positive count direction of the polygon angle corresponds to the count direction of the face (index i) indicated on the polygon housing.

4.1.4 Note that with the polygon in the normal and the inverted position the count directions are opposite.

4.1.5 The angle blocks used are basically a polygon but with only two faces. These blocks, like polygons, also have pyramidal errors. The angle is defined by the angle between the measuring faces with the plain perpendicular to the line being common to both functional planes.

4.1.6 The goal of this CCL key comparison is to demonstrate the equivalence of routine calibration service for angle measurements offered by NMIs to clients, as listed by them in Appendix C of the BIPM Mutual Recognition Agreement (MRA). To this end, participants in this comparison agree to use the same apparatus and methods as routinely applied when calibrating artefacts for clients. Participants are free to tune and operate their systems to best-measurement performance and to take any extra measurements needed to produce a best measurement result, provided that these extra efforts would also be available to a client if requested.

4.2 Measurement methods

4.2.1 The polygon and angle blocks are to be measured in both the normal and inverted positions, but only one set of results; the mean, will be reported. The polygon and angle blocks must be adjusted for eccentricity. The polygon/angle block must be laterally adjusted so that the measuring faces have a minimum run-out.

4.2.2 The autocollimator must be adjusted as precisely as possible, with it's optical axis perpendicular and in true alignment to the table's axis of rotation and central to the centre of the polygon/angle block faces.

4.2.3 The polygon/angle blocks must be adjusted with the aid of an autocollimator in the plane perpendicular to the table's axis of rotation (measuring plane) in such a way that the pyramidal errors of all measuring faces are at a minimum, within ± 2”. The measuring axis of the autocollimator; the x-axis, must be adjusted parallel to the measuring plane of the angle blocks/polygon.

4.2.4 The following methods can be used but are not prescribed;

a) The use of an autocollimator and an index table or angle measuring table.

b) The method of comparison with the fixed pitch angle formed by two autocollimators.

c) Where the autocollimator in method a) is replaced with an interferometer (phase shifting). The interferometer then measures the difference in angle from the index table.

Any alternative method which holds to the minimum requirement in 2.1.3. can be used. So long as it is a non-contact method. No probing of the surfaces is allowed.

5. MEASUREMENT UNCERTAINTIES

5.1 The uncertainty for the measurements of both the polygon and angle blocks must be according to *ISO Guide for the Expression of Uncertainty in Measurement.*

5.2 All the measuring uncertainties must be included in the uncertainty budgets for both the polygon and angle blocks. A template of the uncertainty budget is attached in Appendix A3.

5.3 The uncertainty must be stated as the combined standard uncertainty and also be stated as the expanded uncertainty for k=2.

5.4 The pitch angle deviations are described by:

$$\Delta\alpha_i = \alpha_i - \frac{360°}{n} + \delta A_F + \delta A_P + \delta A_E \qquad (i = 2,3,\ldots,12) \qquad (2)$$

where:

α_i	pitch angle measured by any method described in 4.2.4.
δA_F	correction for flatness deviations of measuring face
δA_P	correction for pyramidal errors of measuring face
δA_E	correction for eccentricity errors in setup of polygon/angle block
i	measuring face index

In most cases the flatness deviations, pyramid and eccentricity will not be corrected but only an uncertainty, $u(x_i)$ included in the uncertainty budget.

5.5 With the pitch angle deviation expressed as a function of input quantities x_i

$$\alpha_i = f(x_i) \qquad (3)$$

the combined standard uncertainty $u_c(\alpha_i)$ is the quadratic sum of the standard uncertainties of the input quantities $u(x_i)$ each weighted by a sensitivity coefficient c_i

$$u_c^2(\alpha_i) = \sum_i c_i^2 u^2(x_i) \text{ with } c_i = \frac{\partial \alpha_i}{\partial x_i} \qquad (4)$$

5.6 The following is an example calculated for the calibration of a 12 sided polygon using an autocollimator and an index table. For simplicity the uncertainty of only one pitch angle deviation is calculated. For the full calibration of all 12 sides, an uncertainty budget for each pitch angle deviation will be calculated. Most of the input quantities are only examples and have no relation to the polygon used for this comparison. The sensitivity coefficients for the systematic uncertainties of the autocollimator were calculated for this autocollimator and must not be used for any other make and manufacturer.

All the uncertainties are calculated for 1 sigma.

Source of uncertainty	x_i	$u(x_i)$	v_i	$c_i = \partial\alpha_i/\partial x_i$	$u_i(\alpha_i)$/sec
Autocollimator (calibration)	1.5”	0.025”	4	1	0.025

Index table	30°	0,05 "	4	1	0.05
Flatness	0	0,08 μm P-V	4	0.35	0.028
Eccentricity	0	0,2 mm	4	0.05	0.01
Pyramid	0	1"	4	0.05	0.05
Repeatability	-	0,03"	3-1=2	-	0.03
		veff.	116.2		
		t distribution	2.00	$u_c^2(\alpha_i)$	0.0081

Expanded standard uncertainty for k = 2: $u_c(\alpha_i) =$ ***0.17"***

The effective degrees of freedom was taken as infinity for the type B uncertainties but can be calculated to be different. For the type B uncertainties, the flatness, eccentricity and pyramidal error a rectangular distribution was assumed and for the repeatability and the calibration of the autocollimator and index table a normal distribution.

The autocollimator was calibrated using a laser small angle generator and the uncertainty in the calibration was estimated to be 0.025" for a 1.5" autocollimator reading between the two faces.

The calibration of the index table was performed against another index table using a closure method and the uncertainty estimated to be 0.05" for a 30° interval.

The flatness of both faces was measured and the difference between the two faces was 0.08 μm P-V. With no correction for the flatness deviation between the two faces the input quantity is zero. The NML calculated, that for the autocollimator used, the sensitivity coefficient, c_i, is 0.625; which results in a 0.05" uncertainty, $u_i(\beta_i)$.

The polygon was centred to within 0.2 mm, the value might be smaller but for this example the maximum value as prescribed in the Euromet Project No 371, was used. For this eccentricity value of 0.2 mm a sensitivity coefficient was calculated to be 0.05 which gives an uncertainty contribution of 0.028".

The polygon was aligned in the Y axis in such a way that the pyramidal errors of all measuring faces were at a minimum. When measured, the pyramidal error between the two faces under calibration was found to be 1". Again no correction is performed and multiplied with the sensitivity coefficient of 0.05, which was calculated for the NML's autocollimator, resulting in 0.05" uncertainty contribution.

Repeatability, the only type A uncertainty, was calculated from 3 readings on each of the two faces of the polygon. The effective degree of freedom was n-1, which is 2. For the example, a value of 0.03" was used.

The effective degrees of freedom was calculated to be 116.2 which gives a coverage factor of 2.

6. REPORTING OF RESULTS

6.1 According to the definitions, only the pitch angle deviations, $\Delta\alpha_{I,}$ must be reported, as it is anticipated that the uncertainty will be different for each pitch angle deviation. Regarding the angle blocks, the deviation of the nominal angle must be reported. Both the polygon and the angle blocks must be reported in arc seconds.

6.2 The results must be sent to the pilot laboratory within 2 months of the completion of the measurements.

6.3 The reference value to be used in this comparison has still to be decided upon. It is however proposed that a weighted average of the results, with weighting factors as normally derived from the stated uncertainties of the results be used as the reference value.

A.1Measurement results

12 sided polygon

Laboratory:...

Method of measurement (as per 4.2.4):...
Maximum pyramidal error: ....arc sec
Serial Number: 9.387 OP 7

Calibration table:

Faces	Pitch angle deviation (arc sec)	Effective degrees of Freedom v_i
1-2		
2-3		
3-4		
4-5		
5-6		
6-7		
7-8		
8-9		
9-10		
10-11		
11-12		
12-1		

Date:....................

Signature:.......................

Angle blocks (4 off)

Laboratory:

Method of measurement: ....
Maximum pyramidal error (LS plane): ....arc sec

Calibration tables:

Angle block: 5”

Angle deviation (arc sec)

Angle block: 30”

Angle deviation (arc sec)

Angle block: 5’

Angle deviation (arc sec)

Angle block: 5

Angle deviation (arc sec)

Date:....................

Signature:.......................

A.2 Description of the measuring system/set-up

Make and type of measuring table (include the uncertainty of the table calibration if app.)

..

..

..

..

Make and type of autocollimator/s used (include the uncertainty of the autocollimator/s)

..

..

..

..

Procedure of the measuring set-up used

..

..

..

..

..

..

A.3 Uncertainty of measurement

Source of uncertainty	x_i	$u(x_i)$	v_i	$c_i = \partial\beta_i / \partial x_i$	$u_i(\beta_i)$/sec
		veff.			
		t distribution		$u_c^2(\alpha_{i\ I})$	

Combined standard uncertainty: $u_c(\alpha_i)$ = **...**

A.4 Return form

Attention: Mr O Kruger
National Metrology Laboratory
P O Box 395
Building No 5
CSIR
Pretoria
South Africa
Fax: +27 12 841 4458
e-mail: oakruger@csir.co.za

We confirm having received the artefacts for the CCL key comparison on angle standards on ....(date)

After visual inspection:

No damage has been observed

Damage has been observed (detailed comments)

...

...

...

Laboratory:...…