



CIPM MRA
Comparison reports

APMP.L-K3.n01

Angle gauge blocks

KEY COMPARISON

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Report on APMP Key Comparison Calibration of Angle Gauge Blocks

APMP.L-K3.n01

Final Report

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Pathumthani, December 2025

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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. Suyebayeva 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.suyebayeva@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.gahtany@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 Puspipstek, 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, Abu Dhabi, 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.

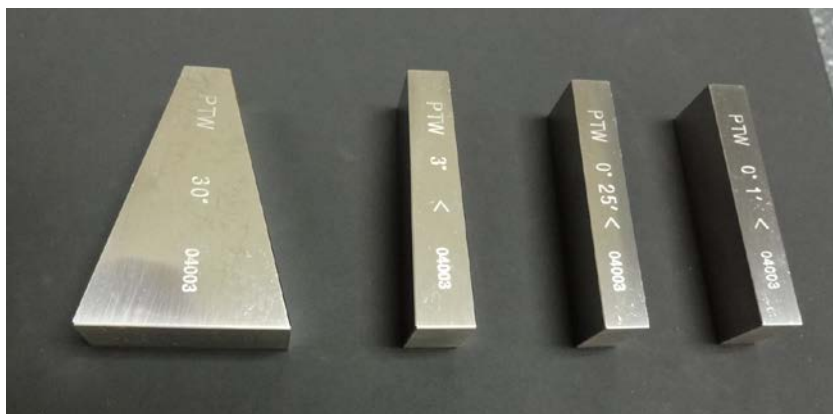


Figure 1. Picture of angle gauge blocks

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.

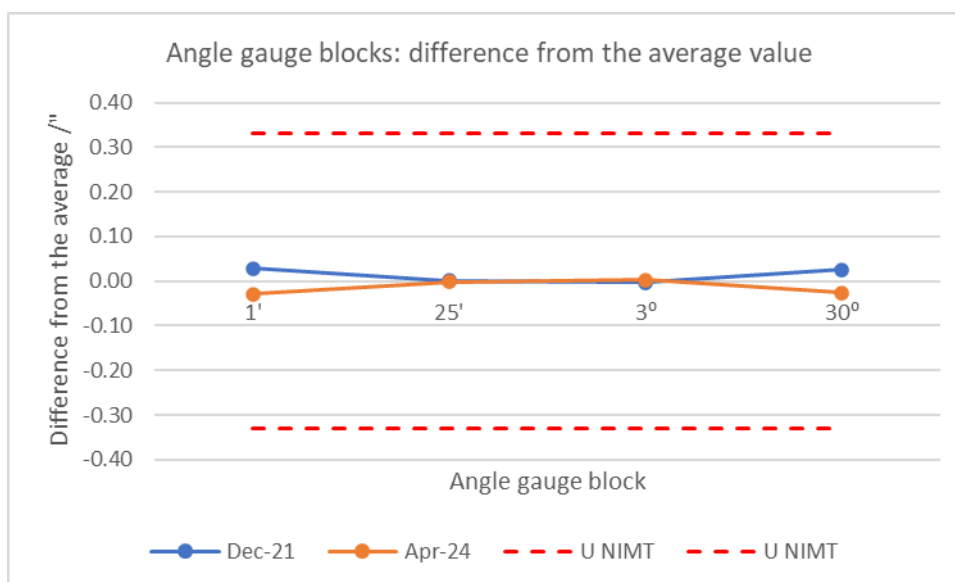


Figure 2. Stability of angle gauge blocks during comparison: angle measurements of the pilot laboratory. The red dashed lines represent the pilot expanded uncertainty ($k=2$).

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:

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

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

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

and the normalising factor, C , is given by:

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

The uncertainty of the weighted mean is calculated as:

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

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).

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

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:

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

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

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

or

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

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: $R_B = 0.856$ | | | | |

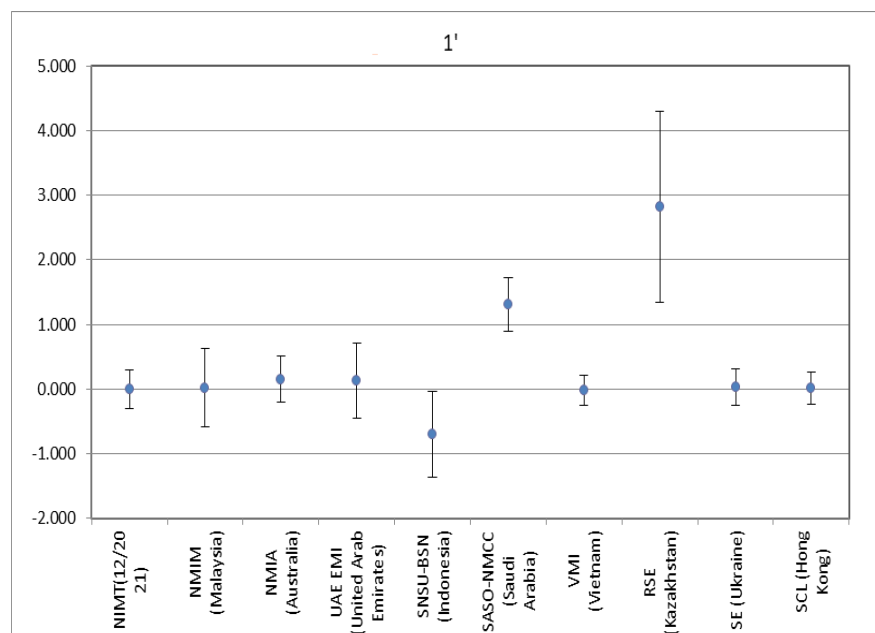


Table 8.

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

| Lab | 25' | | | |
|--|-------------------|----------------------|-------|--------|
| | $x_i - \bar{x}_w$ | $U(x_i - \bar{x}_w)$ | 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: $R_B = 0.472$ | | | | |

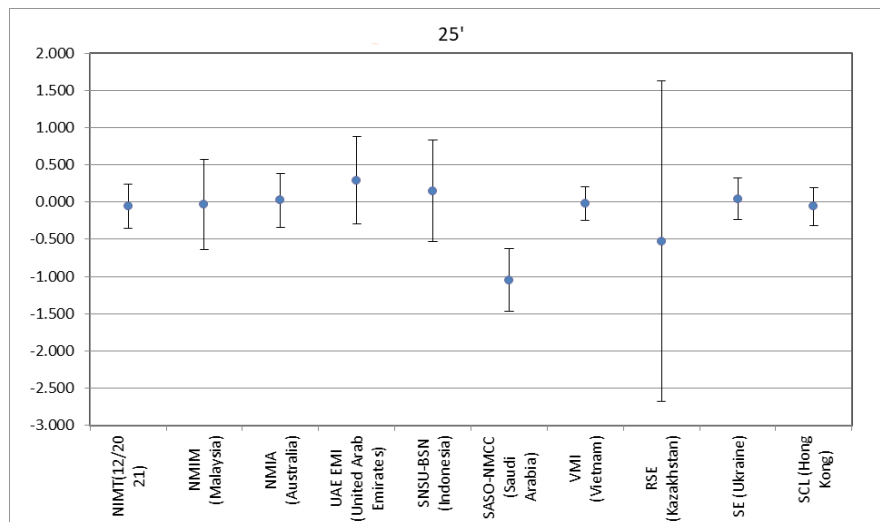


Table 9.

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 | $x_i - \bar{x}_w$ | $U(x_i - \bar{x}_w)$ | 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: $R_B = 1.047$ | | | | |

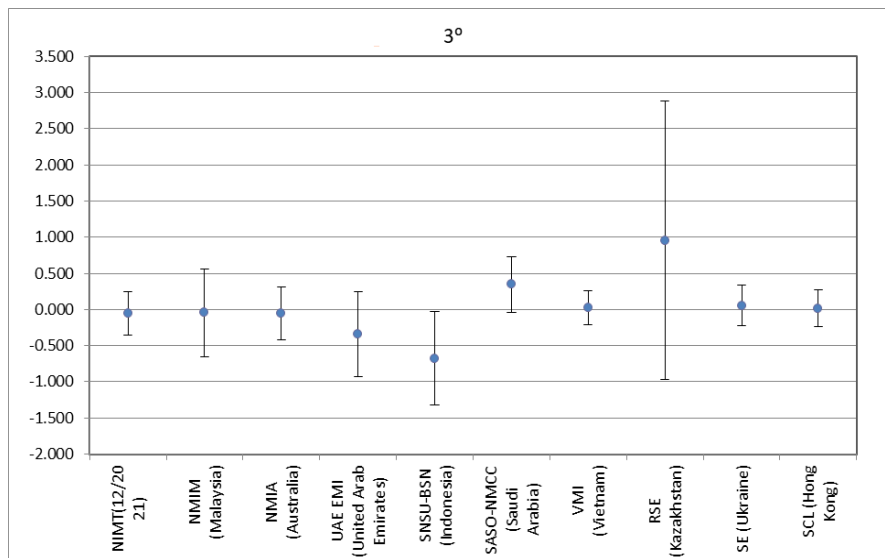
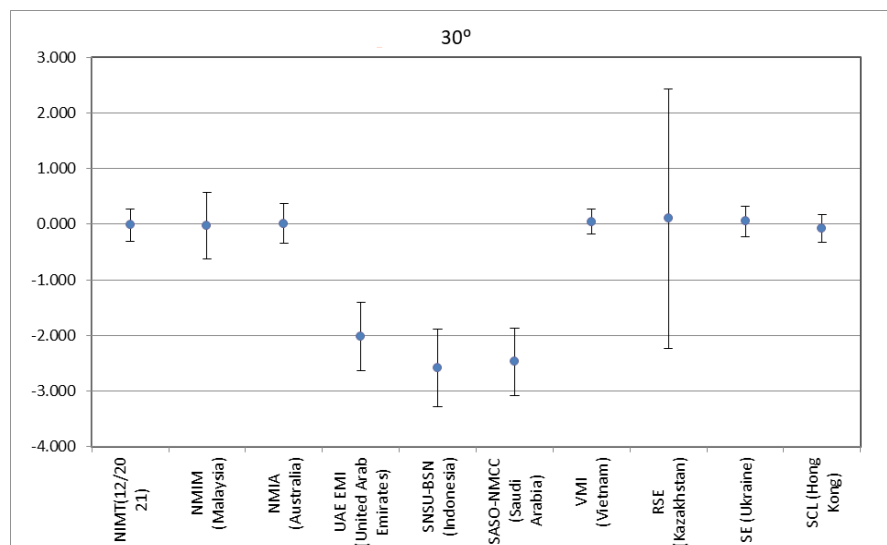


Table 10.

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 $E_n > 1$, 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.