Report on APMP Key Comparison
Calibration of Angle Gauge Blocks

APMP.L-K3.n01

Final Report

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1 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 the APMP TCL meeting in 2018, it was decided to conduct a supplementary comparison on angle gauge block measurements, with NIMT serving as the pilot laboratory. The comparison was registered in March 2021, with artifact circulation commencing in December 2021 and completing in March 2024. In June 2024, this supplementary comparison was upgraded to a key comparison.

2 Organization

2.1 Participants

Table 1. List of participant laboratories and their contacts.

Laboratory code	Contact person	Address	Contact details
NIMT (Pilot)	Ms. Ketsaya Vacharanukul, Mr.Watcharin Samit	3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand	Tel: +66 25775100 ext 1216 e-mail: ketsaya@nimt.or.th watcharin@nimt.or.th
NMIA	Mr. Peter Cox	National Measurement Institute Unit 1/153 Bertie Street, Port Melbourne, Victoria 3207, Australia	Tel: +61 3 9644 4906 email: peter.cox@measurement.gov.au
NMIM	Mr. Razman Mohd Halim, Ms. Rafidah Rosli	National Metrology Institute of Malaysia Lot PT4803 Bandar Baru Salak Tinggi 43900 Sepang, Selangor Malaysia	Tel: +603-87781613 e-mail: razmanmh@sirim.my rafidahr@sirim.my
RSE	Mr. Yepenov Tilek Mrs. Suyeubayeva Gulaikhan	Kazakhstan Standardisation and Metrology Institute Mangilik El avenue, 11, left bank, Astana, 010016, Kazakhstan	Tel: +7 717 228 29 88 +7 717 228 29 37 e-mail: t.epenov@ksm.kz g.suyeubayeva@ksm.kz
SASO-NMCC	Mr. Faisal AlQahtani, Mr. Yasser Bin Talha	Saudi Standards, Metrology and Quality Org. National Measurement and Calibration Center (Building No.4) Riyadh – Al Muhammadiyah -in front of King Saud	Tel: +966112529726 e-mail: f.qahtany@saso.gov.sa Tel: +966112529714 e-mail: y.talhh@saso.gov.sa
SCL	Mr. George Tang Mr. Henry Chiu	Standards & Calibration Laboratory (SCL) 35/F Immigration Tower, 7 Gloucester Road, Wanchai, Hong Kong	Tel: +852 2829 4805, +852 2829 4839 e-mail: george.tang@itc.gov.hk hklchiu@itc.gov.hk
SE	Ms. Anna Fursa, Mr. Yuri Glushko	State Enterprise “All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer” (SE “UKRMETRTESTSTANDART”),	Tel: +38 044 526 3619 e-mail: fursa@ukrcsm.kiev.ua Tel: +38 098 423 9322 e-mail: yygeom@gmail.com

		4, Metrologichna Str., 03143, Kyiv-143, Ukraine	
SNSU-BSN	Mr. Okasatria Novyanto, Ms. Nurul Alfiyati	Komplek Puspiptek, Ged.420, Setu, Tangerang Selatan, Banten 15314 Indonesia	Tel:+62 21 7560533 ext 3078 e-mail: okasatria@bsn.go.id nurul@bsn.go.id
UAE EMI	Mr. Majed Sultan Ali Saeed Al Senaidi	Masdar city, AbuDhabi, United Arab Emirates	Tel: +97124066666, +971506684887 e-mail: m.alsenaidi@qcc.gov.ae
VMI	Mr. Tong Cong Dung, Mr. Vu Khanh Phan	No 8 - Hoang Quoc Viet street, Cau Giay district, Ha Noi 100000, Viet Nam	Tel: +84 986 025 520 e-mail: dungtc@vmi.gov.vn Tel: +84 334 562 818 e-mail: phanvk18@gmail.com

2.2 Schedule

The schedule has been revised several times due to additional participants expressing interest in joining, as well as one individual withdrawing. Unfortunately, significant delays in the intercomparison occurred due to a range of issues at customs.

Table 2. Schedule of the comparison

RMO	Laboratory	Original schedule	Date of measurement	Results received
APMP	NIMT	December 2021	December 2021	
APMP	NMIM	April 2022	April 2022	May 2022
APMP	NMIA	May 2022	May 2022	July 2022
Pilot Lab	NIMT	June 2022		
GULFMET	UAE EMI	July 2022	August 2022	January 2023
APMP	SNSU-BSN	November 2022	November 2022	May 2024
GULFMET	SASO-NMCC	January 2023	January 2023	June 2023
APMP	VMI	May 2023	May 2023	August 2023
COOMET	RSE	June 2023	September 2023	February 2024
EURAMET	SE	July 2023	December 2023	January 2024
APMP	SCL	August 2023	February 2024	March 2024
Pilot Lab	NIMT	March 2024	April 2024	

3 Artefacts

3.1 Description of artefacts

The artefacts to be calibrated are four (4) angle gauge blocks, 1'; 25'; 3° and 30° (Figure 1.). These angle blocks are manufactured by Tsugami Corporation, and all of them have the serial number 04003. The angle blocks have measuring faces that are 15 mm by 50 mm.

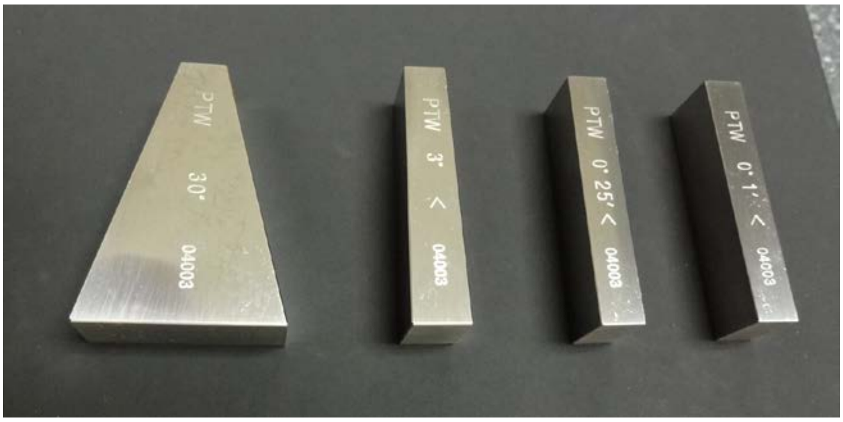


Figure 1. Picture of angle gauge blocks

3.2 Stability of artefacts

NIMT conducted stability measurements on the angle gauge blocks both prior to and following the comparison. No instability was observed, with the maximum deviation consistently remaining below the associated uncertainty value for all blocks.

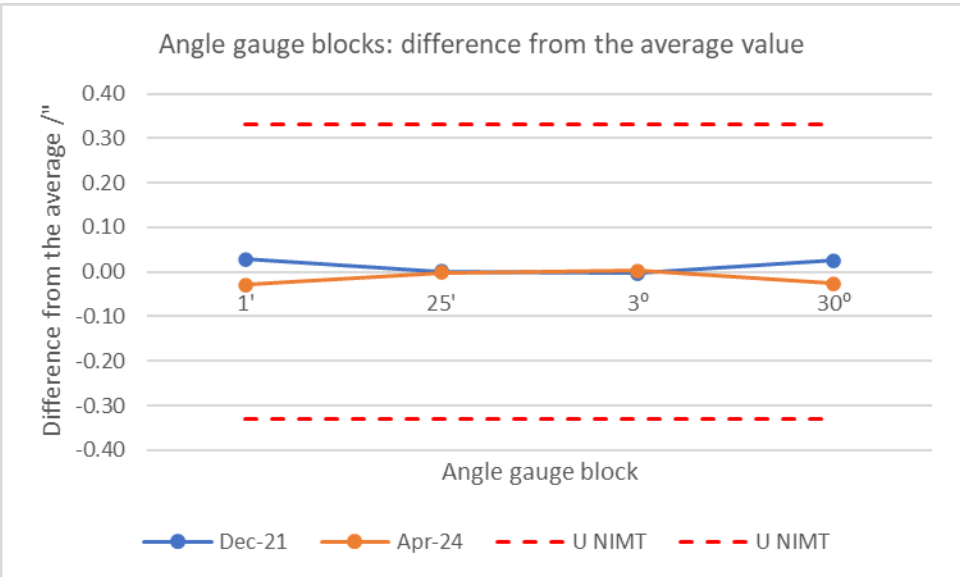


Figure 2. Stability of angle gauge blocks during comparison: angle measurements of the pilot laboratory. The red dashed lines represent the pilot expanded uncertainty (k=2).

3.3 Condition of artefacts at start/end of comparison

The angle gauge blocks were in optimal condition at the commencement of the comparison. However, during circulation, some rust was observed on their faces. Despite this, the interim angle measurement conducted by the pilot laboratory showed no significant change in the measurand.

4 Measuring instructions

4.1 Measurands

The angle gauge block has two reflecting side faces which serve as measuring faces. Ideally, these measuring faces are perpendicular to the measuring plane. However, in practice, the measuring faces may have slight tilts, known as pyramidal errors, resulting in deviations from perfect perpendicularity.

The pitch angle of an angle gauge block is the angle between the measuring faces normal to the measuring plane. The deviation of the pitch angle from its nominal value is referred to as pitch angle deviations. The **measurand** is the pitch angle deviation of the pitch angle.

5 Apparatus and measurement methods

A short description of the measurement apparatus used by the participants is given below. Descriptions are taken and/or summarized from the partner's reports. It is worth noting that the CMC entries in the table 3 are given as quantities as reported in the KCDB (https://www.bipm.org/kcdb/).

Table 3. Instrumentation, traceability and CMC entries of participant laboratories

Participant	Instrument used	Traceability	CMC entry (k=2)
NIMT	Self-calibration angle system and MWO Elcomat 3000 autocollimator		U = 0.33”
NMIA	Moore 1440 precision index table and Hilger&Watts TA51-1 dual axis autocollimator		U = 0.3”
NMIM	Moore 1440 precision index table and MWO Elcomat 3000 autocollimator	METAS	-
RSE	Moore 1440 precision index table and MWO Elcomat 3000 autocollimator		-
SASO-NMCC	7” Ultradex Style “B” Index Table manufactured by AAGAUGE and MWO Elcomat 3000 autocollimator	TUBITAK UME	-
SCL	Moore 1440 index table and MWO Elcomat 3000 autocollimator		U = 0.3”
SE	Angle Measuring System GS-1L (rotating table with build-in ring laser) and an autocollimator		-
SNSU-BSN	Moore 1440 index table and Taylor Hobson DA400 autocollimator	NMIJ	U = 0.93”
UAE EMI	Self-calibration measuring system and MWO Elcomat 3000 autocollimator		-
VMI	Self-calibration measuring system and Trioptics TriAngle autocollimator		-

6 Results

6.1 Results and standard uncertainties as reported by participants

The submitted results are collected in the table below.

Table 4. Pitch angle deviations (in arcsec) of angle gauge blocks, as reported by the laboratories.

	Angle gauge blocks			
Lab	**1′**	**25′**	**3°**	**30°**
NIMT	-1.28	1.02	-0.32	2.63
NMIM	-1.26	1.05	-0.31	2.62
NMIA	-1.13	1.10	-0.32	2.66
UAE EMI	-1.15	1.37	-0.61	0.63
SNSU-BSN	-1.98	1.23	-0.94	0.06
SASO-NMCC	0.03	0.03	0.08	0.17
VMI	-1.30	1.06	-0.24	2.69
RSE	1.54	0.55	0.69	2.75
SE	-1.25	1.12	-0.21	2.70
SCL	-1.26	1.02	-0.25	2.57

Table 5. Standard uncertainties (in arcsec), as reported by the laboratories.

	Angle gauge blocks			
Lab	**1′**	**25′**	**3°**	**30°**
NIMT	0.16	0.16	0.16	0.16
NMIM	0.31	0.31	0.31	0.31
NMIA	0.19	0.19	0.19	0.19
UAE EMI	0.30	0.30	0.30	0.30
SNSU-BSN	0.34	0.35	0.33	0.34
SASO-NMCC	0.20	0.20	0.20	0.30
VMI	0.13	0.13	0.13	0.13
RSE	0.74	1.08	0.97	1.17
SE	0.15	0.15	0.15	0.15
SCL	0.14	0.14	0.14	0.14

7 Analysis

7.1 Calculation of the KCRV

Each laboratory reports a measured value, x_i, and its associated standard uncertainty $u(x_i)$ for each pitch angle.

The key comparison reference value (KCRV) is calculated as the weighted mean of the participant results for each pitch angle.

The weighted mean, $\bar{x}_w$, is given by:

$$\bar{x}_w = \sum_{i=1}^{I} w_i \cdot x_i \tag{1}$$

where the normalised weight, w_i , for the result x_i is given by:

$$w_i = C \cdot \frac{1}{[u(x_i)]^2} \tag{2}$$

and the normalising factor, C, is given by:

$$C = \frac{1}{\sum_{i=1}^{I} \left(\frac{1}{u(x_i)} \right)^2} \tag{3}$$

The uncertainty of the weighted mean is calculated as:

$$u(\bar{x}_w) = \sqrt{\frac{1}{\sum_{i=1}^{I} \left(\frac{1}{u(x_i)} \right)^2}} = \sqrt{C} \tag{4}$$

After deriving the weighted mean and its associated standard uncertainty, the deviation of each laboratory's result from the weighted mean is determined simply as $x_i - \bar{x}_w$. The uncertainty of this deviation is calculated as a combination of the uncertainties of the result, $u(x_i)$, and the uncertainty of the weighted mean $u(\bar{x}_w)$. The uncertainty of the deviation from the weighted mean is given by equation (5), which includes a minus sign to take into account the correlation between the two uncertainties (it would be a plus sign if dealing with uncorrelated uncertainties, such as when comparing data from two separate laboratories).

$$u(x_i - \bar{x}_w) = \sqrt{[u(x_i)]^2 - [u_{int}(\bar{x}_w)]^2} \tag{5}$$

The degrees of equivalence for each laboratory and each pitch angle with respect to the KCRV is evaluated using E_n values defined as the ratio of the deviation from the weighted mean, divided by the expanded uncertainty of this deviation:

$$E_n = \frac{x_i - \bar{x}_w}{2\sqrt{[u(x_i)]^2 - [u_{\text{int}}(\bar{x}_w)]^2}} \tag{6}$$

For the determination of the key comparison reference value KCRV, statistical consistency of the results contributing to the KCRV is required. To this purpose, the so-called Birge ratio R_B is used: this parameter compares the observed spread of the results with the spread expected from the individual reported uncertainties.

The application of least squares algorithms and the χ^2-test leads to the Birge ratio

$$R_B = \frac{u_{ext}(\bar{x}_w)}{u(\bar{x}_w)}, \quad (7)$$

where $u_{ext}(\bar{x}_w)$ is the external standard deviation

$$u_{ext}(\bar{x}_w) = \sqrt{\frac{1}{(I-1)} \cdot \frac{\sum_{i=1}^{I} w_i (x_i - \bar{x}_w)^2}{\sum_{i=1}^{I} w_i}} . \quad (8)$$

The Birge ratio has an expectation value of R_B = 1, when considering standard uncertainties. For a coverage factor of k = 2, the expectation value is increased and the data in a comparison are consistent provided that

$$R_B < \sqrt{1+\sqrt{8/(I-1)}} \quad (9)$$

where I is the number of laboratories. As an example, in case of I = 10, data are consistent provided that R_B < 1.39.

Hence, if the Birge ratio criterion is not satisfied, the result with largest $|E_n|$ is considered as inconsistent result and is excluded from the contribution to the weighted mean – *i.e.* it has a weighting of zero. Because inconsistent results are no longer correlated with the weighted mean, when calculating their deviation from the weighted mean, and when calculating their E_n value, a positive sign is used in equation (5) and consequently in the denominator of equation (6).

This process is iterated until Eq. (9) is fulfilled, hence there are no inconsistent results contributing to the weighted mean, even if values for $|E_n|$> 1 are remaining.

Table 6. Key comparison reference value $\bar{x}_w$ and associated standard uncertainty $u(\bar{x}_w)$ expressed in arcsecond for the angle gauge blocks

	Angle gauge blocks			
	1′	**25′**	**3°**	**30°**
$\bar{x}_w$	-1.276	1.078	-0.265	2.649
$u(\bar{x}_w)$	0.063	0.063	0.060	0.066

7.2 Calculation of Degrees of Equivalence

The Degree of Equivalence, DoE, for a laboratory result x_i is calculated simply as $x_i - \bar{x}_w$. The uncertainty of the DoE is calculated using either

$u(x_i - \bar{x}_w) = \sqrt{[u(x_i)]^2 - [u_{int}(\bar{x}_w)]^2}$ for results which contributed to the weighted mean

or

$u(x_i - \bar{x}_w) = \sqrt{[u(x_i)]^2 + [u_{\text{int}}(\bar{x}_w)]^2}$ for results which made no contribution.

Tables 7 to 10 summarize the degrees of equivalence for participants. Results with $|E_n|$> 1 are highlighted in grey. The indication “1” in column “On/off” means that the corresponding value was considered for evaluating the reference value; otherwise, the indication is “0”.

Table 7.
Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle gauge block: 1′)

	1′			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
NIMT	-0.004	0.294	0.01	1
NMIM	0.016	0.605	0.03	1
NMIA	0.146	0.358	0.41	1
UAE EMI	0.126	0.587	0.22	1
SNSU-BSN	-0.704	0.668	1.05	1
SASO-NMCC	1.306	0.419	3.11	0
VMI	-0.024	0.227	0.10	1
RSE	2.819	1.481	1.90	0
SE	0.026	0.279	0.09	1
SCL	0.016	0.248	0.07	1
	Consistency: R_B = 0.856			

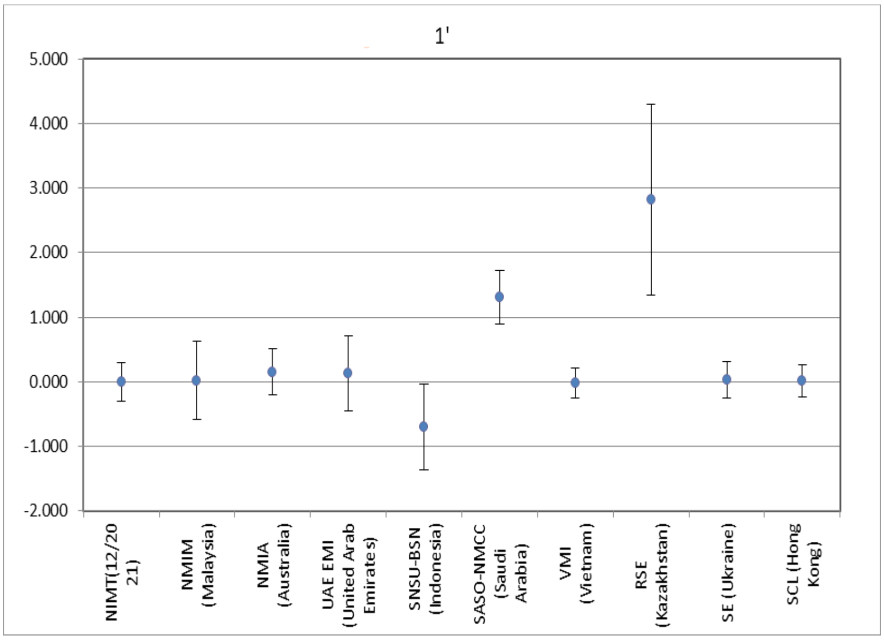


Table 8.
Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle gauge block: 25′)

	25′			
Lab	$x_i - \overline{x}_w$	$U\left(x_i - \overline{x}_w\right)$	E_n	On/off
NIMT	-0.058	0.294	0.20	1
NMIM	-0.028	0.605	0.05	1
NMIA	0.022	0.358	0.06	1
UAE EMI	0.292	0.586	0.50	1
SNSU-BSN	0.152	0.688	0.22	1
SASO-NMCC	-1.048	0.420	2.50	0
VMI	-0.018	0.227	0.08	1
RSE	-0.526	2.154	0.24	1
SE	0.042	0.278	0.15	1
SCL	-0.058	0.256	0.23	1
	Consistency: R_B = 0.472			

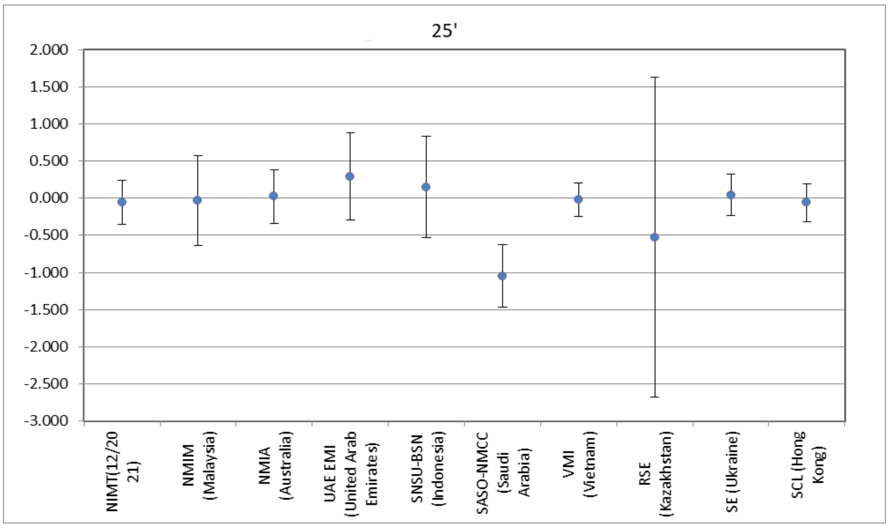


Table 9.
Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle gauge block: 3°)

	3°			
Lab	$x_i - \overline{x}_w$	$U\left(x_i - \overline{x}_w\right)$	E_n	On/off
NIMT	-0.055	0.297	0.19	1
NMIM	-0.045	0.606	0.07	1
NMIA	-0.055	0.360	0.15	1
UAE EMI	-0.345	0.588	0.59	1
SNSU-BSN	-0.675	0.649	1.04	1
SASO-NMCC	0.345	0.381	0.90	1
VMI	0.025	0.231	0.11	1
RSE	0.953	1.926	0.49	1
SE	0.055	0.281	0.19	1
SCL	0.015	0.253	0.06	1
	Consistency: R_B = 1.047			

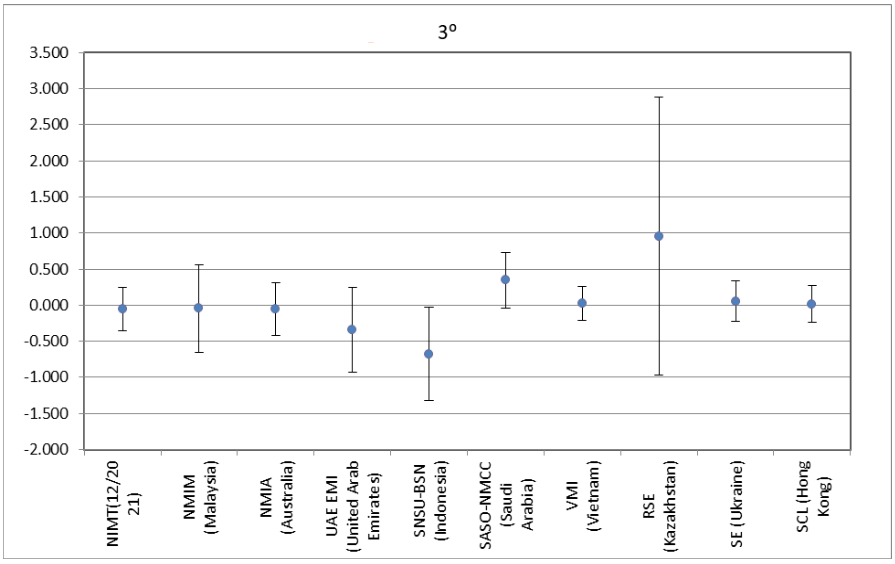
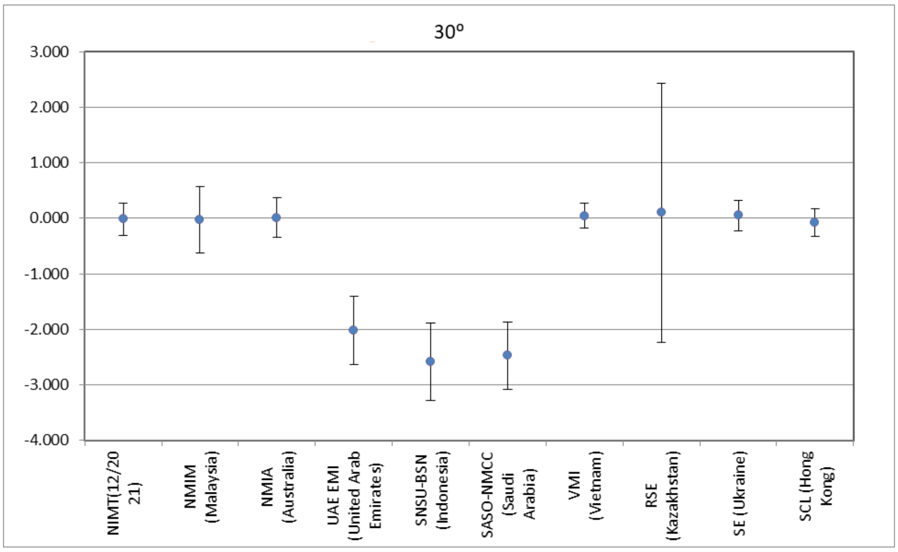


Table 10.
Degrees of equivalence, associated expanded uncertainty, E_n values and indication whether the value contributed to the weighted mean (angle gauge block: 30°)

	30°			
Lab	$x_i - \bar{x}_w$	$U(x_i - \bar{x}_w)$	E_n	On/off
NIMT	-0.019	0.292	0.06	1
NMIM	-0.029	0.604	0.05	1
NMIA	0.011	0.356	0.03	1
UAE EMI	-2.019	0.614	3.29	0
SNSU-BSN	-2.589	0.693	3.74	0
SASO-NMCC	-2.479	0.614	4.04	0
VMI	0.041	0.224	0.18	1
RSE	0.098	2.338	0.04	1
SE	0.051	0.276	0.19	1
SCL	-0.079	0.247	0.32	1
	Consistency: R_B = 0.306			



7.3 Discussion of results

NMIM, RSE, SASO-NMCC, SE, UAE EMI, and VMI do not have CMC in this field; consequently, the uncertainty values reported by these laboratories may be regarded as provisional for potential future CMC. Both SCL and SNSU-BSN reported uncertainties lower than their approved CMC. Other participants reported uncertainties consistent with their approved CMC. No correlation was observed between laboratories, as some participants referenced traceability to NMIs not included in the comparison (see Table 3).

The stability of the artifacts was maintained throughout the comparison.

The results do not exhibit good agreement, as 8 out of 40 results exhibit En > 1, with 3 from SASO-NMCC, 3 from SNSU-BSN, 1 from RSE, and 1 from UAE EMI.

8 Comments by partners

8.1 Comments before draft A

According to the Key-comparison guidelines, after the initial overview of the submitted results and a provisional calculation of reference values, the NMIs having possible outliers were asked by the pilot to check their results for arithmetic, typographical or transcription errors. All participating NMIs have reviewed their own measurement results and have provided confirmation accordingly.

8.2 Comments after draft A1

Comments from RSE 02/09/2024

Before that, you also sent our results, and we confirmed our values. However, in the result for the angle block (1 minute), we did not take into account the minus sign. Is it possible to fix this at this stage?

Reply from NIMT 17/10/2024

Following up on my previous email regarding consent, I have received feedback from several of you. However, not all suggestions align with the requirements set forth by RSE, and therefore, the error noted by RSE will remain unchanged.

Comments from SNSU-BSN 09/09/2024

I am sorry for not replying your previous email, since our data were similar to our report.

Thank you very much for the draft A.1 of APMP.L-K3.n01 comparison report. I confirmed that the result of SNSU BSN on the draft A excel file are same with our measurement and our report.

The result of 30 degrees is quite interesting, since the three participants around (including) SNSU BSN have similar results. However when we saw your last measurement, it was still stable.

Overall, we accepted the draft A.1 result.

In our case, we will investigate the result and our calibration system for next improvement.

By the way, there was a typo on the draft A graph, it should be 25 minutes not 5 minutes.