中国计量科学研究院
National Institute of Metrology,China

APMP Supplementary Comparison

APMP.L-S5.2.n01

Calibration of Parallel Thread Gauges

Final Report

National Institute of Metrology, China

Beijing, May 2025

Contents

1 Document control

Draft A Issued on 24 Dec 2021.

Draft B Issued on 28 Mar 2022.

Final Report Issued on 13 May 2025.

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.

The APMP TCL Meeting in Nov. 2017 decided to start a supplementary comparison on calibration of parallel thread gauges, named APMP.L-S5.2.n01. NIM, China is the pilot laboratory. The comparison was registered in December 2018, artefact circulation started in March 2019 and was completed in August 2020.

3 Organization

3.1 Participants

The list of the participants is showed in Table 3-1.

Table 3-1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Email
NIM (Pilot)	Weinong Wang, Hengzheng Wei National Institute of Metrology (China)	wangwn@nim.ac.cn weihz@nim.ac.cn
NIMT	Yodying Moukngam National Institute of Metrology (Thailand)	yodying@nimt.or.th
PTB	Marlen Krause Physikalisch-Technische Bundesanstalt	Marlen.Krause@ptb.de
SASO-NMCC	Faisal A. AlQahtani SAudi Standards, Metrology and Quality Org (SASO) National Measurement & Calibration Center (NMCC)	f.qahtany@saso.gov.sa

3.2 Schedule

The circulation of artefacts started in March 2019 and completed in August 2020. The detailed schedule is given in Table 3-2. A period of two months was allowed for the measurements in each laboratory, including the time necessary for transportation. The artefacts were re-measured by the pilot laboratory after the end of the loop in order to detect potential changes related to transport. Original time schedule was changed in several occasions due to the problems of the COVID 2019. During the loop, there was an intermediate measurement by the pilot laboratory to confirm artefact stability.

NMC, A*STAR decided to withdrew from the comparison in Aug. 2020 because of the COVID 2019 and also the deadline of the ATA.

SASO-NMCC participated in during the circulation.

Table 3-2. Schedule of the comparison.

Country	Laboratory	Period (starting date)
China	NIM	2019-1
Germany	PTB	2019-3
China	NIM	2019-6
Thailand	NIMT	2019-8
Saudi Arabia	SASO-NMCC	2019-10
China	NIM	2020-8

4 Artefacts

4.1 Description of artefacts

Seven thread gauges were measured, see table 4-1:

- three thread plugs (GO side),
- three thread rings, and
- one special thread plug (GO side) with larger pitch.

Table 4-1. List of artefacts.

	Thread gauges	Serial Number
Plugs	M6×1-6H-GO	A18061319
	M12×1.75-6H-GO	A18010121
	M36×1.5-6H-GO	A18040603
	M10×2-6H-GO	A18050744
Rings	M18×2.5-6g-GO	A18091831
	M30×1.5-6g-GO	A18091842
	M42×4.5-6g-GO	A18091896

4.2 Stability of the Artefacts

NIM, the pilot laboratory measured the gauges three times with the length measurement machine and the scanner. The time points were before the gauges sent out, after the test of the first laboratory and all tests finished. The measurement results showed in Figure 1. The vertical axis shows the bias of the pitch diameter from the nominal value. And the up and low dashed lines are determined by the uncertainty (k=2) from the first calibration values of the pitch diameters, with three pins or T-Probe method. The calibration values showed in the same chart so that the stability of both measurement methods and the difference between both measurement methods could be known. The test results showed that the gauges are stable. But the measurement results with two measurement methods could be different.

Figure 1. Stability of the 7 gauges during comparison: pitch diameter measurements of the pilot laboratory.

4.3 Condition of artefacts at start/end of comparison

The artefacts were brand-new at the beginning of the comparison. They kept be stable during the comparison and they could be better because of the clearing procedure that the surfaces could be polished, see the data changes of Ring M42 and M30 by scanner's in figure 1.

5 Measurands

Participating laboratories are encouraged to follow Calibration Guide EURAMET cg-10, version 2.1 (12/2012).

Each laboratory should, according to its measurement capabilities, measure:

• Simple pitch diameter

• Pitch diameter

• Thread angle (flank angle)

• Pitch

Consider of the quality of the samplings, measurement positions were defined:

• Measurement plane: Sectional plane defined by axis and marking direction.

• Diameter measurement: Approximately middle of the cylinder.

• Pitch measurement: Average over the three threads for pitch measurement in approximate middle of the cylinder.

• Angle measurement: Approximately middle of the cylinder.

6 ANALYSIS OF RESULTS

The weighted mean is used as the reference value in the comparison.

For each laboratory (*i*) the normalized weight, w_i is calculated by the following expression:

$$\boldsymbol{w_i = C \cdot \frac{1}{u_{x_i}^2}} \quad \textbf{(1)}$$

where u_{x_i} is the standard uncertainty given by the laboratory "*i*" and *C* is the normalizing factor calculated by the expression:

$$\boldsymbol{C = \frac{1}{\sum_{i=1}^{n} \frac{1}{u_{x_i}^2}}} \quad \textbf{(2)}$$

where *n* is number of laboratories. The weighted mean (reference value) is:

$$\boldsymbol{\bar{x}_w = \sum_{i=1}^{n} w_i \cdot x_i} \quad \textbf{(3)}$$

The uncertainty of weighted mean is:

$$\boldsymbol{u_{int(\bar{x}_w)} = \sqrt{C}} \quad \textbf{(4)}$$

The statistical consistency of the results with uncertainties given by the participants is checked by the normalized deviation (E_n value) calculated for each laboratory:

$$\boldsymbol{E_n = \frac{x_i - \bar{x}_w}{2 \cdot \sqrt{u_{x_i}^2 - u_{int(\bar{x}_w)}^2}}} \quad \textbf{(5)}$$

where $x_i - \bar{x}_w$ is the deviation from the weighted mean for the result of a laboratory.

Absolute values of E_n are expected to be less than 1 for a factor of k = 2.

The statistical consistency of the comparison is analyzed by the Birge ratio test. Birge ratio compares the observed spread of the results with the spread expected from the individual reported uncertainties.

The Birge ratio is:

$$R_B = \frac{u_{ext(\bar{x}_w)}}{u_{int(\bar{x}_w)}} \quad (6)$$

Where $u_{ext(\bar{x}_w)}$is external standard deviation and can be calculated by the following formula:

$$u_{ext(\bar{x}_w)} = \sqrt{\frac{1}{n-1} \cdot \frac{\sum_{i=1}^{n} \frac{(x_i - \bar{x}_w)^2}{u_{x_i}^2}}{\sum_{i=1}^{n} \frac{1}{u_{x_i}^2}}} \quad (7)$$

The Birge ratio has an expectation value of RB = 1, when considering standard uncertainties. For a coverage factor of k = 2, the expectation value is increased and data in a comparison are consistent when: $R_B < R_{Bcirit}$.

$$R_{Bcirit} = \sqrt{1 + \sqrt{\frac{8}{n-1}}} \quad (8)$$

If the results are inconsistent, the largest consistent subset is determined by elimination, starting with excluding the result having the largest E_n value that makes the largest contribution to overall chi-squared value. The iteration runs until $R_B < R_{Bcirit}$.

After reaching consistency, the calculated weighted mean is the KCRV.

When result x_i is excluded from the calculation of the reference value, its E_n value is calculated by:

$$E_n = \frac{x_i - \bar{x}_w}{2 \cdot \sqrt{u_{x_i}^2 + u_{int(\bar{x}_w)}^2}} \quad (9)$$

Reference values of angle measurements are calculated by the means of arithmetic mean:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} \mathbf{x}_i \quad (10)$$

Where n is number of the laboratories taken in the calculation.

The statistical consistency of the results of angle measurements was checked by the normalized deviation En value is calculated by:

$$E_n = \frac{x_i - \bar{x}}{2 \cdot \sqrt{(1 - \frac{2}{n}) \cdot u_{x_i}^2 + u_{\bar{x}}^2}} \quad (11)$$

Where $u_{\bar{x}}$ is uncertainty of arithmetic mean calculated by:

$$u_{\bar{x}} = \frac{1}{n} \sqrt{\sum_{i=1}^{n} u_{x_i}^2} \quad (12)$$

Absolute values of E_n are expected to be less than 1 for a factor of k = 2.

7 Results

7.1 Results and Standard Uncertainty Reported by Participants

7.1.1 Four laboratories reported measurement results and uncertainty. Two of them reported all four results of pitch diameter. The other two laboratories reported two results for pitch diameter. Three laboratories reported the measurement results of pitch, thread angle and flank angle. Another laboratory reported pitch measurement result.

7.1.2 NIM and PTB provided the results with two methods. The measurement results in this section were discussed based on three wires/double sphere method. Appendix A gives the results based on the scanning method in details.

7.2 Measurement equipment used by the participants

<table>
<tr><th colspan="3">Parameters</th><th>NIM</th><th>NIMT</th><th>PTB</th><th>SASO NMCC</th></tr>
<tr><td rowspan="3">Pitch diameter</td><td colspan="2">Measurement device</td><td>Universal Length Measuring Machine

Trimos LABC Nano 350</td><td>Universal Length Measuring Machine

Mahr Rubin 800</td><td>CMM

UPMC 850 CARAT</td><td>CMM</td></tr>
<tr><td rowspan="2">Method</td><td>Plug</td><td>Three wires</td><td>Three wires</td><td rowspan="2">Two-ball</td><td rowspan="2">Two-ball</td></tr>
<tr><td>Ring</td><td>Two-ball</td><td>Two-ball</td></tr>
<tr><td>Pitch</td><td colspan="2">Measurement device</td><td rowspan="2">Thread scanner

IAC Master Scanner 10060</td><td rowspan="2">Contour Measuring Machine Taylor Hobson, Form Talysurf 120</td><td rowspan="2">CMM</td><td>CMM</td></tr>
<tr><td>Thread angle (flank angles)</td><td colspan="2">Measurement device</td><td>---</td></tr>
</table>

7.3 Measurement results reported by participants

Table 7- 1 Reported measurement results and uncertainty (k=1) of thread plug M6 x 1

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Measured value	u	Measured value	u	Measured value	u	Measured value	u
Pitch diameter $2a$-d_2 / mm	5.3634	0.0010	5.3643	0.00085	-	-	5.36174	0.00100
Simple pitch Diameter 1a-d_2 / mm	5.3637	0.0010	5.3642	0.00075	5.3646	0.0010	5.36181	0.00090
Pitch diameter $2b$-d_2 / mm	5.3635	0.0010	5.3643	0.00085	5.3638	0.0010	-	-
Simple pitch diameter $1b$-d_2 / mm	5.3638	0.0010	5.3642	0.00075	-	-	-	-
α / rad	1.0490 (60°6′12″)	0.0012 (4′8″)	1.0491 (60°6′32″)	0.0010 (3′26″)	1.046923 (59°59′3″)	0.000412 (1′25″)	-	-
β / rad	0.52366 (30°0′13″)	0.00087 (2′59″)	0.5243 (30°2′25″)	0.0017 (5′51″)	0.522543 (29°56′22″)	0.000291 (1′0″)	-	-
γ / rad	0.52535 (30°6′1″)	0.00087 (2′59″)	0.5248 (30°4′8″)	0.0011 (3′47″)	0.524380 (30°2′41″)	0.000291 (1′0″)	-	-
P / mm	0.9996	0.0004	1.0001	0.0009	0.9992	0.00025	0.99992	0.0005

Table 7- 2 Reported measurement results and uncertainty (k=1) of thread plug M10 x 2

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Measured value	u	Measured value	u	Measured value	u	Measured value	u
Pitch diameter $2a$-d_2 / mm	8.7176	0.0010	8.71939	0.0009	-	-	8.71207	0.00112
Simple pitch Diameter 1a-d_2 / mm	8.7174	0.0010	8.71881	0.00075	8.7172	0.0010	8.71221	0.00103
Pitch diameter $2b$-d_2 / mm	8.7178	0.0010	8.71937	0.0009	8.7182	0.0010	-	-
Simple pitch diameter $1b$-d_2 / mm	8.7177	0.0010	8.71859	0.00075	-	-	-	-

α / rad	1.04352 (59°47′21″)	0.00062 (2′8″)	1.0435 (59°47′17″)	0.0008 (2′45″)	1.042618 (59°44′15″)	0.000412 (1′25″)	-	-
β / rad	0.52094 (29°50′52″)	0.00044 (1′31″)	0.5211 (29°51′25″)	0.0020 (6′53″)	0.521326 (29°52′11″)	0.000291 (1′0″)	-	-
γ / rad	0.52258 (29°56′30″)	0.00044 (1′31″)	0.5224 (29°55′53″)	0.0017 (5′51″)	0.521292 (29°52′4″)	0.000291 (1′0″)	-	-
P / mm	2.0002	0.0004	2.0007	0.00095	1.9998	0.00025	1.99984	0.0005

Table 7- 3 Reported measurement results and uncertainty (k=1) of thread plug M12 x 1.75

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Measured value	u	Measured value	u	Measured value	u	Measured value	u
Pitch diameter $2a$-d_2 / mm	10.8754	0.0010	10.8768	0.0009	-	-	10.87412	0.00100
Simple pitch Diameter 1a-d_2 / mm	10.8754	0.0011	10.8764	0.00075	10.8759	0.0010	10.87439	0.00090
Pitch diameter $2b$-d_2 / mm	10.8752	0.0010	10.8768	0.0009	10.8755	0.0010	-	-
Simple pitch diameter $1b$-d_2 / mm	10.8751	0.0010	10.8764	0.00075	-	-	-	-
α / rad	1.04635 (59°57′5″)	0.00072 (2′29″)	1.0464 (59°57′15″)	0.0008 (2′45″)	1.045864 (59°55′25″)	0.000412 (1′25″)	-	-
β / rad	0.52116 (29°51′37″)	0.00051 (1′45″)	0.5222 (29°55′11″)	0.0011 (3′47″)	0.521738 (29°53′36″)	0.000291 (1′0″)	-	-
γ / rad	0.52518 (30°5′26″)	0.00051 (1′45″)	0.5242 (30°2′4″)	0.0010 (3′26″)	0.524126 (30°1′49″)	0.000291 (1′0″)	-	-
P / mm	1.7499	0.0004	1.7503	0.0009	1.7496	0.00025	1.74969	0.0005

Table 7- 4 Reported measurement results and uncertainty (k=1) of thread plug M36 x 1.5

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Measured value	u	Measured value	u	Measured value	u	Measured value	u

Pitch diameter $2a$-d_2 / mm	35.0388	0.0010	35.0406	0.00085	-	-	35.04114	0.00100
Simple pitch Diameter 1a-d_2 / mm	35.0387	0.0010	35.0404	0.00075	35.0400	0.0010	35.04104	0.00090
Pitch diameter $2b$-d_2 / mm	35.0389	0.0010	35.0406	0.00085	35.0402	0.0010	-	-
Simple pitch diameter $1b$-d_2 / mm	35.0388	0.0010	35.0403	0.00075	-	-	-	-
α / rad	1.04912 (60°6′37″)	0.00082 (2′49″)	1.0498 (60°8′57″)	0.0008 (2′45″)	1.047947 (60°2′35″)	0.000412 (1′25″)	-	-
β / rad	0.52368 (30°0′17″)	0.00058 (2′0″)	0.5242 (30°2′4″)	0.0009 (3′6″)	0.523707 (30°0′22″)	0.000291 (1′0″)	-	-
γ / rad	0.52544 (30°6′20″)	0.00058 (2′0″)	0.5256 (30°6′53″)	0.0008 (2′45″)	0.524241 (30°2′12″)	0.000291 (1′0″)	-	-
P / mm	1.5001	0.0004	1.5003	0.00085	1.5001	0.00025	1.50012	0.0005

Table 7- 5 Reported measurement results and uncertainty (k=1) of thread Ring M18 x 2.5

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Measured value	u	Measured value	u	Measured value	u	Measured value	u
Pitch diameter $2a$-d_2 / mm	16.3255	0.0010	16.3277	0.0010	-	-	16.31721	0.00100
Simple pitch Diameter 1a-d_2 / mm	16.3262	0.0010	16.3268	0.00075	16.3267	0.0010	16.31814	0.00090
Pitch diameter $2b$-d_2 / mm	16.3255	0.0010	16.3278	0.0009	16.3258	0.0010	-	-
Simple pitch diameter $1b$-d_2 / mm	16.3262	0.0010	16.3269	0.00075	-	-	-	-
α / rad	1.04700 (59°59′19″)	0.00062 (2′8″)	1.0478 (60°2′4″)	0.0008 (2′45″)	1.046223 (59°56′39″)	0.000412 (1′25″)	-	-
β / rad	0.52418 (30°2′0″)	0.00044 (1′31″)	0.5250 (30°4′49″)	0.0016 (5′30″)	0.523062 (29°58′9″)	0.000291 (1′0″)	-	-

γ / rad	0.52282 (29°57′19″)	0.00044 (1′31″)	0.5228 (29°57′15″)	0.0018 (6′11″)	0.523161 (29°58′30″)	0.000291 (1′0″)	-	-
P / mm	2.5008	0.0004	2.4989	0.0009	2.5009	0.00025	2.50108	0.0005

Table 7- 6 Reported measurement results and uncertainty (k=1) of thread Ring M30 x 1.5

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Measured value	u	Measured value	u	Measured value	u	Measured value	u
Pitch diameter $2a$-d_2 / mm	28.9760	0.0010	28.9765	0.0009	-	-	28.52243	0.00100
Simple pitch Diameter 1a-d_2 / mm	28.9760	0.0010	28.9765	0.00075	28.9782	0.0010	28.52266	0.00090
Pitch diameter $2b$-d_2 / mm	28.9760	0.0010	28.9766	0.0009	28.9779	0.0010	-	-
Simple pitch diameter $1b$-d_2 / mm	28.9761	0.0010	28.9765	0.00075	-	-	-	-
α / rad	1.04695 (59°59′9″)	0.00082 (2′49″)	1.0466 (59°57′57″)	0.0008 (2′45″)	1.046419 (59°57′19″)	0.000412 (1′25″)	-	-
β / rad	0.52226 (29°55′24″)	0.00058 (2′0″)	0.5226 (29°56′34″)	0.0009 (3′6″)	0.522279 (29°55′28″)	0.000291 (1′0″)	-	-
γ / rad	0.52469 (30°3′45″)	0.00058 (2′0″)	0.5241 (30°1′43″)	0.0008 (2′45″)	0.524140 (30°1′52″)	0.000291 (1′0″)	-	-
P / mm	1.5001	0.0004	1.4999	0.0009	1.5004	0.00025	1.50026	0.0005

Table 7- 7 Reported measurement results and uncertainty (k=1) of thread Ring M42 x 4.5

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Measured value	u	Measured value	u	Measured value	u	Measured value	u
Pitch diameter $2a$-d_2 mm	38.9861	0.0010	38.9861	0.0009	-	-	38.98944	0.00153
Simple pitch Diameter 1a-d_2 mm	38.9861	0.0011	38.9863	0.00075	38.9906	0.0010	38.98998	0.00146
Pitch diameter	38.9860	0.0010	38.9861	0.0009	38.9895	0.0010	-	-

$2b\text{-}d_2$ mm								
Simple pitch diameter $1b\text{-}d_2$ mm	38.9861	0.0011	38.9863	0.00075	-	-	-	-
α rad	1.04701 (59°59′21″)	0.00062 (2′8″)	1.0473 (60°0′21″)	0.0010 (3′26″)	1.047308 (60°0′23″)	0.000412 (1′25″)	-	-
β rad	0.52308 (29°58′13″)	0.00044 (1′31″)	0.5237 (30°0′21″)	0.0009 (3′6″)	0.523655 (30°0′12″)	0.000291 (1′0″)	-	-
γ rad	0.52392 (30°1′6″)	0.00044 (1′31″)	0.5236 (30°0′0″)	0.0007 (2′24″)	0.523653 (30°0′11″)	0.000291 (1′0″)	-	-
P mm	4.5002	0.0004	4.5002	0.0009	4.5013	0.00025	4.50063	0.0005

7.4 Statistical parameters and SCRV

Table 7- 8 Statistical parameters of measurements results (Thread Plug M6 x 1)

Measurand	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	$u_{ext(\bar{x}_w)}$	R_B	R_{Bcirit}
Pitch diameter $2a$-d_2 / mm	5.36328	0.00054	0.00075	1.38311	1.73205
Simple pitch Diameter $1a$-d_2 / mm	5.36359	0.00045	0.00061	1.36691	1.62265
Pitch diameter $2b$-d_2 / mm	5.36392	0.00054	0.00024	0.44193	1.73205
Simple pitch diameter $1b$-d_2 / mm	5.36406	0.00060	0.00019	0.32000	1.95664
α / rad	1.048341 (60°3′56″)	0.000538 (1′51″)	0.000916 (3′9″)	1.70063	1.73205
β / rad	0.523501 (29°59′40″)	0.000644 (2′13″)	0.000642 (2′12″)	0.99629	1.73205
γ / rad	0.524843 (30°4′17″)	0.000477 (1′38″)	0.000321 (1′6″)	0.67229	1.73205
P / mm	0.99944	0.00019	0.00018	0.92025	1.62265

Table 7- 9 Statistical parameters of measurements results (Thread Plug M10 x 2)

Measurand	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	$u_{ext(\bar{x}_w)}$	R_B	R_{Bcirit}
Pitch diameter $2a$-d_2 / mm	8.71859	0.00067	0.00089	1.33050	1.95664
Simple pitch Diameter $1a$-d_2 / mm	8.71801	0.00051	0.00054	1.04067	1.73205
Pitch diameter $2b$-d_2 / mm	8.71852	0.00056	0.00048	0.86970	1.73205
Simple pitch diameter $1b$-d_2 / mm	8.71827	0.00060	0.00043	0.71200	1.95664
α / rad	1.043213 (59°46′18″)	0.000364 (1′15″)	0.000350 (1′12″)	0.95979	1.73205
β / rad	0.521122 (29°51′29″)	0.000689 (2′22″)	0.000139 (0′29″)	0.20116	1.73205
γ / rad	0.522091 (29°54′49″)	0.000593 (2′2″)	0.000504 (1′44″)	0.84961	1.73205
P / mm	1.99993	0.00019	0.00013	0.68678	1.62265

Table 7- 10 Statistical parameters of measurements results (Thread Plug M12 x 1.75)

Measurand	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	$u_{ext(\bar{x}_w)}$	R_B	R_{Bcirit}
Pitch diameter $2a$-d_2 / mm	10.87554	0.00056	0.00079	1.41351	1.73205
Simple pitch Diameter $1a$-d_2 / mm	10.87561	0.00045	0.00046	1.01119	1.62265
Pitch diameter $2b$-d_2 / mm	10.87590	0.00056	0.00051	0.90828	1.73205

Simple pitch diameter $1b$-d_2 / mm	10.87593	0.00060	0.00062	1.04000	1.95664
α / rad	1.046205 (59°56′35″)	0.000384 (1′19″)	0.000204 (0′42″)	0.53210	1.73205
β / rad	0.521699 (29°53′28″)	0.000416 (1′26″)	0.000202 (0′42″)	0.48569	1.73205
γ / rad	0.524502 (30°3′6″)	0.000387 (1′20″)	0.000325 (1′7″)	0.84196	1.73205
P / mm	1.74971	0.00019	0.00010	0.53241	1.62265

Table 7- 11 Statistical parameters of measurements results (Thread Plug M36 x 1.5)

Measurand	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	$u_{ext(\bar{x}_w)}$	R_B	R_{Bcirit}
Pitch diameter $2a$-d_2 / mm	35.04023	0.00054	0.00067	1.23743	1.73205
Simple pitch Diameter $1a$-d_2 / mm	35.04014	0.00045	0.00046	1.03495	1.62265
Pitch diameter $2b$-d_2 / mm	35.03998	0.00054	0.00051	0.93457	1.73205
Simple pitch diameter $1b$-d_2 / mm	35.03976	0.00060	0.00072	1.20000	1.95664
α / rad	1.048956 (60°6′3″)	0.000406 (1′24″)	0.000632 (2′10″)	1.55796	1.73205
β / rad	0.523862 (30°0′54″)	0.000370 (1′16″)	0.000128 (0′26″)	0.34599	1.73205
γ / rad	0.525094 (30°5′8″)	0.000343 (1′11″)	0.000535 (1′50″)	1.55700	1.73205
P / mm	1.50011	0.00019	0.00003	0.13211	1.62265

Table 7- 12 Statistical parameters of measurements results (Thread Ring M18 x 2.5)

Measurand	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	$u_{ext(\bar{x}_w)}$	R_B	R_{Bcirit}
Pitch diameter $2a$-D_2 / mm	16.32660	0.00071	0.00110	1.55563	1.95664
Simple pitch Diameter $1a$- D_2 / mm	16.32661	0.00051	0.00018	0.34662	1.73205
Pitch diameter $2b$- D_2 / mm	16.32647	0.00056	0.00074	1.33672	1.73205
Simple pitch diameter $1b$- D_2 / mm	16.32665	0.00060	0.00034	0.56000	1.95664
α / rad	1.047008 (59°59′21″)	0.000364 (1′15″)	0.000479 (1′39″)	1.31418	1.73205
β / rad	0.524081 (30°1′39″)	0.000562 (1′56″)	0.000603 (2′4″)	1.07407	1.73205
γ / rad	0.522927 (29°57′41″)	0.000625 (2′9″)	0.000143 (0′29″)	0.22934	1.73205
P / mm	2.50081	0.00019	0.00024	1.28131	1.62265

Table 7- 13 Statistical parameters of measurements results (Thread Ring M30 x 1.5)

Measurand	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	$u_{ext(\bar{x}_w)}$	R_B	R_{Bcirit}
Pitch diameter $2a$-D_2 / mm	28.97628	0.00067	0.00025	0.37165	1.95664
Simple pitch Diameter $1a$- D_2 / mm	28.97682	0.00051	0.00060	1.17448	1.73205
Pitch diameter $2b$- D_2 / mm	28.97682	0.00056	0.00054	0.97430	1.73205
Simple pitch diameter $1b$- D_2 / mm	28.97636	0.00060	0.00019	0.32000	1.95664
α / rad	1.046656 (59°58′08″)	0.000406 (1′24″)	0.000161 (0′33″)	0.39739	1.73205
β / rad	0.522380 (29°55′49″)	0.000370 (1′16″)	0.000083 (0′17″)	0.22518	1.73205
γ / rad	0.524310 (30°2′27″)	0.000343 (1′11″)	0.000160 (0′33″)	0.46671	1.73205
P / mm	1.50029	0.00019	0.00009	0.45114	1.62265

Table 7- 14 Statistical parameters of measurements results (Thread Ring M42 x 4.5)

Measurand	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	$u_{ext(\bar{x}_w)}$	R_B	R_{Bcirit}
Pitch diameter $2a$-D_2 / mm	38.98664	0.00061	0.00087	1.41434	1.73205
Simple pitch Diameter $1a$- D_2 / mm	38.98681	0.00057	0.00095	1.67231	1.73205
Pitch diameter $2b$- D_2 / mm	38.98606	0.00067	0.00005	0.07433	1.95664
Simple pitch diameter $1b$- D_2 / mm	38.98624	0.00062	0.00009	0.15022	1.95664
α / rad	1.047206 (60°0′2″)	0.000416 (1′26″)	0.000095 (0′20″)	0.22776	1.73205
β / rad	0.523478 (29°59′35″)	0.000348 (1′12″)	0.000185 (0′38″)	0.53253	1.73205
γ / rad	0.523724 (30°0′26″)	0.000292 (1′0″)	0.000087 (0′18″)	0.29857	1.73205
P / mm	4.50090	0.00019	0.00028	1.47409	1.62265

7.5 Overview of measurement results with respect to SCRV reference values

In the following measurement results analysis there are two kinds of situation for |En|>1. The red colour indicates that the measurement data is excluded from calculation of SCRV. And the yellow colour indicates the measurement data is included in calculation of SCRV.

Diff	*En*
$x_i - \bar{x}_w$	*En* value

Diff	*En*

Consistent Result, |*En*|<1

Diff	*En*

Inconsistent Result, |*En*|>1,

Excluded from calculation of SCRV

Diff	*En*

Inconsistent Result, |*En*|>1

Table 7- 15 Thread plug M6×1- Measurement Results with respect to SRCV

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Diff	E_N	*Diff*	E_N	*Diff*	E_N	*Diff*	E_N
Pitch diameter $2a\text{-}d_2$ / mm	0.0001	0.07	0.0010	0.78	-	-	-0.00154	-0.92
Simple pitch Diameter $1a\text{-}d_2$ / mm	0.0001	0.06	0.0006	0.51	0.0010	0.56	-0.00178	-1.14
Pitch diameter $2b\text{-}d_2$ / mm	-0.0004	-0.25	0.0004	0.29	-0.0001	-0.07	-	-
Simple pitch diameter $1b\text{-}d_2$ / mm	-0.0003	-0.16	0.0001	0.16	-	-	-	-
α / rad	0.0007 (2′24″)	0.38	0.0008 (2′45″)	0.48	-0.00142 (-4′53″)	-1.20	-	-
β / rad	0.00016 (0′33″)	0.10	0.0008 (2′45″)	0.34	-0.000958 (-3′18″)	-0.72	-	-
γ / rad	0.00051 (1′45″)	0.37	0.0000 (-0′9″)	-0.03	-0.000463 (-1′36″)	-0.46	-	-
P / mm	0.0002	0.23	0.0007	0.38	-0.0002	-0.73	0.00048	0.52

Table 7- 16 Thread plug M10×2- Measurement Results with respect to SRCV

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Diff	E_N	*Diff*	E_N	*Diff*	E_N	*Diff*	E_N
Pitch diameter $2a\text{-}d_2$ / mm	-0.0010	-0.67	0.0008	0.67	-	-	-0.00652	-2.50
Simple pitch Diameter $1a\text{-}d_2$ / mm	-0.0006	-0.36	0.0008	0.73	-0.0008	-0.47	-0.00580	-2.52
Pitch diameter $2b\text{-}d_2$ / mm	-0.0007	-0.43	0.0008	0.60	-0.0003	-0.19	-	-
Simple pitch diameter $1b\text{-}d_2$ / mm	-0.0006	-0.36	0.0003	0.36	-	-	-	-
α / rad	0.00031 (1′4″)	0.30	0.0003 (1′2″)	0.24	-0.000595 (-2′3″)	-0.68	-	-

β / rad	-0.00018 (-0′37″)	-0.12	0.0000 (-0′5″)	-0.01	0.000204 (0′42″)	0.14	-	-
γ / rad	0.00049 (1′41″)	0.38	0.0003 (1′2″)	0.13	-0.000799 (-2′45″)	-0.65	-	-
P / mm	0.0003	0.38	0.0008	0.41	-0.0001	-0.41	-0.00009	-0.10

Table 7- 17 Thread plug M12×1.75- Measurement Results with respect to SRCV

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Diff	E_N	*Diff*	E_N	*Diff*	E_N	*Diff*	E_N
Pitch diameter $2a\text{-}d_2$ / mm	-0.0001	-0.08	0.0013	0.89	-	-	-0.00142	-0.85
Simple pitch Diameter $1a\text{-}d_2$ / mm	-0.0002	-0.11	0.0008	0.66	0.0003	0.16	-0.00122	-0.79
Pitch diameter $2b\text{-}d_2$ / mm	-0.0007	-0.42	0.0009	0.63	-0.0004	-0.24	-	-
Simple pitch diameter $1b\text{-}d_2$ / mm	-0.0008	-0.52	0.0005	0.52	-	-	-	-
α / rad	0.00015 (0′31″)	0.13	0.0002 (0′41″)	0.16	-0.000341 (-1′10″)	-0.38	-	-
β / rad	-0.00054 (-1′51″)	-0.53	0.0005 (1′43″)	0.33	0.000039 (0′8″)	0.04	-	-
γ / rad	0.00068 (2′20″)	0.70	-0.0003 (-1′2″)	-0.22	-0.000376 (-1′18″)	-0.45	-	-
P / mm	0.00019	0.27	0.0006	0.33	-0.0001	-0.35	-0.00002	-0.02

Table 7- 18 Thread plug M36×1.5- Measurement Results with respect to SRCV

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Diff	E_N	*Diff*	E_N	*Diff*	E_N	*Diff*	E_N
Pitch diameter $2a\text{-}d_2$ / mm	-0.0014	-0.85	0.0004	0.28	-	-	0.00091	0.54
Simple pitch Diameter $1a\text{-}d_2$ / mm	-0.0014	-0.80	0.0003	0.22	-0.0001	-0.08	0.00090	0.58
Pitch diameter	-0.0011	-0.64	0.0006	0.47	0.0002	0.13	-	-

$2b$-d_2 / mm								
Simple pitch diameter $1b$-d_2 / mm	-0.0010	-0.60	0.0005	0.60	-	-	-	-
α / rad	0.00016 (0′33″)	0.13	0.0008 (2′45″)	0.69	-0.001009 (-3′28″)	-1.07	-	-
β / rad	-0.00018 (-0′37″)	-0.18	0.0003 (1′2″)	0.26	-0.000155 (-0′32″)	-0.19	-	-
γ / rad	0.00035 (1′12″)	0.36	0.0005 (1′43″)	0.44	-0.000853 (-2′56″)	-1.12	-	-
P / mm	0.0000	-0.02	0.0002	0.11	0.0000	-0.04	0.00001	0.01

Table 7- 19 Thread Ring M18×2.5- Measurement Results with respect to SRCV

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Diff	E_N	*Diff*	E_N	*Diff*	E_N	*Diff*	E_N
Pitch diameter $2a$-D_2 / mm	-0.0011	-0.78	0.0011	0.78	-	-	-0.00939	-3.83
Simple pitch Diameter $1a$- D_2 / mm	-0.0004	-0.24	0.0002	0.17	0.0001	0.05	-0.00847	-4.09
Pitch diameter $2b$- D_2 / mm	-0.0010	-0.58	0.0013	0.94	-0.0007	-0.40	-	-
Simple pitch diameter $1b$- D_2 / mm	-0.0004	-0.28	0.0003	0.28	-	-	-	-
α / rad	-0.00001 (-0′2″)	-0.01	0.0008 (2′45″)	0.67	-0.000785 (-2′42″)	-0.90	-	-
β / rad	0.00010 (0′21″)	0.08	0.0009 (3′6″)	0.43	-0.001019 (-3′30″)	-0.87	-	-
γ / rad	-0.00011 (-0′23″)	-0.08	-0.0001 (-0′21″)	-0.05	0.000234 (0′48″)	0.18	-	-
P / mm	0.0000	-0.02	-0.0019	-1.09	0.0001	0.27	0.00027	0.29

Table 7- 20 Thread Ring M30×1.5- Measurement Results with respect to SRCV

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Diff	E_N	*Diff*	E_N	*Diff*	E_N	*Diff*	E_N

Pitch diameter $2a$-D_2 / mm	-0.0003	-0.19	0.0002	0.19	-	-	-0.45385	-188.61
Simple pitch Diameter $1a$- D_2 / mm	-0.0008	-0.48	-0.0003	-0.29	0.0014	0.81	-0.45416	-219.04
Pitch diameter $2b$- D_2 / mm	-0.0008	-0.49	-0.0002	-0.15	0.0011	0.65	-	-
Simple pitch diameter $1b$- D_2 / mm	-0.0003	-0.16	0.0001	0.16	-	-	-	-
α / rad	0.00029 (1′0″)	0.24	-0.0001 (-0′21″)	-0.05	-0.000237 (-0′49″)	-0.25	-	-
β / rad	-0.00012 (-0′25″)	-0.12	0.0002 (0′41″)	0.17	-0.000101 (-0′21″)	-0.12	-	-
γ / rad	0.00038 (1′18″)	0.40	-0.0002 (-0′41″)	-0.18	-0.000170 (-0′35″)	-0.22	-	-
P / mm	-0.0002	-0.27	-0.0004	-0.22	0.0001	0.34	-0.00003	-0.03

Table 7- 21 Thread Ring M42×4.5- Measurement Results with respect to SRCV

MEASURAND	NIM		NIMT		PTB		SASO NMCC	
	Diff	E_N	*Diff*	E_N	*Diff*	E_N	*Diff*	E_N
Pitch diameter $2a$-D_2 / mm	-0.0005	-0.34	-0.0005	-0.41	-	-	0.00280	1.00
Simple pitch Diameter $1a$- D_2 / mm	-0.0007	-0.38	-0.0005	-0.52	0.0038	1.65	0.00317	1.18
Pitch diameter $2b$- D_2 / mm	-0.0001	-0.04	0.0000	0.04	0.0034	1.43	-	-
Simple pitch diameter $1b$- D_2 / mm	-0.0001	-0.08	0.0001	0.08	-	-	-	-
α / rad	-0.00020 (-0′41″)	-0.18	0.0001 (0′21″)	0.07	0.000102 (0′21″)	0.11	-	-
β / rad	-0.00040 (-1′23″)	-0.46	0.0002 (0′41″)	0.18	0.000177 (0′37″)	0.23	-	-
γ / rad	0.00020 (0′41″)	0.25	-0.0001 (-0′21″)	-0.12	-0.000071 (-0′15″)	-0.11	-	-
P / mm	-0.0007	-1.00	-0.0007	-0.40	0.0004	1.23	-0.00027	-0.30

8 Graphical Representation

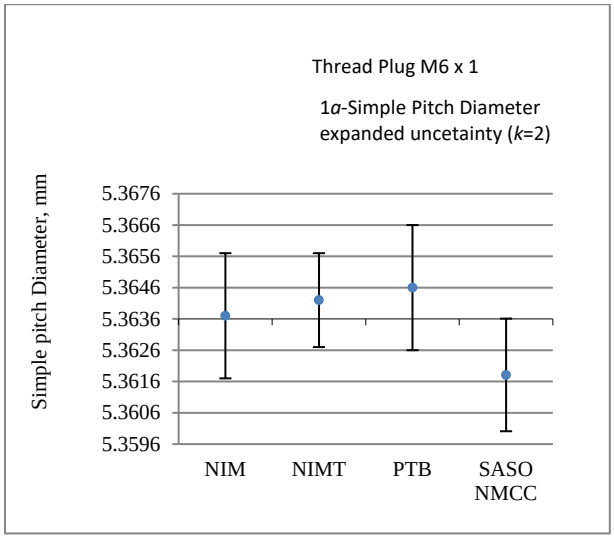
8.1 Thread plug M6×1

Table 8- 1 Measurement results of simple pitch diameter (1*a*)

Participants	1*a* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (k=1) / mm	$x_i - \bar{x}_w$ mm	En
NIM	5.3637	0.0010	0.0001	0.06
NIMT	5.3642	0.00075	0.0006	0.51
PTB	5.3646	0.0010	0.0010	0.56
SASO NMCC	5.36181	0.00090	-0.00178	-1.14
$\bar{x}_w$	5.36359	0.00045		
n	4			
$u_{ext(\bar{x}_w)}$	0.00061			
R_B	1.36691			
R_{Bcrit}	1.62265			

Table 8- 2 Measurement results of pitch diameter (2*a*)

Participants	2*a* Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	5.3634	0.0010	0.0001	0.07
NIMT	5.3643	0.00085	0.0010	0.78
PTB	-	-	-	-
SASO NMCC	5.36174	0.00100	-0.00154	-0.92
$\bar{x}_w$	5.36328	0.00054		
n	3			
$u_{ext(\bar{x}_w)}$	0.00075			
R_B	1.38311			
R_{Bcrit}	1.73205			



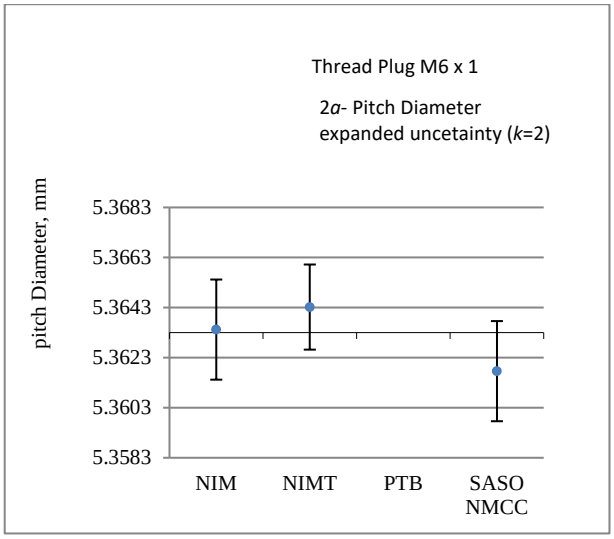
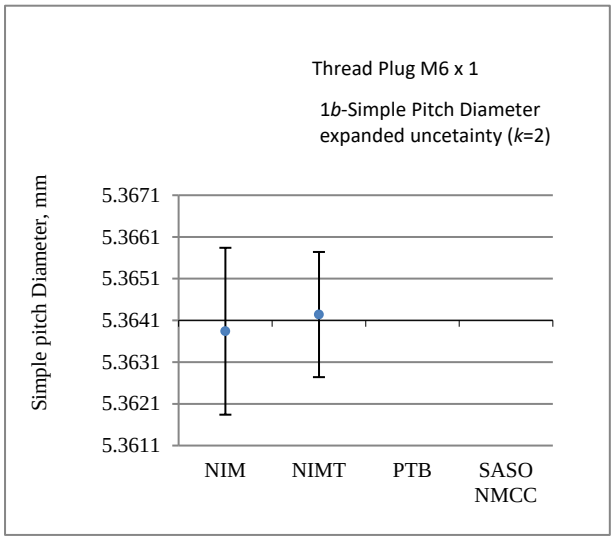


Table 8- 3 Measurement results of simple pitch diameter (1*b*)

Participants	1*b* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	5.3638	0.0010	-0.0003	-0.16
NIMT	5.3642	0.00075	0.0001	0.16
PTB	-	-	-	-
SASO NMCC	-	-	-	-
$\bar{x}_w$	5.36406	0.00060		
n	2			
$u_{ext(\bar{x}_w)}$	0.00019			
R_B	0.32000			
R_{Bcrit}	1.95664			

Table 8- 4 Measurement results of pitch diameter (2*b*)

Participants	2*b* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	5.3635	0.0010	-0.0004	-0.25
NIMT	5.3643	0.00085	0.0004	0.29
PTB	5.3638	0.0010	-0.0001	-0.07
SASO NMCC	-	-	-	-
$\bar{x}_w$	5.36392	0.00054		
n	3			
$u_{ext(\bar{x}_w)}$	0.00024			
R_B	0.44193			
R_{Bcrit}	1.73205			



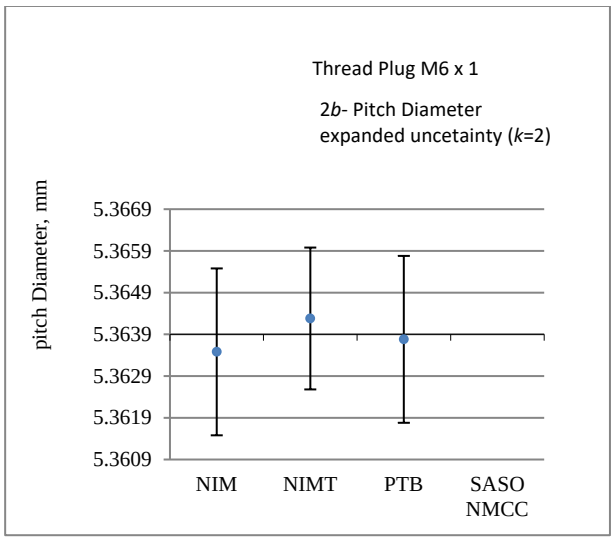
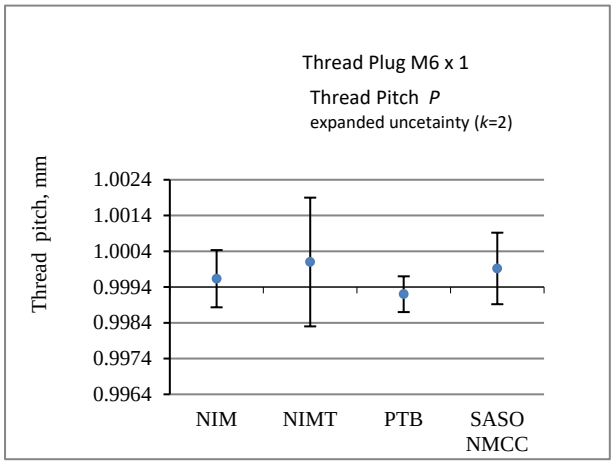


Table 8- 5 Measurement results of Thread pitch

Participants	Thread pitch P			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	0.9996	0.0004	0.0002	0.23
NIMT	1.0001	0.0009	0.0007	0.38
PTB	0.9992	0.00025	-0.0002	-0.73
SASO NMCC	0.99992	0.0005	0.00048	0.52
$\bar{x}_w$	0.99944	0.00019		
n	4			
$u_{ext(\bar{x}_w)}$	0.00018			
R_B	0.92025			
R_{Bcrit}	1.62265			

Table 8- 6 Measurement results of Thread angle

Participants	Thread angle α			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	1.0490 (60°6′12″)	0.0012 (4′8″)	0.0007 (2′24″)	0.38
NIMT	1.0491 (60°6′32″)	0.0010 (3′26″)	0.0008 (2′45″)	0.48
PTB	1.046923 (59°59′3″)	0.000412 (1′25″)	-0.001418 (-4′52″)	-1.20
SASO NMCC	-	-	-	-
$\bar{x}$	1.048341 (60°3′56″)	0.000538 (1′51″)		
n	3			
$u_{ext(\bar{x})}$	0.000916 (3′9″)			
R_B	1.70063			
R_{Bcrit}	1.73205			



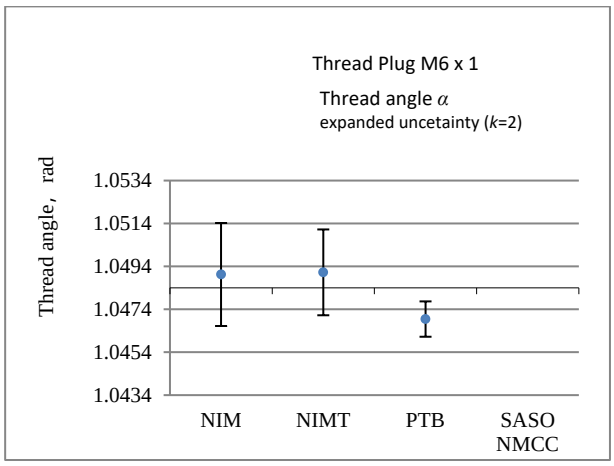
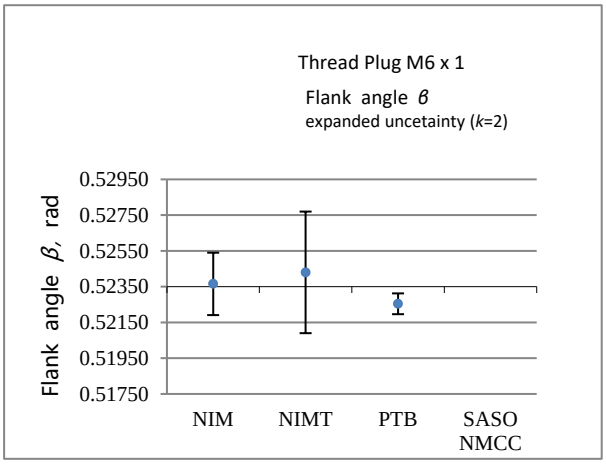


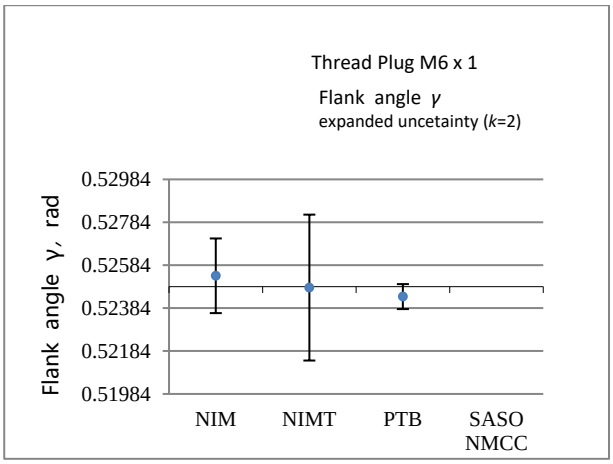
Table 8- 7 Measurement results of flank angle β

Participants	Flank angle β			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52366 (30°0′13″)	0.00087 (2′59″)	0.00016 (33″)	0.10
NIMT	0.5243 (30°2′25″)	0.0017 (5′51″)	0.0008 (2′45″)	0.34
PTB	0.522543 (29°56′22″)	0.000291 (1′0″)	-0.000958 (-3′18″)	-0.72
SASO NMCC	-	-	-	-
$\bar{x}$	0.523501 (29°59′40″)	0.000644 (2′13″)		
n	3			
$u_{ext(\bar{x})}$	0.000642 (2′12″)			
R_B	0.99629			
R_{Bcrit}	1.73205			

Table 8- 8 Measurement results of flank angle γ

Participants	Flank angle γ			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52535 (30°6′1″)	0.00087 (2′59″)	0.00051 (1′45″)	0.37
NIMT	0.5248 (30°4′8″)	0.0011 (3′47″)	0.0000 (0″)	-0.03
PTB	0.524380 (30°2′41″)	0.000291 (1′0″)	-0.000463 (-1′36″)	-0.46
SASO NMCC	-	-	-	-
$\bar{x}$	0.524843 (30°4′17″)	0.000477 (1′38″)		
n	3			
$u_{ext(\bar{x})}$	0.000321 (1′6″)			
R_B	0.67229			
R_{Bcrit}	1.73205			





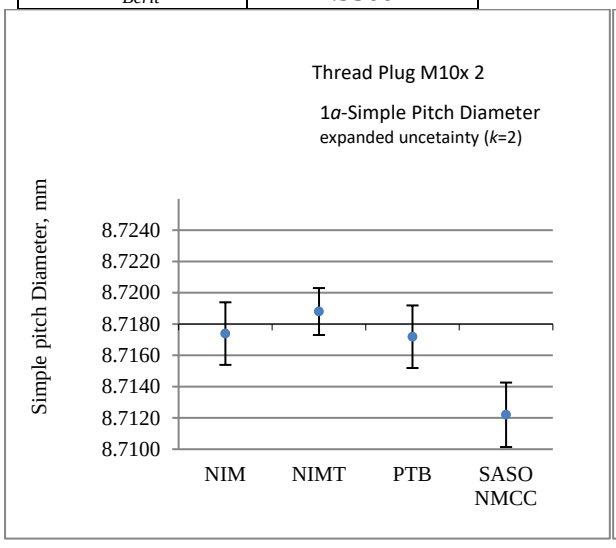
8.2 Thread plug M10×2

Table 8- 9 Measurement results of simple pitch diameter (1*a*)

Participants	1*a* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	8.7174	0.0010	-0.0006	-0.36
NIMT	8.71881	0.00075	0.00080	0.73
PTB	8.7172	0.0010	-0.0008	-0.47
SASO NMCC	8.71221	0.00103	-0.00580	-2.52*
$\bar{x}_w$	8.71801	0.00051		
n	3		Excluded from the SCRV	
$u_{ext(\bar{x}_w)}$	0.00054			*En* *
R_B	1.04067		SASO NMCC	-2.52*
R_{Bcrit}	1.73205			

Table 8- 10 Measurement results of pitch diameter (2*a*)

Participants	2*a* Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	8.7176	0.0010	-0.0010	-0.67
NIMT	8.71939	0.0009	0.00080	0.67
PTB	-	-	-	-
SASO NMCC	8.71207	0.00112	-0.00652	-2.50*
$\bar{x}_w$	8.71859	0.00067		
n	2		Excluded from the SCRV	
$u_{ext(\bar{x}_w)}$	0.00089			*En* *
R_B	1.33050		SASO NMCC	-2.50*
R_{Bcrit}	1.95664			



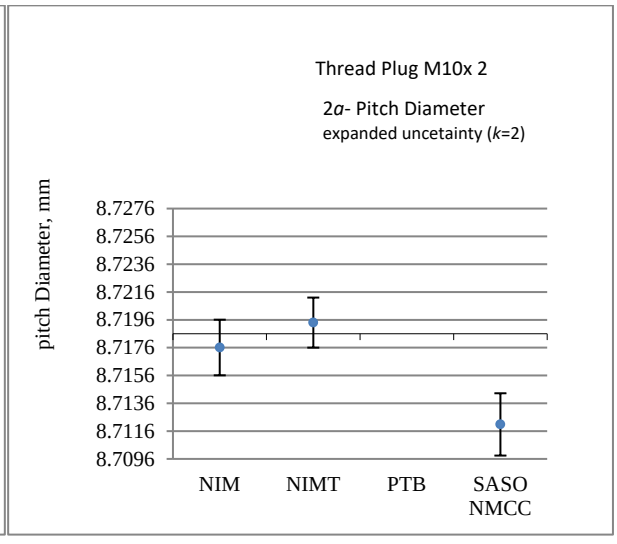
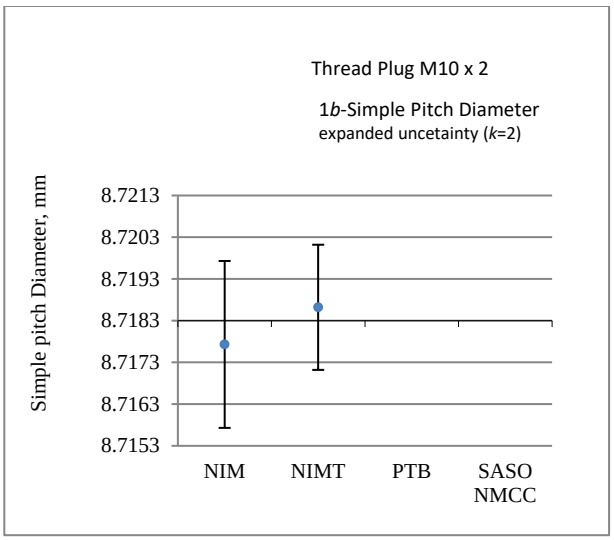


Table 8- 11 Measurement results of simple pitch diameter (1*b*)

Participants	1*b* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	8.7177	0.0010	-0.0006	-0.36
NIMT	8.71859	0.00075	0.00032	0.36
PTB	-	-	-	-
SASO NMCC	-	-	-	-
$\bar{x}_w$	8.71827	0.00060		
n	2			
$u_{ext(\bar{x}_w)}$	0.00043			
R_B	0.71200			
R_{Bcrit}	1.95664			

Table 8- 12 Measurement results of pitch diameter (2*b*)

Participants	2*b* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	8.7178	0.0010	-0.0007	-0.43
NIMT	8.71937	0.0009	0.0008	0.60
PTB	8.7182	0.0010	-0.0003	-0.19
SASO NMCC	-	-	-	-
$\bar{x}_w$	8.71852	0.00056		
n	3			
$u_{ext(\bar{x}_w)}$	0.00048			
R_B	0.86970			
R_{Bcrit}	1.73205			



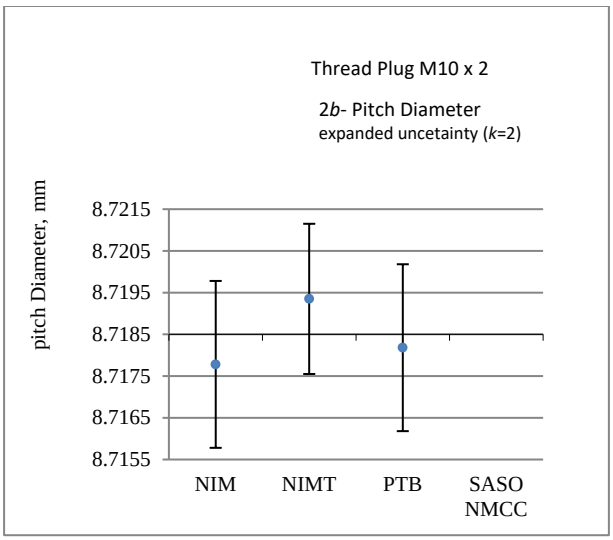
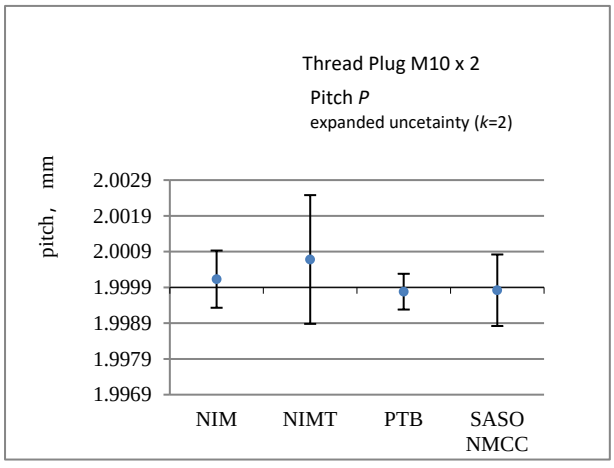


Table 8- 13 Measurement results of Thread pitch

Participants	Thread pitch P			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	2.0002	0.0004	0.0003	0.38
NIMT	2.0007	0.00095	0.0008	0.41
PTB	1.9998	0.00025	-0.0001	-0.41
SASO NMCC	1.99984	0.0005	-0.00009	-0.10
$\bar{x}_w$	1.99993	0.00019		
n	4			
$u_{ext(\bar{x}_w)}$	0.00013			
R_B	0.68678			
R_{Bcrit}	1.62265			

Table 8- 14 Measurement results of Thread angle

Participants	Thread angle α			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	1.04352 (59°47′21″)	0.00062 (2′8″)	0.00031 (1′4″)	0.30
NIMT	1.0435 (59°47′17″)	0.0008 (2′45″)	0.0003 (1′2″)	0.24
PTB	1.042618 (59°44′15″)	0.000412 (1′25″)	-0.000595 (-2′3″)	-0.68
SASO NMCC	-	-	-	-
$\bar{x}$	1.043213 (59°46′18″)	0.000364 (1′15″)		
n	3			
$u_{ext(\bar{x})}$	0.000350 (1′12″)			
R_B	0.95979			
R_{Bcrit}	1.73205			



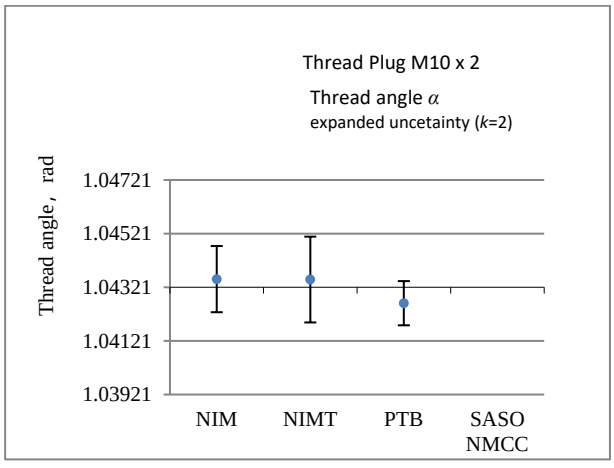
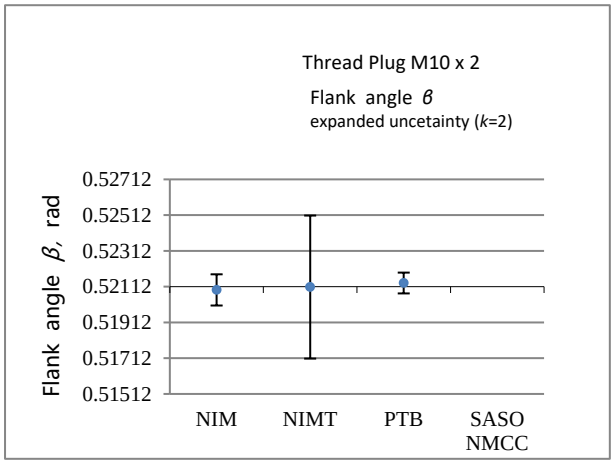


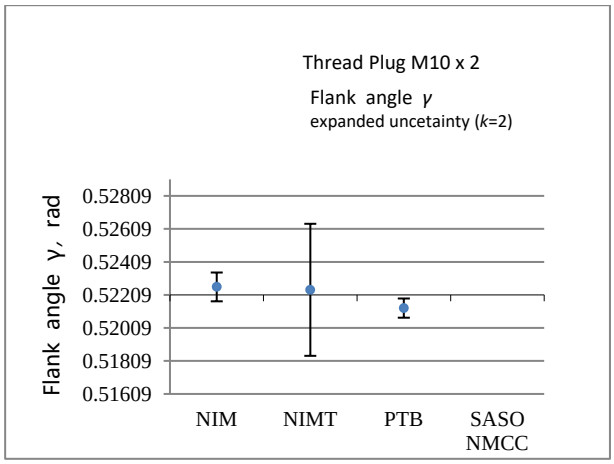
Table 8- 15 Measurement results of flank angle β

Participants	Flank angle β			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52094 (29°50′52″)	0.00044 (1′31″)	-0.00018 (-0′37″)	-0.12
NIMT	0.5211 (29°51′25″)	0.0020 (6′53″)	0.0000 (0″)	-0.01
PTB	0.521326 (29°52′11″)	0.000291 (1′0″)	0.000204 (0′42″)	0.14
SASO NMCC	-	-	-	-
$\bar{x}$	0.521122 (29°51′29″)	0.000689 (2′22″)		
n	3			
$u_{ext(\bar{x})}$	0.000139 (0′29″)			
R_B	0.20116			
R_{Bcrit}	1.73205			

Table 8- 16 Measurement results of flank angleγ

Participants	Flank angle γ			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52258 (29°56′30″)	0.00044 (1′31″)	0.00049 (1′41″)	0.38
NIMT	0.5224 (29°55′53″)	0.0017 (5′51″)	0.0003 (1′2″)	0.13
PTB	0.521292 (29°52′4″)	0.000291 (1′0″)	-0.000799 (-2′45″)	-0.65
SASO NMCC	-	-	-	-
$\bar{x}$	0.522091 (29°54′49″)	0.000593 (2′2″)		
n	3			
$u_{ext(\bar{x})}$	0.000504 (1′44″)			
R_B	0.84961			
R_{Bcrit}	1.73205			





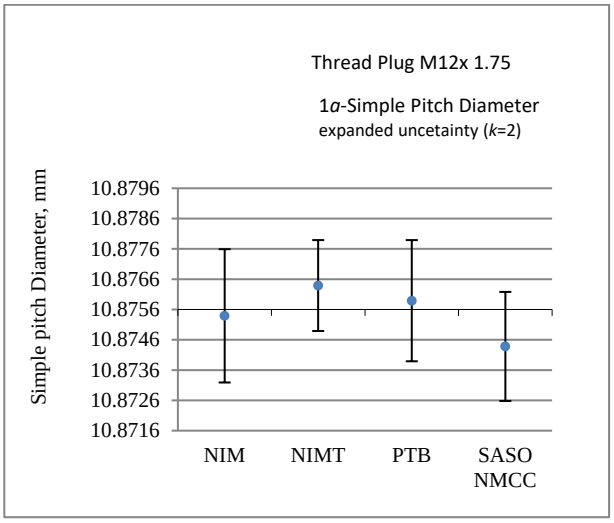
8.3 Thread plug M12×1.75

Table 8- 17 Measurement results of simple pitch diameter (1*a*)

Participants	1*a* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	10.8754	0.0011	-0.0002	-0.11
NIMT	10.8764	0.00075	0.0008	0.66
PTB	10.8759	0.0010	0.0003	0.16
SASO NMCC	10.87439	0.00090	-0.00122	-0.79
$\bar{x}_w$	10.87561	0.00045		
n	4			
$u_{ext(\bar{x}_w)}$	0.00046			
R_B	1.01119			
R_{Bcrit}	1.62265			

Table 8- 18 Measurement results of pitch diameter (2*a*)

Participants	2*a* Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	10.8754	0.0010	-0.0001	-0.08
NIMT	10.8768	0.0009	0.0013	0.89
PTB	-	-	-	-
SASO NMCC	10.87412	0.00100	-0.00142	-0.85
$\bar{x}_w$	10.87554	0.00056		
n	3			
$u_{ext(\bar{x}_w)}$	0.00079			
R_B	1.41351			
R_{Bcrit}	1.73205			



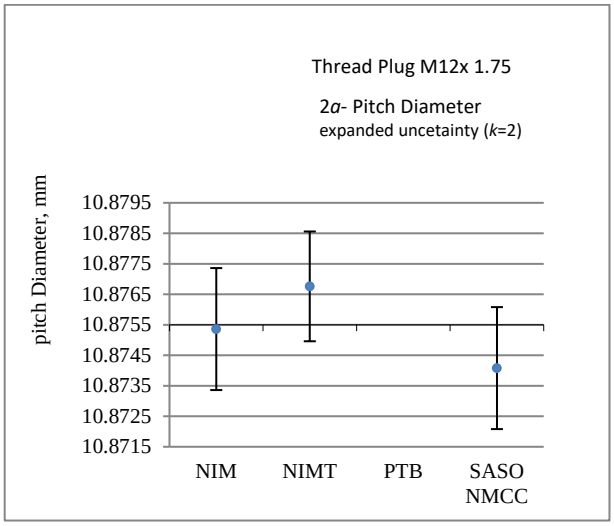
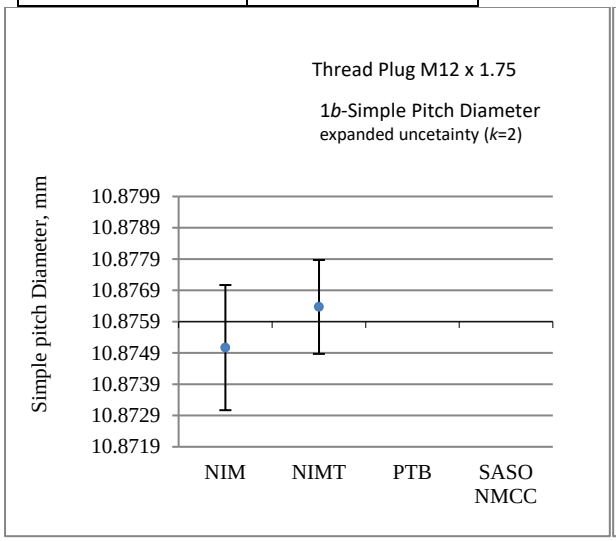


Table 8- 19 Measurement results of simple pitch diameter (1*b*)

Participants	1*b* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	10.8751	0.0010	-0.0008	-0.52
NIMT	10.8764	0.00075	0.0005	0.52
PTB	-	-	-	-
SASO NMCC	-	-	-	-
$\bar{x}_w$	10.87593	0.00060		
n	2			
$u_{ext(\bar{x}_w)}$	0.00062			
R_B	1.04000			
R_{Bcrit}	1.95664			

Table 8- 20 Measurement results of pitch diameter (2*b*)

Participants	2*b* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	10.8752	0.0010	-0.0007	-0.42
NIMT	10.8768	0.00090	0.0009	0.63
PTB	10.8755	0.0010	-0.0004	-0.24
SASO NMCC	-	-	-	-
$\bar{x}_w$	10.87590	0.00056		
n	3			
$u_{ext(\bar{x}_w)}$	0.00051			
R_B	0.90828			
R_{Bcrit}	1.73205			



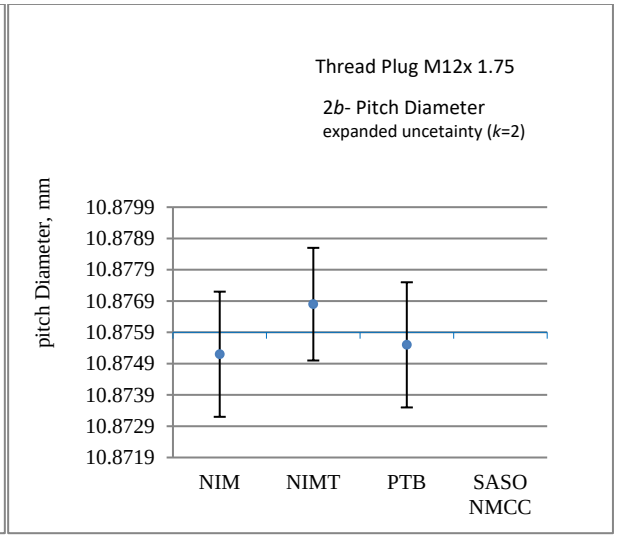
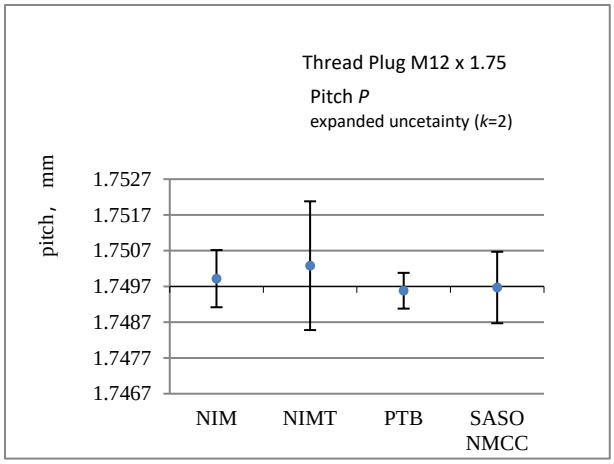


Table 8- 21 Measurement results of Thread pitch

Participants	Thread pitch P			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	1.7499	0.0004	0.0002	0.27
NIMT	1.7503	0.0009	0.0006	0.33
PTB	1.7496	0.00025	-0.0001	-0.35
SASO NMCC	1.74969	0.0005	-0.00002	-0.02
$\bar{x}_w$	1.74971	0.00019		
n	4			
$u_{ext(\bar{x}_w)}$	0.00010			
R_B	0.53241			
R_{Bcrit}	1.62265			

Table 8- 22 Measurement results of Thread angle

Participants	Thread angle α			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	1.04635 (59°57′5″)	0.00072 (2′29″)	0.00015 (0′31″)	0.13
NIMT	1.0464 (59°57′15″)	0.0008 (2′45″)	0.0002 (0′41″)	0.16
PTB	1.045864 (59°55′25″)	0.000412 (1′25″)	-0.000341 (-1′10″)	-0.38
SASO NMCC	-	-	-	-
$\bar{x}$	1.046205 (59°56′35″)	0.000384 (1′19″)		
n	3			
$u_{ext(\bar{x})}$	0.000204 (0′42″)			
R_B	0.53210			
R_{Bcrit}	1.73205			



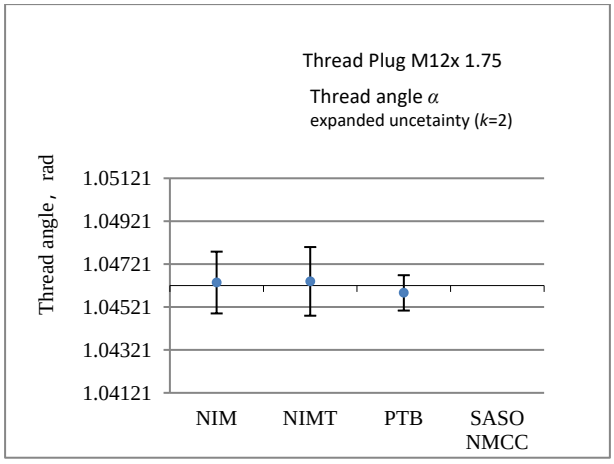
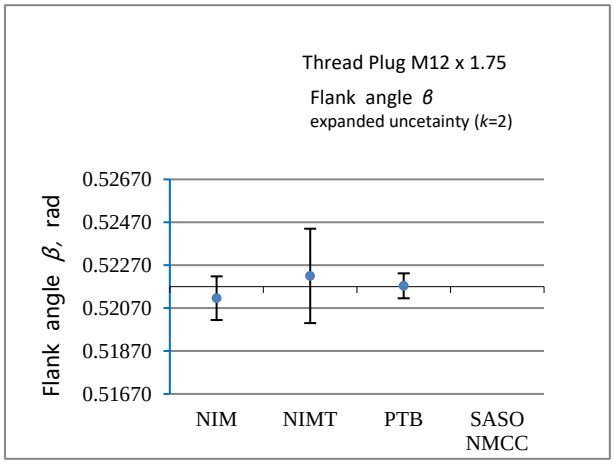


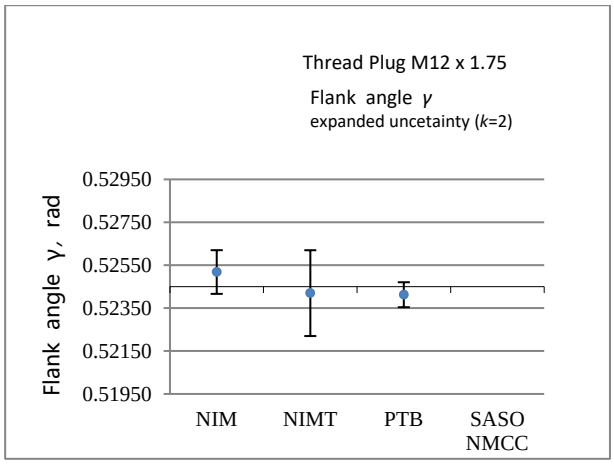
Table 8- 23 Measurement results of flank angle β

Participants	Flank angle β			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52116 (29°51′37″)	0.00051 (1′45″)	-0.00054 (-1′51″)	-0.53
NIMT	0.5222 (29°55′11″)	0.0011 (3′47″)	0.0005 (1′43″)	0.33
PTB	0.521738 (29°53′36″)	0.000291 (1′0″)	0.000039 (0′8″)	0.04
SASO NMCC	-	-	-	-
$\bar{x}$	0.521699 (29°56′28″)	0.000416 (1′26″)		
n	3			
$u_{ext(\bar{x})}$	0.000202 (0′42″)			
R_B	0.48569			
R_{Bcrit}	1.73205			

Table 8- 24 Measurement results of flank angleγ

Participants	Flank angle γ			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52518 (30°5′26″)	0.00051 (1′45″)	0.00068 (2′20″)	0.70
NIMT	0.5242 (30°2′4″)	0.0010 (3′26″)	-0.0003 (-1′2″)	-0.22
PTB	0.524126 (30°1′49″)	0.000291 (1′0″)	-0.000376 (-1′18″)	-0.45
SASO NMCC	-	-	-	-
$\bar{x}$	0.524502 (30°3′6″)	0.000387 (1′20″)		
n	3			
$u_{ext(\bar{x})}$	0.000325 (1′7″)			
R_B	0.84196			
R_{Bcrit}	1.73205			





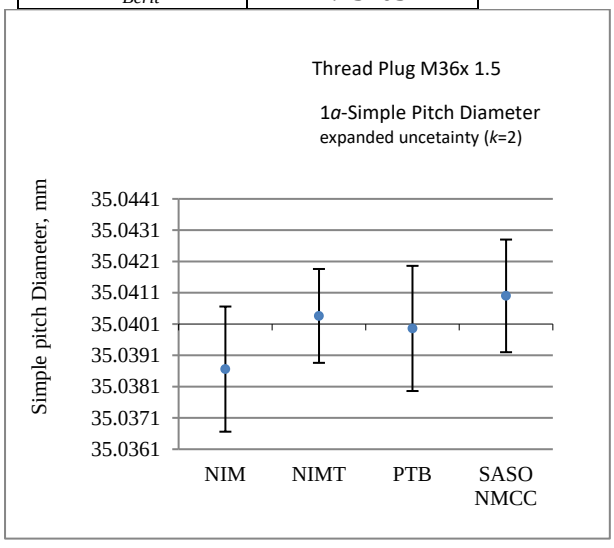
8.4 Thread plug M36×1.5

Table 8- 25 Measurement results of simple pitch diameter (1*a*)

Participants	1*a* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	35.0387	0.0010	-0.0014	-0.80
NIMT	35.0404	0.00075	0.0003	0.22
PTB	35.0400	0.0010	-0.0001	-0.08
SASO NMCC	35.04104	0.00090	0.00090	0.58
$\bar{x}_w$	35.04014	0.00045		
n	4			
$u_{ext(\bar{x}_w)}$	0.00046			
R_B	1.03495			
R_{Bcrit}	1.62265			

Table 8- 26 Measurement results of pitch diameter (2*a*)

Participants	2*a* Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	35.0388	0.0010	-0.0014	-0.85
NIMT	35.0406	0.00085	0.0004	0.28
PTB	-	-	-	-
SASO NMCC	35.04114	0.00100	0.00091	0.54
$\bar{x}_w$	35.04023	0.00054		
n	3			
$u_{ext(\bar{x}_w)}$	0.00067			
R_B	1.23743			
R_{Bcrit}	1.73205			



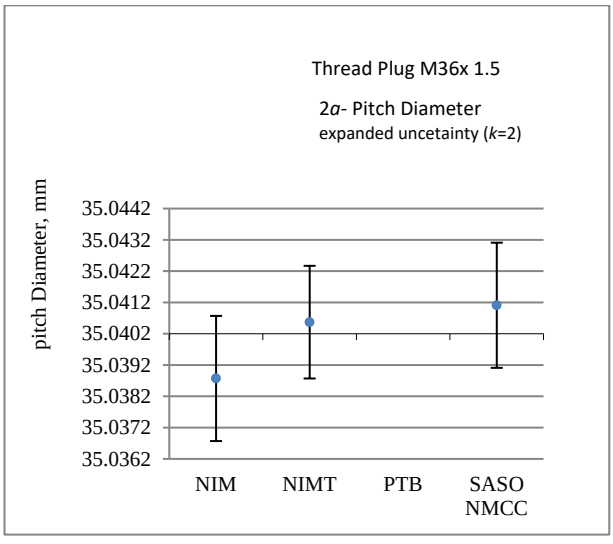
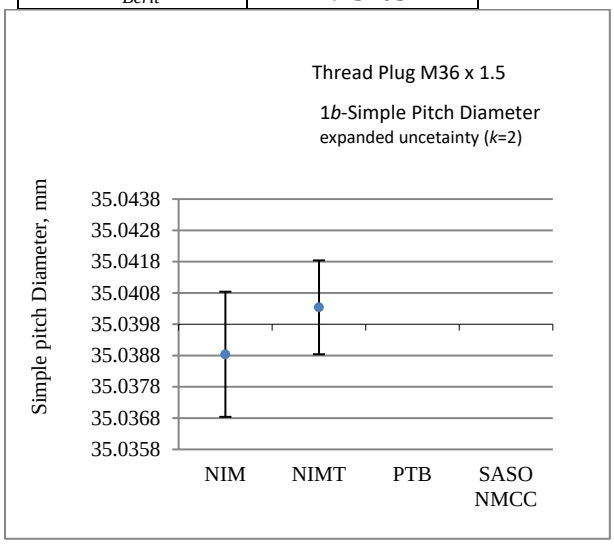


Table 8- 27 Measurement results of simple pitch diameter (1*b*)

Participants	1*b* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	35.0388	0.0010	-0.0010	-0.60
NIMT	35.0403	0.00075	0.0005	0.60
PTB	-	-	-	-
SASO NMCC	-	-	-	-
$\bar{x}_w$	35.03976	0.00060		
n	2			
$u_{ext(\bar{x}_w)}$	0.00072			
R_B	1.20000			
R_{Bcrit}	1.95664			

Table 8- 28 Measurement results of pitch diameter (2*b*)

Participants	2*b* Simple Pitch diameter $d_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	35.0389	0.0010	-0.0011	-0.64
NIMT	35.0406	0.00085	0.0006	0.47
PTB	35.0402	0.0010	0.0002	0.13
SASO NMCC	-	-	-	-
$\bar{x}_w$	35.03998	0.00054		
n	3			
$u_{ext(\bar{x}_w)}$	0.00051			
R_B	0.93457			
R_{Bcrit}	1.73205			



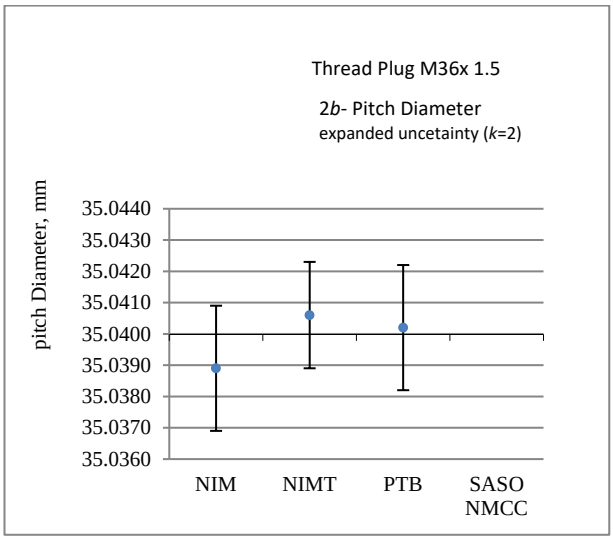
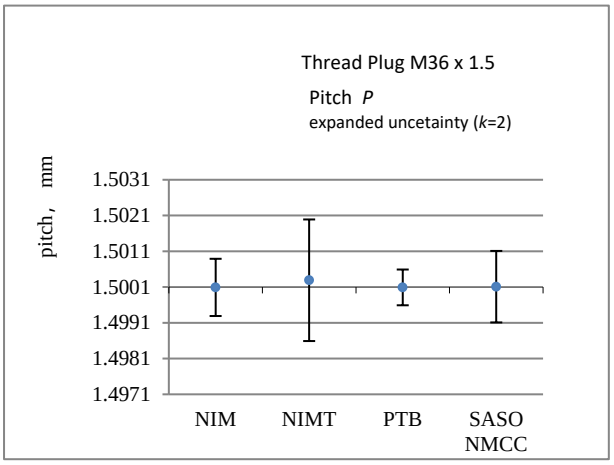


Table 8- 29 Measurement results of Thread pitch

Participants	Thread pitch P			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	1.5001	0.0004	0.0000	-0.02
NIMT	1.5003	0.00085	0.0002	0.11
PTB	1.5001	0.00025	0.0000	-0.04
SASO NMCC	1.50012	0.0005	0.00001	0.01
$\bar{x}_w$	1.50011	0.00019		
n	4			
$u_{ext(\bar{x}_w)}$	0.00003			
R_B	0.13211			
R_{Bcrit}	1.62265			

Table 8- 30 Measurement results of Thread angle

Participants	Thread angle α			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	1.04912 (60°6′37″)	0.00082 (2′49″)	0.00016 (0′33″)	0.13
NIMT	1.0498 (60°8′57″)	0.0008 (2′45″)	0.0008 (2′45″)	0.69
PTB	1.047947 (60°2′35″)	0.000412 (1′25″)	-0.001009 (-3′28″)	-1.07
SASO NMCC	-	-	-	-
$\bar{x}$	1.048956 (60°6′3″)	0.000406 (1′24″)		
n	3			
$u_{ext(\bar{x})}$	0.000632 (2′10″)			
R_B	1.55796			
R_{Bcrit}	1.73205			



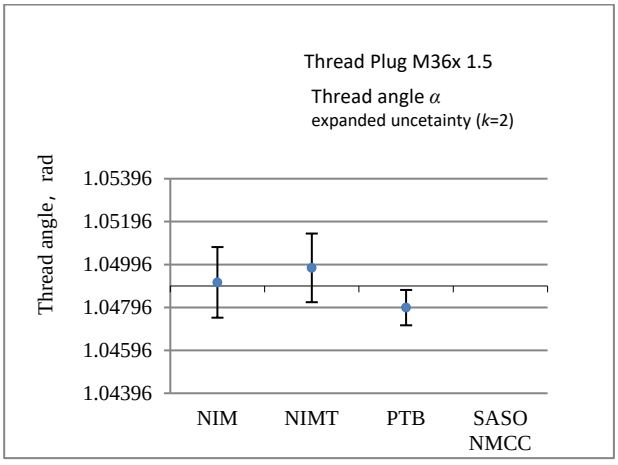
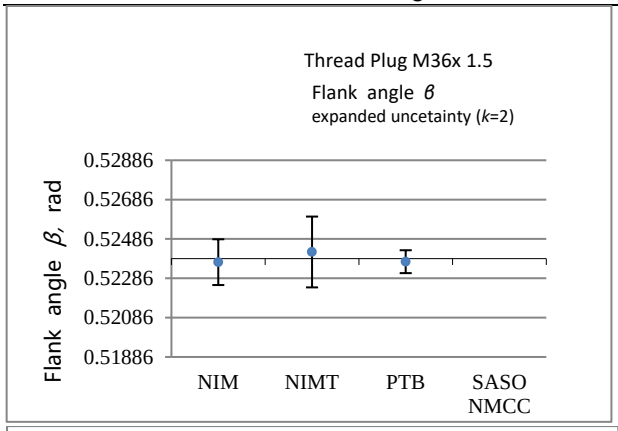


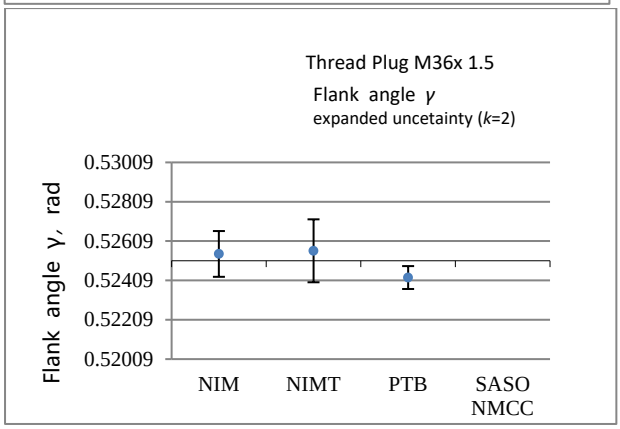
Table 8- 31 Measurement results of flank angle β

Participants	Flank angle β			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52368 (30°0′17″)	0.00058 (2′0″)	-0.00018 (-0′37″)	-0.18
NIMT	0.5242 (30°2′4″)	0.0009 (3′6″)	0.0003 (1′2″)	0.26
PTB	0.523707 (30°0′22″)	0.000291 (1′0″)	-0.000155 (-0′32″)	-0.19
SASO NMCC	-	-	-	-
$\bar{x}$	0.523862 (30°0′54″)	0.000370 (1′16″)		
n	3			
$u_{ext(\bar{x})}$	0.000128 (0′26″)			
R_B	0.34599			
R_{Bcrit}	1.73205			

Table 8- 32 Measurement results of flank angleγ

Participants	Flank angle γ			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52544 (30°6′20″)	0.00058 (2′0″)	0.00035 (1′12″)	0.36
NIMT	0.5256 (30°6′53″)	0.0008 (2′45″)	0.0005 (1′43″)	0.44
PTB	0.524241 (30°2′12″)	0.000291 (1′0″)	-0.000853 (-2′56″)	-1.12
SASO NMCC	-	-	-	-
$\bar{x}$	0.525094 (30°5′8″)	0.000343 (1′11″)		
n	3			
$u_{ext(\bar{x})}$	0.000535 (1′50″)			
R_B	1.55700			
R_{Bcrit}	1.73205			





8.5 Thread ring M18×2.5

Table 8- 33 Measurement results of simple pitch diameter (1*a*)

Participants	1*a* Simple Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	16.3262	0.0010	-0.0004	-0.24
NIMT	16.3268	0.00075	0.0002	0.17
PTB	16.3267	0.0010	0.0001	0.05
SASO NMCC	16.31814	0.00090	-0.00847	-4.09*
$\bar{x}_w$	16.32661	0.00051		
n	3		Excluded from the SCRV	
$u_{ext(\bar{x}_w)}$	0.00018			*En* *
R_B	0.34662		SASO NMCC	-4.09*
R_{Bcrit}	1.73205			

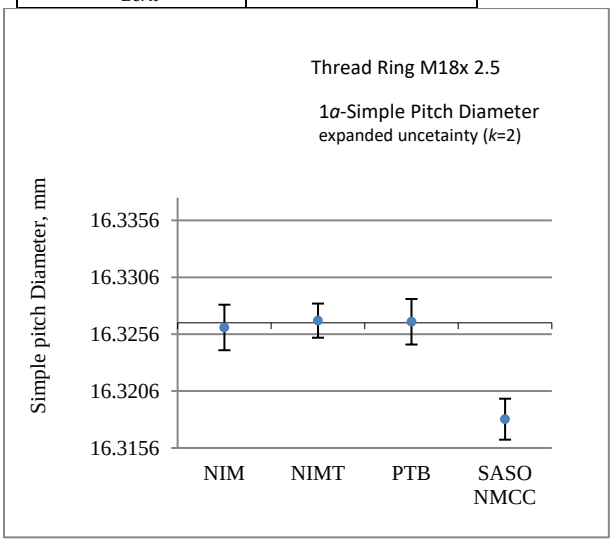
Table 8- 34 Measurement results of pitch diameter (2*a*)

Participants	2*a* Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	16.3255	0.0010	-0.0011	-0.78
NIMT	16.3277	0.0010	0.0011	0.78
PTB	-	-	-	-

SASO NMCC	16.31721	0.00100	-0.00939	-3.83*
$\bar{x}_w$	16.32660	0.00071		
n	2			
$u_{ext(\bar{x}_w)}$	0.00110			
R_B	1.55563			
R_{Bcrit}	1.95664			

Excluded from the SCRV

	En *
SASO NMCC	-3.83*



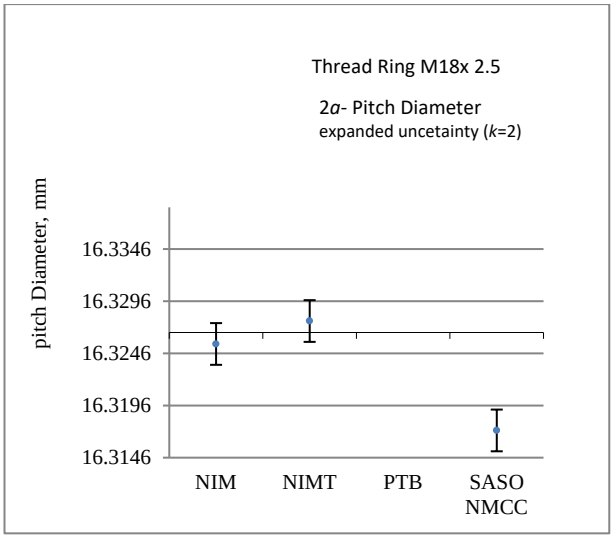


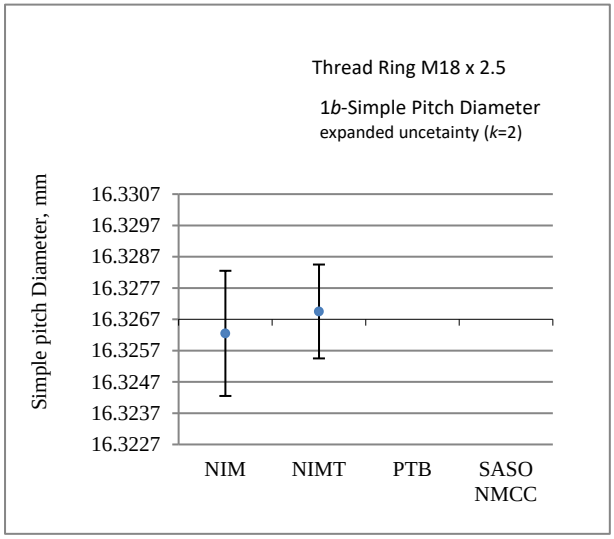
Table 8- 35 Measurement results of simple pitch diameter (1*b*)

Participants	1*b* Simple Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	16.3262	0.0010	-0.0004	-0.28
NIMT	16.3269	0.00075	0.0003	0.28
PTB	-	-	-	-
SASO NMCC	-	-	-	-
$\bar{x}_w$	16.32665	0.00060		
n	2			
$u_{ext(\bar{x}_w)}$	0.00034			
R_B	0.56000			
R_{Bcrit}	1.95664			

Table 8- 36 Measurement results of pitch diameter (2*b*)

Participants	2*b* Simple Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	16.3255	0.0010	-0.0010	-0.58
NIMT	16.3278	0.00090	0.0013	0.94

PTB	16.3258	0.0010	-0.0007	-0.40
SASO NMCC	-	-	-	-
$\bar{x}_w$	16.32647	0.00056		
n	3			
$u_{ext(\bar{x}_w)}$	0.00074			
R_B	1.33672			
R_{Bcrit}	1.73205			



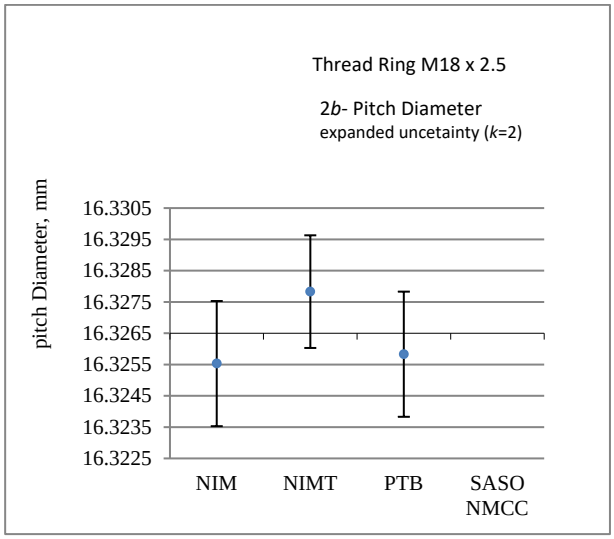
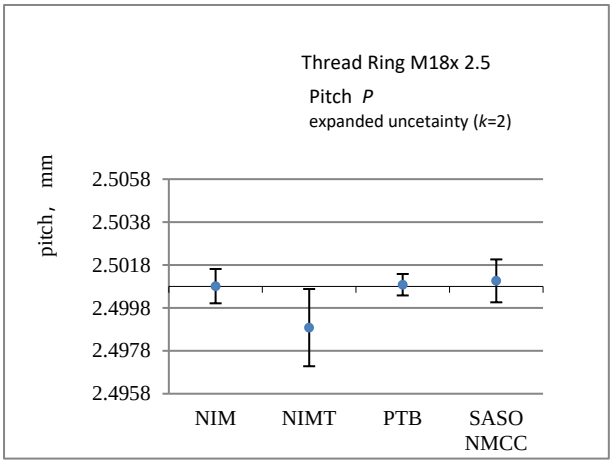


Table 8- 37 Measurement results of Thread pitch

Participants	Thread pitch P			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	2.5008	0.0004	0.0000	-0.02
NIMT	2.4989	0.0009	-0.0019	-1.09
PTB	2.5009	0.00025	0.0001	0.27
SASO NMCC	2.50108	0.0005	0.00027	0.29
$\bar{x}_w$	2.50081	0.00019		
n	4			
$u_{ext(\bar{x}_w)}$	0.00024			
R_B	1.28131			
R_{Bcrit}	1.62265			

Table 8- 38 Measurement results of Thread angle

Participants	Thread angle α			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	1.04700 (59°59′19″)	0.00062 (2′8″)	-0.00001 (-0′2″)	-0.01
NIMT	1.0478 (60°2′4″)	0.0008 (2′45″)	0.0008 (2′45″)	0.67
PTB	1.046223 (59°56′39″)	0.000412 (1′25″)	-0.000785 (-2′42″)	-0.90
SASO NMCC	-	-	-	-
$\bar{x}$	1.047008 (59°59′21″)	0.000364 (1′15″)		
n	3			
$u_{ext(\bar{x})}$	0.000479 (1′39″)			
R_B	1.31418			
R_{Bcrit}	1.73205			



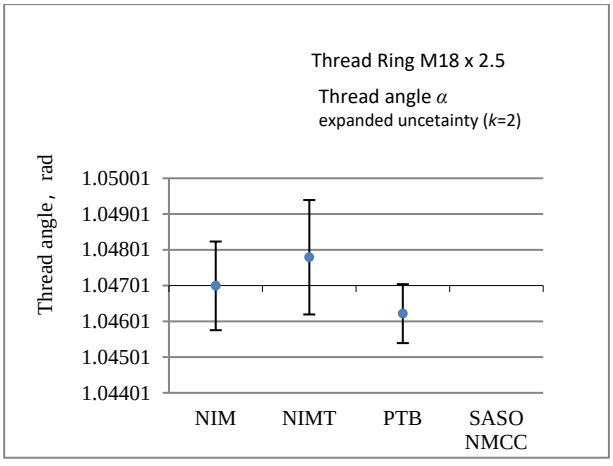
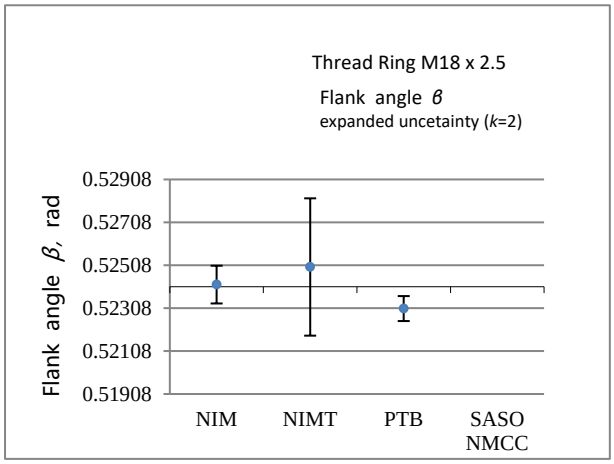


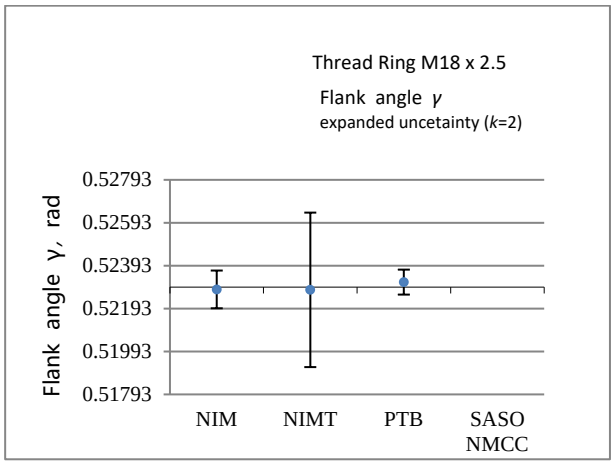
Table 8- 39 Measurement results of flank angle β

Participants	Flank angle β			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52418 (30°2′0″)	0.00044 (1′31″)	0.00010 (0′21″)	0.08
NIMT	0.5250 (30°4′49″)	0.0016 (5′30″)	0.0009 (3′6″)	0.43
PTB	0.523062 (29°58′9″)	0.000291 (1′0″)	-0.001019 (-3′30″)	-0.87
SASO NMCC	-	-	-	-
$\bar{x}$	0.524081 (30°1′39″)	0.000562 (1′56″)		
n	3			
$u_{ext(\bar{x})}$	0.000603 (2′4″)			
R_B	1.07407			
R_{Bcrit}	1.73205			

Table 8- 40 Measurement results of flank angleγ

Participants	Flank angle γ			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52282 (29°57′19″)	0.00044 (1′31″)	-0.00011 (-0′23″)	-0.08
NIMT	0.5228 (29°57′15″)	0.0018 (6′11″)	-0.0001 (-0′21″)	-0.05
PTB	0.523161 (29°58′30″)	0.000291 (1′0″)	0.000234 (0′48″)	0.18
SASO NMCC	-	-	-	-
$\bar{x}$	0.522927 (29°57′41″)	0.000625 (2′9″)		
n	3			
$u_{ext(\bar{x})}$	0.000143 (0′30″)			
R_B	0.22934			
R_{Bcrit}	1.73205			





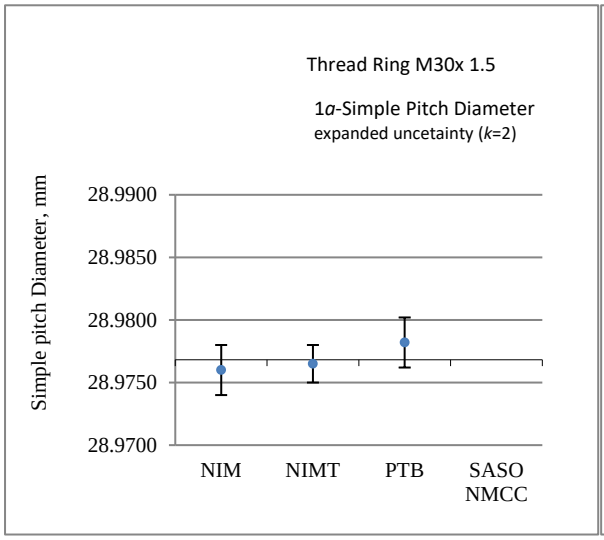
8.6 Thread ring M30×1.5

Table 8- 41 Measurement results of simple pitch diameter (1*a*)

Participants	1*a* Simple Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty （*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	28.9760	0.0010	-0.0008	-0.48
NIMT	28.9765	0.00075	-0.0003	-0.29
PTB	28.9782	0.0010	0.0014	0.81
SASO NMCC	28.52266	0.00090	-0.45416	-219.04*
$\bar{x}_w$	28.97682	0.00051		
n	3			
$u_{ext(\bar{x}_w)}$	0.00060			
R_B	1.17448			
R_{Bcrit}	1.73205			

Excluded from the SCRV

	En *
SASO NMCC	-219.04*



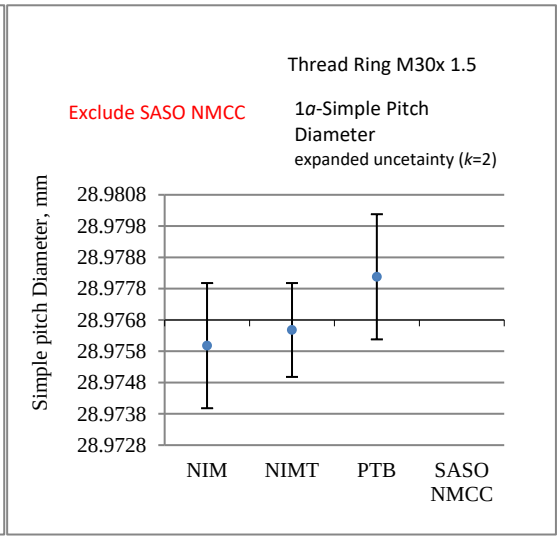
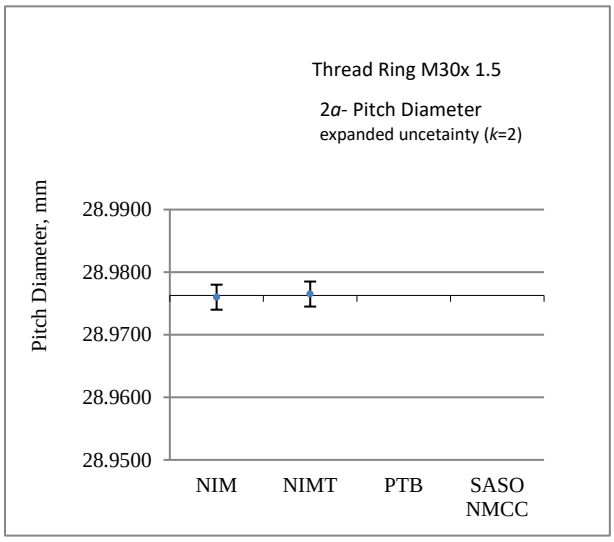


Table 8- 42 Measurement results of pitch diameter (2*a*)

Participants	2*a* Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	28.9760	0.0010	-0.0003	-0.19
NIMT	28.9765	0.0009	0.0002	0.19
PTB	-	-	-	-
SASO NMCC	28.52243	0.00100	-0.45385	-188.61*
$\bar{x}_w$	28.97628	0.00067		
n	2			
$u_{ext(\bar{x}_w)}$	0.00025			
R_B	0.37165			
R_{Bcrit}	1.95664			

Excluded from the SCRV

	En *
SASO NMCC	-188.61*



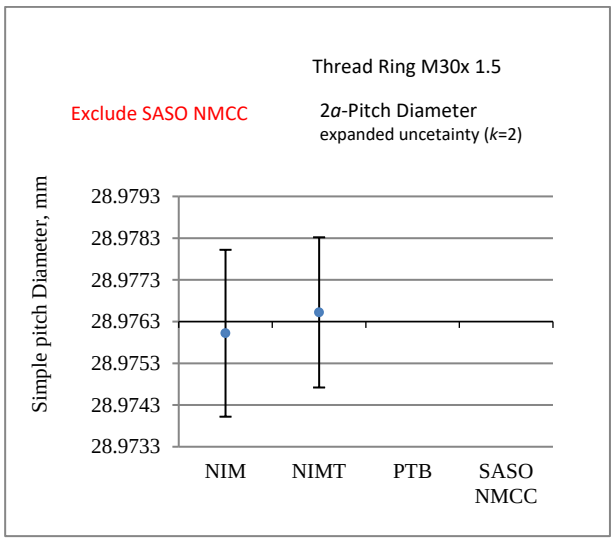
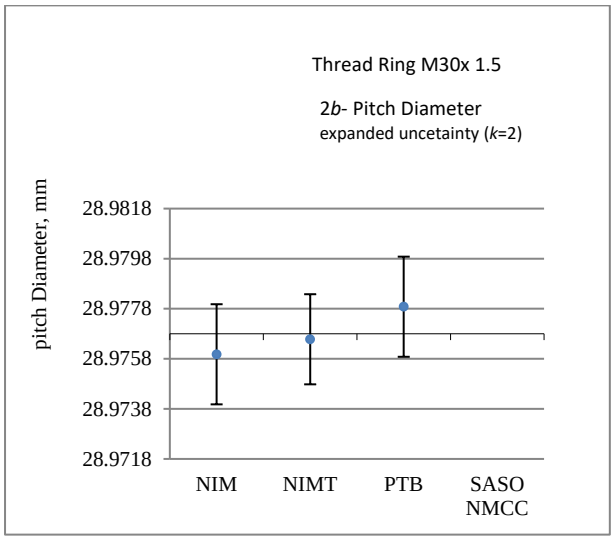


Table 8- 43 Measurement results of simple pitch diameter (1*b*)

Participants	1*b* Simple Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	28.9761	0.0010	-0.0003	-0.16
NIMT	28.9765	0.00075	0.0001	0.16
PTB	-	-	-	-
SASO NMCC	-	-	-	-
$\bar{x}_w$	28.97636	0.00060		
n	2			
$u_{ext(\bar{x}_w)}$	0.00019			
R_B	0.32000			
R_{Bcrit}	1.95664			

Table 8- 44 Measurement results of pitch diameter (2*b*)

Participants	2*b* Simple Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	28.9760	0.0010	-0.0008	-0.49
NIMT	28.9766	0.0009	-0.0002	-0.15
PTB	28.9779	0.0010	0.0011	0.65
SASO NMCC	-	-	-	-
$\bar{x}_w$	28.97682	0.00056		
n	3			
$u_{ext(\bar{x}_w)}$	0.00054			
R_B	0.97430			
R_{Bcrit}	1.73205			



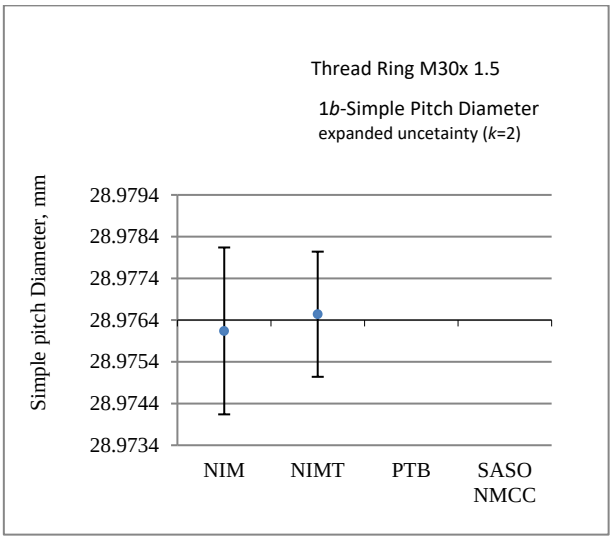
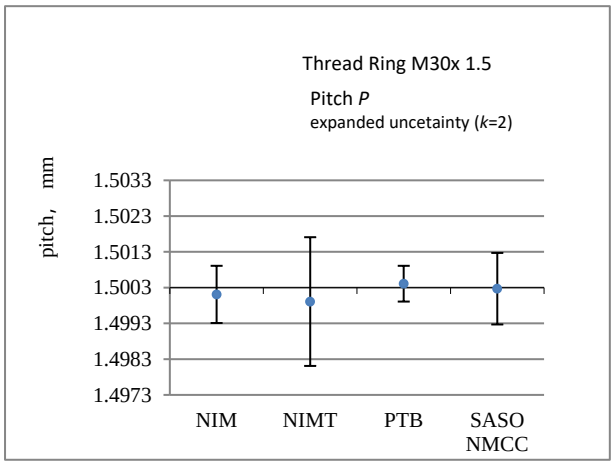


Table 8- 45 Measurement results of Thread pitch

Participants	Thread pitch P			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	1.5001	0.0004	-0.0002	-0.27
NIMT	1.4999	0.0009	-0.0004	-0.22
PTB	1.5004	0.00025	0.0001	0.34
SASO NMCC	1.50026	0.0005	-0.00003	-0.03
$\bar{x}_w$	1.50029	0.00019		
n	4			
$u_{ext(\bar{x}_w)}$	0.00009			
R_B	0.45114			
R_{Bcrit}	1.62265			

Table 8- 46 Measurement results of Thread angle

Participants	Thread angle α			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	1.04695 (59°59′9″)	0.00082 (2′49″)	0.00029 (1′0″)	0.24
NIMT	1.0466 (59°57′57″)	0.0008 (2′45″)	-0.0001 (-0′21″)	-0.05
PTB	1.046419 (59°57′19″)	0.000412 (1′25″)	-0.000237 (-0′49″)	-0.25
SASO NMCC	-	-	-	-
$\bar{x}$	1.046656 (59°58′8″)	0.000406 (1′24″)		
n	3			
$u_{ext(\bar{x})}$	0.000161 (33″)			
R_B	0.39739			
R_{Bcrit}	1.73205			



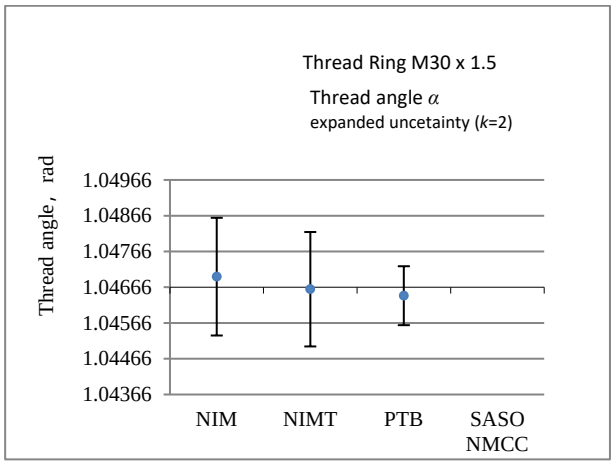
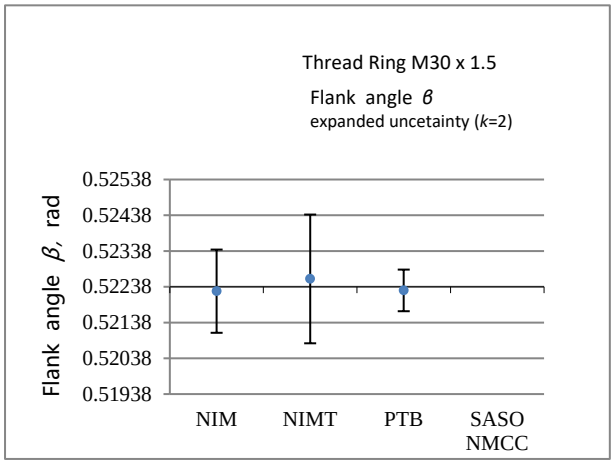


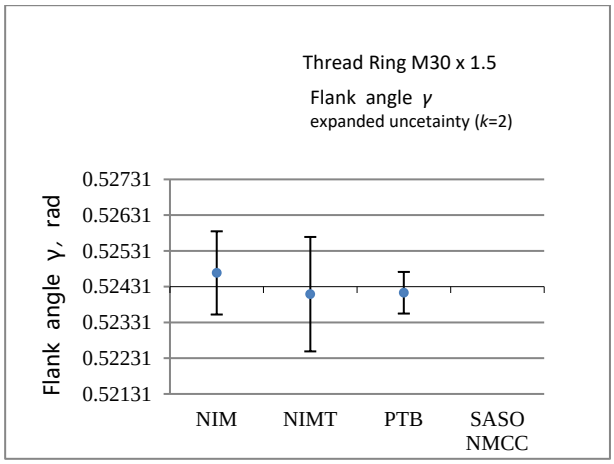
Table 8- 47 Measurement results of flank angle β

Participants	Flank angle β			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52226 (29°55′24″)	0.00058 (2′0″)	-0.00012 (-0′25″)	-0.12
NIMT	0.5226 (29°56′34″)	0.0009 (3′6″)	0.0002 (0′41″)	0.17
PTB	0.522279 (29°55′28″)	0.000291 (1′0″)	-0.000101 (-0′21″)	-0.12
SASO NMCC	-	-	-	-
$\bar{x}$	0.522380 (29°55′49″)	0.000370 (1′16″)		
n	3			
$u_{ext(\bar{x})}$	0.000083 (17″)			
R_B	0.22518			
R_{Bcrit}	1.73205			

Table 8- 48 Measurement results of flank angleγ

Participants	Flank angle γ			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52469 (30°3′45″)	0.00058 (2′0″)	0.00038 (1′18″)	0.40
NIMT	0.5241 (30°1′43″)	0.0008 (2′45″)	-0.0002 (-0′41″)	-0.18
PTB	0.524140 (30°1′52″)	0.000291 (1′0″)	-0.000170 (-0′35″)	-0.22
SASO NMCC	-	-	-	-
$\bar{x}$	0.524310 (30°2′27″)	0.000343 (1′11″)		
n	3			
$u_{ext(\bar{x})}$	0.000160 (0′33″)			
R_B	0.46671			
R_{Bcrit}	1.73205			





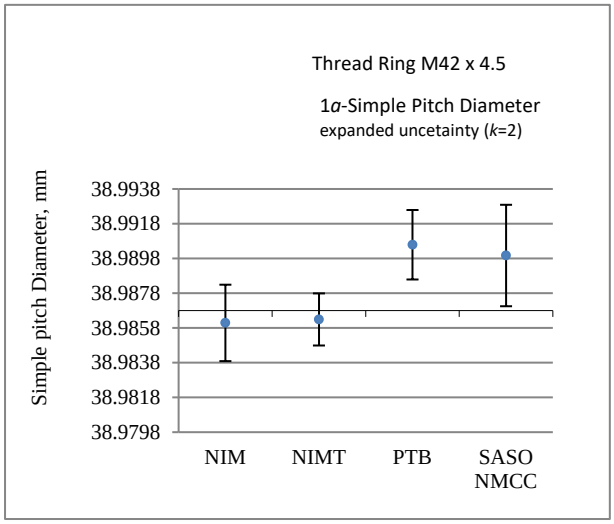
8.7 Thread ring M42×4.5

Table 8- 49 Measurement results of simple pitch diameter (1*a*)

Participants	1*a* Simple Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	38.9861	0.0011	-0.0007	-0.38
NIMT	38.9863	0.00075	-0.0005	-0.52
PTB	38.9906	0.0010	0.0038	1.65*
SASO NMCC	38.98998	0.00146	0.00317	1.18
$\bar{x}_w$	38.98681	0.00057		
n	3		Excluded from the SCRV	
$u_{ext(\bar{x}_w)}$	0.00095			En *
R_B	1.67231		PTB	1.63*
R_{Bcrit}	1.73205			

Table 8- 50 Measurement results of pitch diameter (2*a*)

Participants	2*a* Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	38.9861	0.0010	-0.0005	-0.34
NIMT	38.9861	0.0009	0.0005	-0.41
PTB	-	-	-	-
SASO NMCC	38.98944	0.00153	0.00280	1.00
$\bar{x}_w$	38.98664	0.00061		
n	3			
$u_{ext(\bar{x}_w)}$	0.00087			
RB	1.41434			
RBcrit	1.73205			



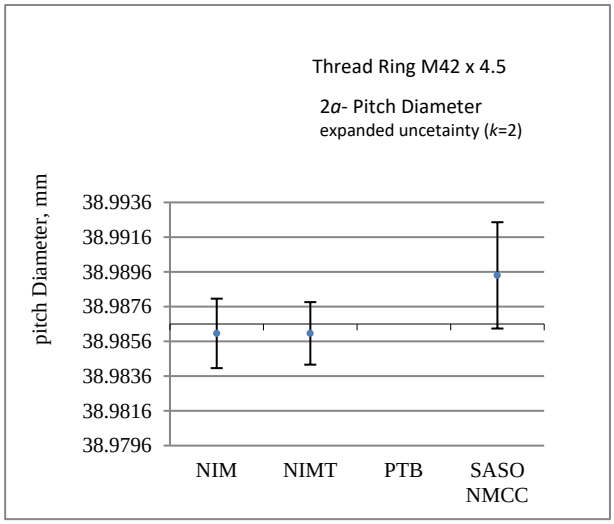


Table 8- 51 Measurement results of simple pitch diameter (1*b*)

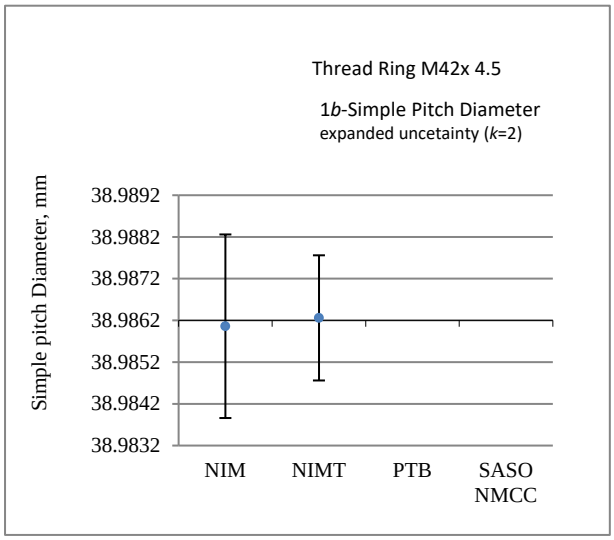
Participants	1*b* Simple Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	38.9861	0.0011	-0.0001	-0.08
NIMT	38.9863	0.00075	0.0001	0.08
PTB	-	-	-	-
SASO NMCC	-	-	-	-
$\bar{x}_w$	38.98624	0.00062		
n	2			
$u_{ext(\bar{x}_w)}$	0.00009			
R_B	0.15022			
R_{Bcrit}	1.95664			

Table 8- 52 Measurement results of pitch diameter (2*b*)

Participants	2*b* Simple Pitch diameter $D_{2simple}$			
	Measured values mm	uncertainty (*k*=1) mm	$x_i - \bar{x}_w$ mm	*En*
NIM	38.9860	0.0010	-0.0001	-0.04
NIMT	38.9861	0.0009	0.0000	0.04
PTB	38.9895	0.0010	0.0034	1.43*
SASO NMCC	-	-	-	-
$\bar{x}_w$	38.98606	0.00067		
n	2			
$u_{ext(\bar{x}_w)}$	0.00005			
R_B	0.07433			
R_{Bcrit}	1.95664			

Excluded from the SCRV

	En *
PTB	1.43*



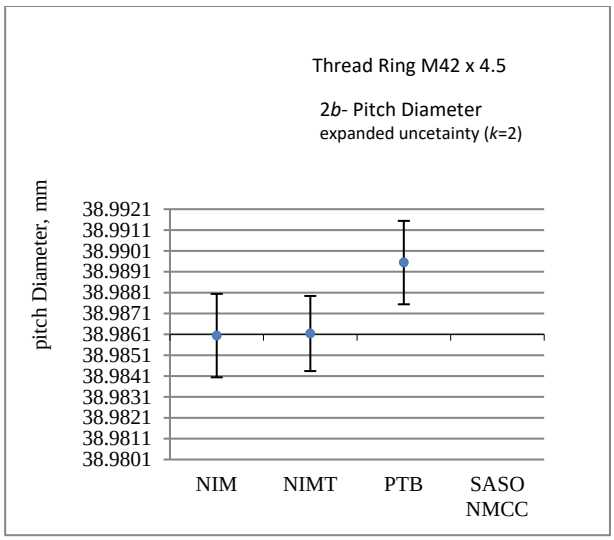
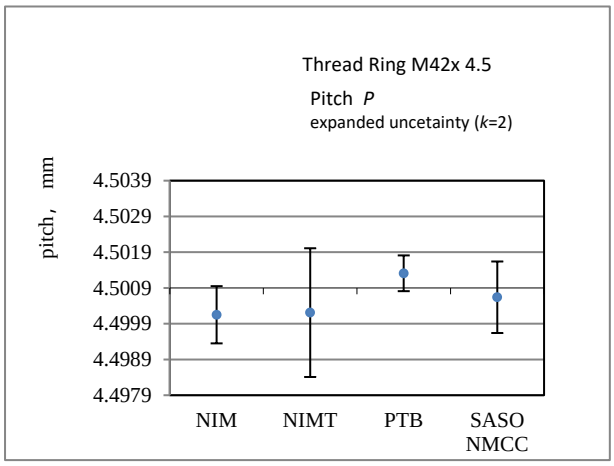


Table 8- 53 Measurement results of Thread pitch

Participants	Thread pitch P			
	Measured values mm	uncertainty (k=1) mm	$x_i - \bar{x}_w$ mm	En
NIM	4.5002	0.0004	-0.0007	-1.00
NIMT	4.5002	0.0009	-0.0007	-0.40
PTB	4.5013	0.00025	0.0004	1.23
SASO NMCC	4.50063	0.0005	-0.00027	-0.30
$\bar{x}_w$	4.50090	0.00019		
n	4			
$u_{ext(\bar{x}_w)}$	0.00028			
R_B	1.47409			
R_{Bcrit}	1.62265			

Table 8- 54 Measurement results of Thread angle

Participants	Thread angle α			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	1.04701 (59°59′21″)	0.00062 (2′8″)	-0.00020 (-0′41″)	-0.18
NIMT	1.0473 (60°0′21″)	0.0010 (3′26″)	0.0001 (0′21″)	0.07
PTB	1.047308 (60°0′23″)	0.000412 (1′25″)	0.000102 (0′21″)	0.11
SASO NMCC	-	-	-	-
$\bar{x}$	1.047206 (60°0′2″)	0.000416 (1′26″)		
n	3			
$u_{ext(\bar{x})}$	0.000095 (0′20″)			
R_B	0.22776			
R_{Bcrit}	1.73205			



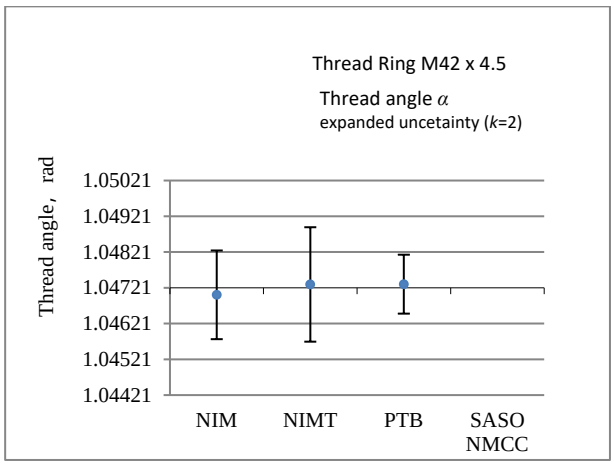
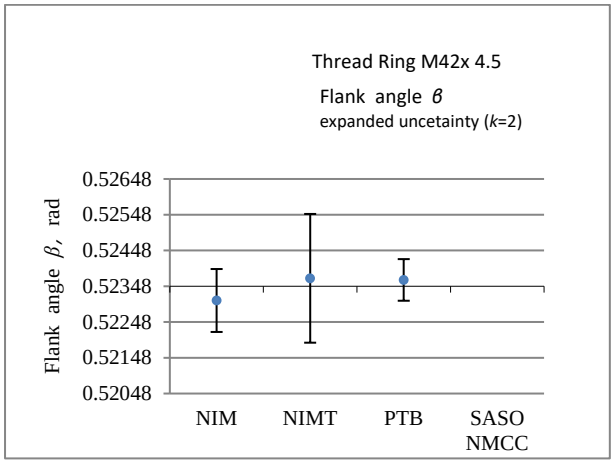


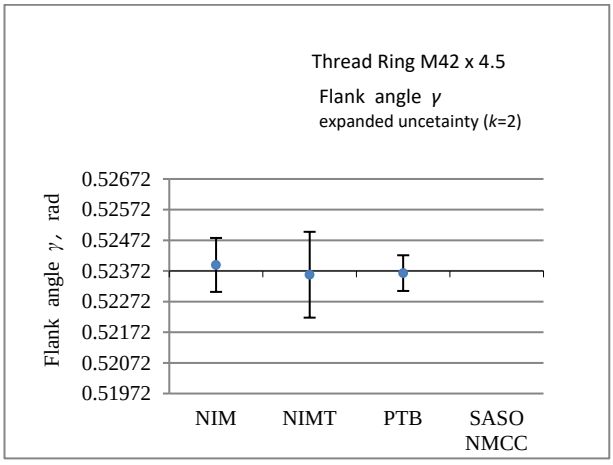
Table 8- 55 Measurement results of flank angle β

Participants	Flank angle β			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52308 (29°58′13″)	0.00044 (1′31″)	-0.00040 (-1′23″)	-0.46
NIMT	0.5237 (30°0′21″)	0.0009 (3′6″)	0.0002 (0′41″)	0.18
PTB	0.523655 (30°0′12″)	0.000291 (1′0″)	0.000177 (0′37″)	0.23
SASO NMCC	-	-	-	-
$\bar{x}$	0.523478 (29°59′35″)	0.000348 (1′12″)		
n	3			
$u_{ext(\bar{x})}$	0.000185 (0′38″)			
R_B	0.53253			
R_{Bcrit}	1.73205			

Table 8- 56 Measurement results of flank angleγ

Participants	Flank angle γ			
	Measured values rad	uncertainty (k=1) rad	$x_i - \bar{x}$ rad	En
NIM	0.52392 (30°1′6″)	0.00044 (1′31″)	0.00020 (41″)	0.25
NIMT	0.5236 (30°0′0″)	0.0007 (2′24″)	-0.0001 (-0′21″)	-0.12
PTB	0.523653 (30°0′11″)	0.000291 (1′0″)	-0.000071 (-0′15″)	-0.11
SASO NMCC	-	-	-	-
$\bar{x}$	0.523724 (30°0′26″)	0.000292 (1′0″)		
n	3			
$u_{ext(\bar{x})}$	0.000087 (0′18″)			
R_B	0.29857			
R_{Bcrit}	1.73205			





9 Participant Responses

Following the circulation of the results the pilot received responses regarding discrepancies from several participants. Details of these are included below.

9.1 PTB

PTB's results for the thread and flank angles systematically deviate from the NIM's and NIMT's values. We suppose that this systematic effect is due to the different measuring methods applied at PTB (coordinate measuring machine) and NIM/NIMT (contour measuring machine, also referred to as scanner). The SCRV tends to the scanner results as they are double-weighted in the calculation. This discrepancy could probably be reduced if the measurement ranges used to determine the angles would have been specified for the intercomparison (in terms of a diameter range).

Moreover, the ring M42x4.5 really seems to feature high form deviations on the flanks. This can be visualized by the 3D measurement that we conducted on all parts. The graphics attached show a 3D measurement of the two thread flanks of the ring M42x4.5 . In radial direction 6 traces (18.5mm - 21mm) along the helical surface were measured in scanning mode. The different colors indicate a form deviation of approx. 4 µm. Especially in this case the measuring range is essential for determining the flank angle. If the profiles were evaluated in different measuring ranges, the measurement results will be different too.
Best regards

The flank angle measured value of participants are consistent. But there is a big difference for the measurement uncertainty. This will affect the SCRV calculation. Normally the uncertainty of flank angle measurement is inversely proportional to the measurement length on the flanks. So the measurement uncertainty will be different for different pitch gauge.

We also found the flank form of M42 ring gauge is not good. It results in pitch diameter measurement results inconsistent. This gauge results are not acceptable in this comparison .

9.2 SASO NMCC

Probably, the reason (of inconsistent results) *was because of incorrect stylus shaft alignment, It would be better if we checked the alignment on several times.*

10 Discussion of Results

- The tooth surface of M42 gauge is not good and the straightness is not good also. PTB reported this defect during comparison. As a result there is an obvious systematic deviation between the measurement results of traditional length measuring machine and coordinate measuring machine. It can be concluded that the tooth surface roughness and straightness have a great influence on the measurement results of pitch diameter. This gauge is not suitable as a comparison artifact, and its measurement data is not used as the final comparison result.
- Using the probe close to the best ball diameter the flank angles have little effect on the pitch diameter.
- Pitch diameter and Simple pitch Diameter measurement results have good consistency.
- Appendix A gives the measurement results with scanning methods provided by NIM and PTB.
- Because the measurement length on the tooth surface is related to the measurement uncertainty of flank angle the measurement uncertainty of flank angle should be inversely proportional to the measurement length of flank angle on the tooth surface.

  A simple model of measurement uncertainty of flank angle is given below

$$\alpha/2=\operatorname{atan}(z/x)$$

where: z- The axial distance of the probe along the tooth surface.

x- The radial distance of the probe along the tooth surface.

coefficient of sensitivity

$$C_1=\frac{\partial\frac{\alpha}{2}}{\partial z}=\frac{\cos^2\frac{\alpha}{2}}{x},\qquad C_2=\frac{\partial\frac{\alpha}{2}}{\partial x}=\frac{\cos^2\frac{\alpha}{2}}{x^2}z,$$

x and z is related to the measured length L, $x=L\sin(\alpha/2)$, $z=L\cos(\alpha/2)$

Therefore, it can be concluded that the uncertainty is inversely proportional to the measurement length L.

Reference:

1. Calibration Guide EURAMET cg-10, Determination of Pitch Diameter of Parallel Thread Gauges by Mechanical Probing, Version 2.1 (12/2012), ISBN 978-3-942992-27-5.

2. EURAMET.L-S21 Supplementary comparison of Parallel Thread Gauges, FINAL REPORT.

Appendix A Supplementary Results

A.1 General description of supplementary results

In this section the scanning method used by NIM and PTB to calibrate the plug and ring gauges were discussed.

- NIM uses thread scanner (IAC Master Scanner 10060) to calibrate the simple diameter 1*a* and pitch diameter *2b*. This method can get more points and full information of thread.
- PTB uses CMM (Zeiss Prismo Ultra) with Vast Gold probe and integrated rotary table, t-shaped stylus configuration, reversal measurements in single-point contact, measured seven helix scans on evenly distributed diameters for each flank, one helix scan on nominal d_2 substitution measurement with ring gauges, measured pitch diameter 2*b* and pitch, thread angle and flank angles.

Parameters		NIM	PTB
Pitch diameter	Measurement device	Thread scanner IAC Master Scanner 10060	CMM Zeiss Prismo Ultra ,rotary table, t-shaped stylus
	Method	Scan on the thread flank, Least Square calculated	Reversal measurements in single-points contact, Seven helix scans on evenly distributed diameters for each flank, one helix scan on nominal d_2
Pitch	/	/	CMM
Thread angle (flank angles)			

Because these values are not used to calculated SCRV, so the formula (9) are used in calculated E_n value.

A.2 Supplementary results and analysis of results

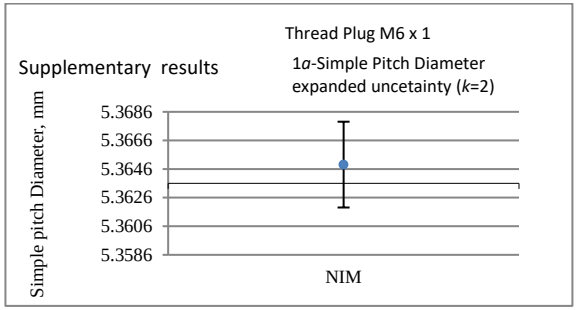
A.2.1 Measurement results reported by participants and with respect to SCRV

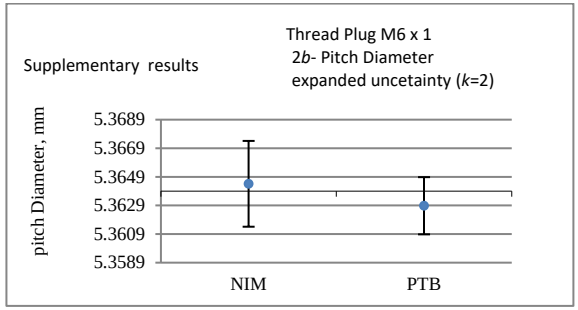
A.2.2 Discussion of results

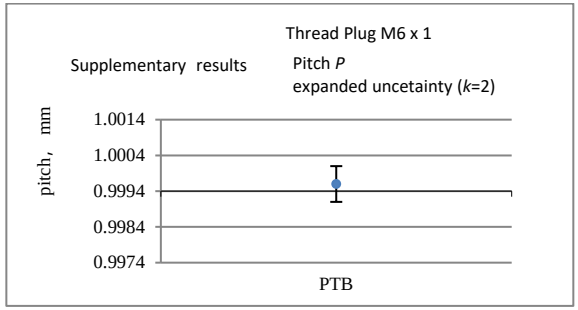
- Scanning measurement method can obtain more information of thread flank and help to improve thread quality. The pitch diameter measurement results of scanning measurement method, traditional three wires, and two ball method are consistent.
- M42 ring gauge results have great difference in pitch diameter measurement by different methods due to poor tooth surface.

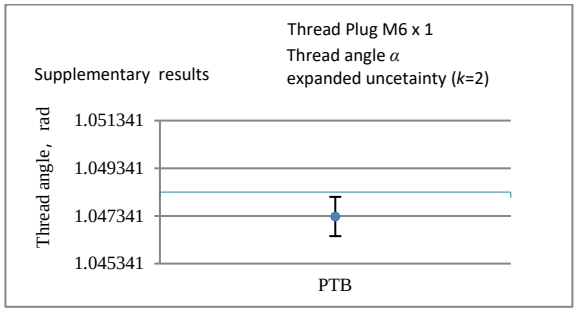
Table A- 1 Thread plug M6 x 1- supplementary measurement results and with respect to SRCV

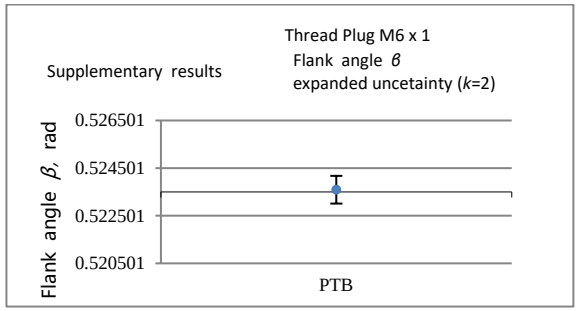
MEASURAND	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	NIM				PTB			
			Measured value	u (k=1)	$x_i - \bar{x}_w$	En	Measured value	u (k=1)	$x_i - \bar{x}_w$	En
Simple pitch Diameter $1a$-d_2 / mm	5.36359	0.00045	5.3649	0.0015	0.0013	0.42	-	-	-	-
Pitch diameter $2b$-d_2 / mm	5.36392	0.00054	5.3644	0.0015	0.0005	0.15	5.3629	0.0010	-0.0010	-0.45
α / rad	1.048341 (60°3′56″)	0.000538 (1′51″)	-	-	-	-	1.047317 (60°0′25″)	0.000412 (1′25″)	-0.001024 (-3′31″)	-0.76
β / rad	0.523501 (29°59′40″)	0.000644 (2′13″)	-	-	-	-	0.523594 (29°59′59″)	0.000291 (1′0″)	0.000093 (0′19″)	0.07
γ / rad	0.524843 (30°4′17″)	0.000477 (1′38″)	-	-	-	-	0.523722 (30°0′25″)	0.000291 (1′0″)	-0.001121 (-3′51″)	-1.00
P / mm	0.99944	0.00019	-	-	-	-	0.9996	0.00025	0.0002	0.26











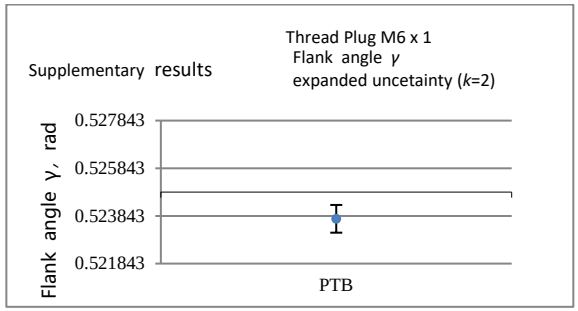
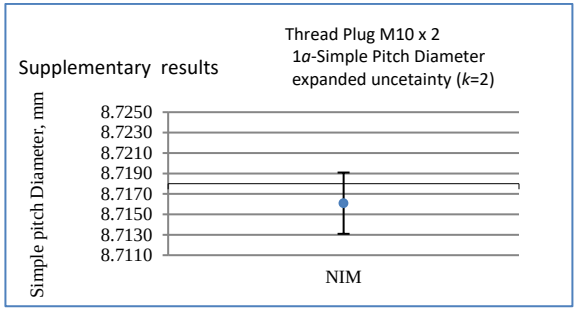
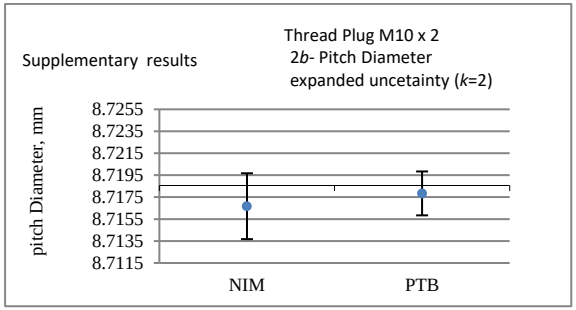
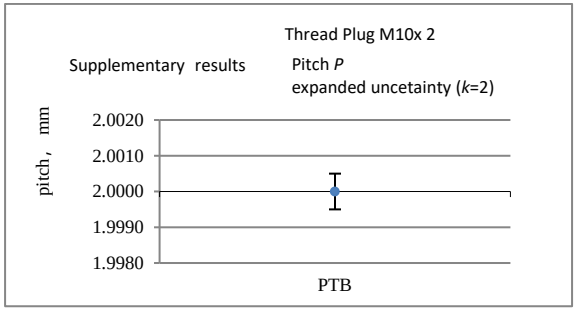


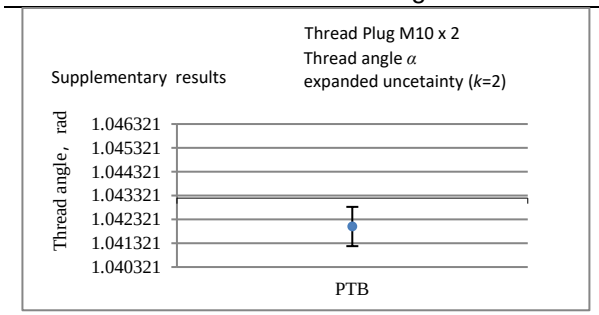
Table A- 2 Thread plug M10 x 2- supplementary measurement results and with respect to SRCV

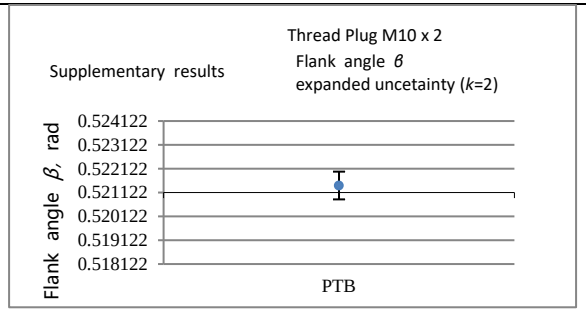
MEASURAND	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	NIM				PTB			
			Measured value	u (k=1)	$x_i - \bar{x}_w$	En	Measured value	u (k=1)	$x_i - \bar{x}_w$	En
Simple pitch Diameter $1a$-d_2 / mm	8.71801	0.00051	8.7161	0.0015	-0.0019	-0.60	-	-	-	-
Pitch diameter $2b$-d_2 / mm	8.71852	0.00056	8.7166	0.0015	-0.0019	-0.60	8.7178	0.0010	-0.0007	-0.32
α / rad	1.043213 (59° 46′18″)	0.000364 (1′15″)	-	-	-	-	1.042022 (59°42′12″)	0.000412 (1′25″)	-0.001191 (-4′6″)	-1.08
β / rad	0.521122 (29° 51′29″)	0.000689 (2′22″)	-	-	-	-	0.521417 (29°52′30″)	0.000291 (1′0″)	0.000295 (1′1″)	0.20
γ / rad	0.522091 (29° 54′49″)	0.000593 (2′2″)	-	-	-	-	0.520605 (29°49′42″)	0.000291 (1′0″)	-0.001486 (-5′7″)	-1.12
P / mm	1.99993	0.00019	-	-	-	-	2.0000	0.00025	0.0001	0.11











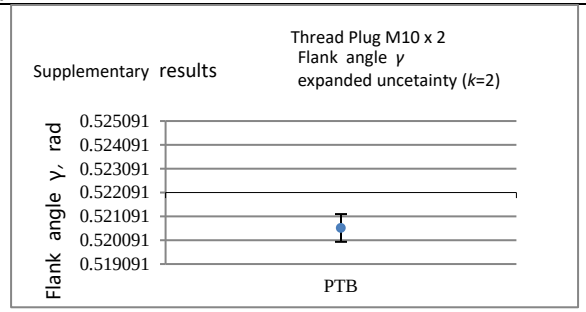
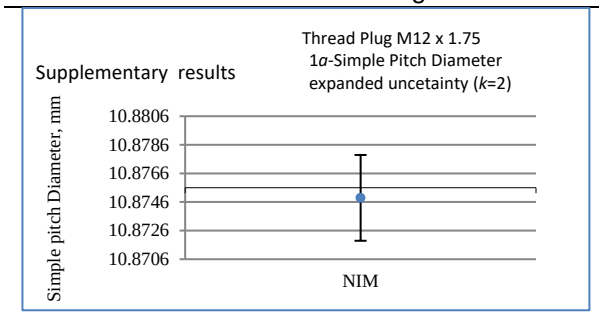
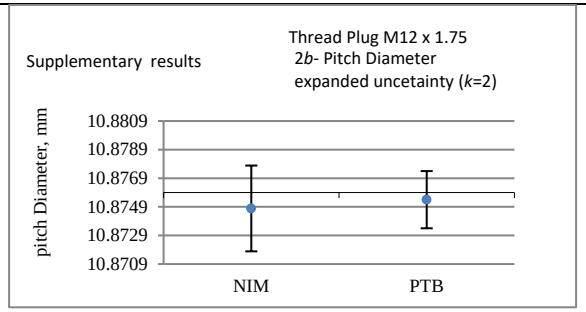
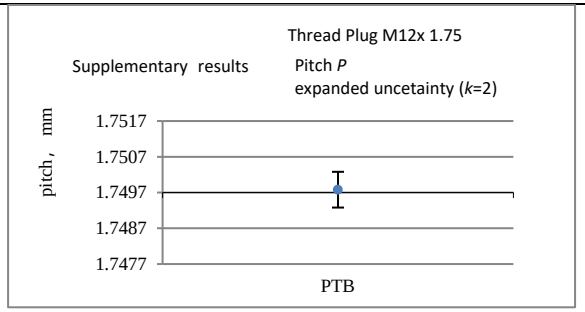


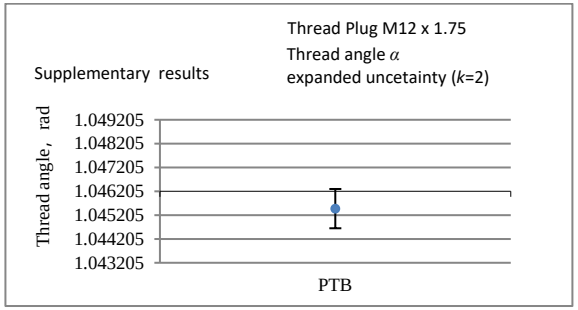
Table A- 3 Thread plug M12 x 1.75- supplementary measurement results and with respect to SRCV

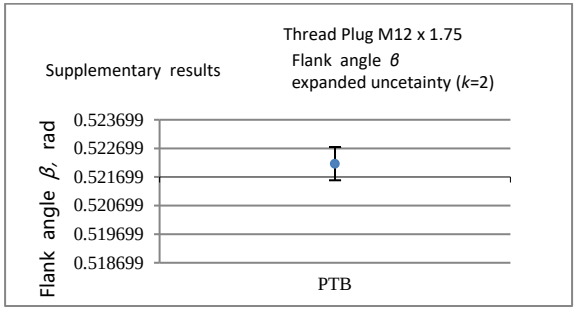
MEASURAND	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	NIM				PTB			
			Measured value	u (k=1)	$x_i - \bar{x}_w$	En	Measured value	u (k=1)	$x_i - \bar{x}_w$	En
Simple pitch Diameter $1a$-d_2 / mm	10.87561	0.00045	10.8749	0.0015	-0.0007	-0.23	-	-	-	-
Pitch diameter $2b$-d_2 / mm	10.87590	0.00056	10.8748	0.0015	-0.0011	-0.34	10.8754	0.0010	-0.0005	-0.22
α / rad	1.046205 (59° 56′35″)	0.000384 (1′19″)	-	-	-	-	1.045477 (59°54′5″)	0.000412 (1′25″)	-0.000728 (-2′30″)	-0.65
β / rad	0.521699 (29° 53′28″)	0.000416 (1′26″)	-	-	-	-	0.522165 (29°55′4″)	0.000291 (1′0″)	0.000466 (1′36″)	0.46
γ / rad	0.524502 (30°3′6″)	0.000387 (1′20″)	-	-	-	-	0.523312 (29°59′1″)	0.000291 (1′0″)	-0.001190 (-4′5″)	-1.23
P / mm	1.74971	0.00019	-	-	-	-	1.7498	0.00025	0.0001	0.14











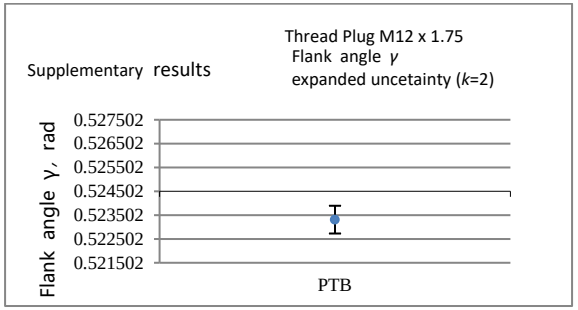
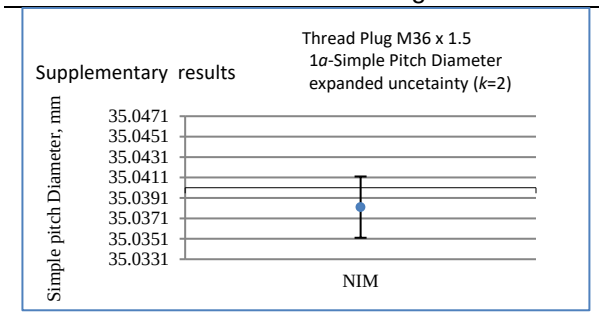
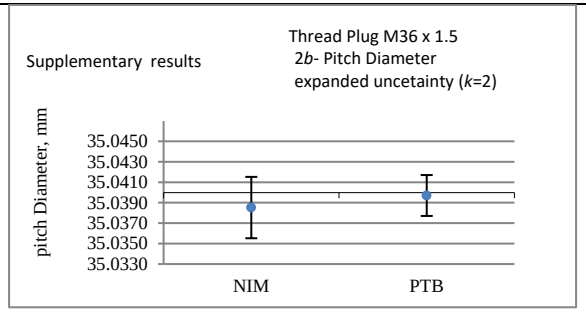
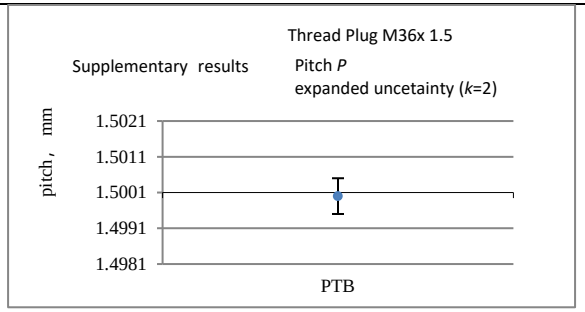


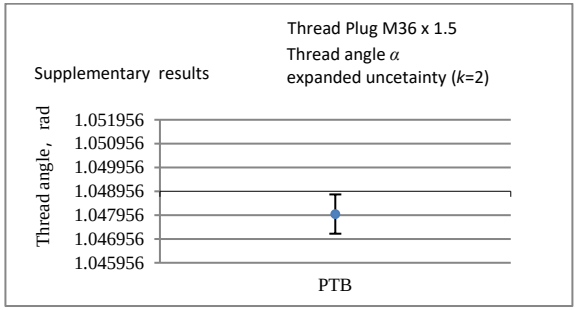
Table A- 4 Thread plug M36 x 1.5- supplementary measurement results and with respect to SRCV

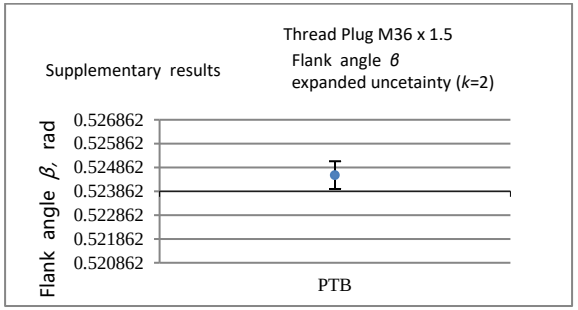
MEASURAND	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	NIM				PTB			
			Measured value	u (k=1)	$x_i - \bar{x}_w$	En	Measured value	u (k=1)	$x_i - \bar{x}_w$	En
Simple pitch Diameter $1a$-d_2 / mm	35.04014	0.00045	35.0382	0.0015	-0.0019	-0.62	-	-	-	-
Pitch diameter $2b$-d_2 / mm	35.03998	0.00054	35.0385	0.0015	-0.0015	-0.46	35.0397	0.0010	-0.0003	-0.12
α / rad	1.048956 (60°6′3″)	0.000406 (1′24″)	-	-	-	-	1.048000 (60°2′46″)	0.000412 (1′25″)	-0.000956 (-3′17″)	-0.83
β / rad	0.523862 (30°0′54″)	0.000370 (1′16″)	-	-	-	-	0.524540 (30°3′14″)	0.000291 (1′0″)	0.000678 (2′20″)	0.72
γ / rad	0.525094 (30°5′8″)	0.000343 (1′11″)	-	-	-	-	0.523460 (29°59′31″)	0.000291 (1′0″)	-0.001634 (-5′37″)	-1.81
P / mm	1.50011	0.00019	-	-	-	-	1.5000	0.00025	-0.0001	-0.18











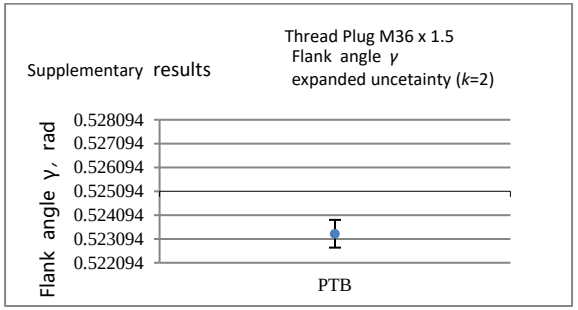
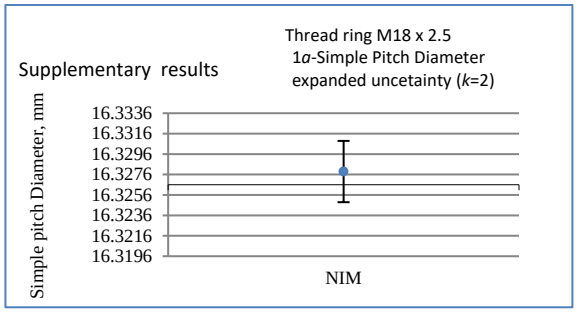
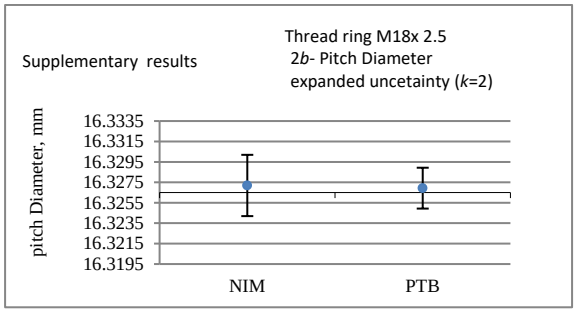
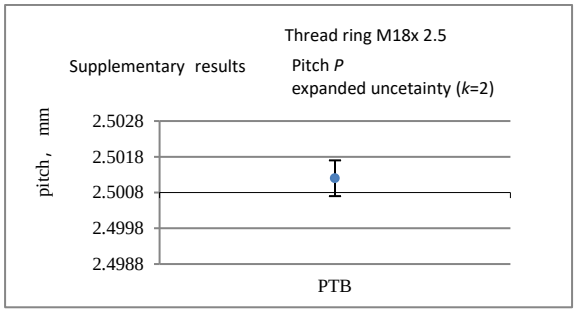


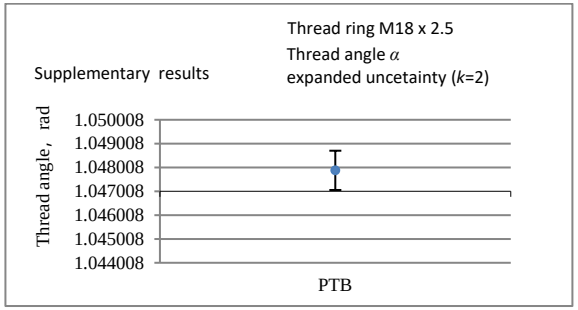
Table A- 5 Thread ring M18 x 2.5-supplementary measurement results and with respect to SRCV

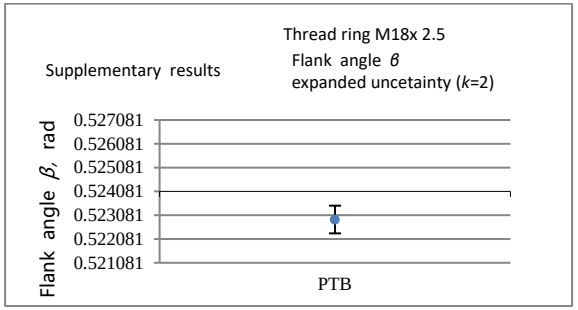
MEASURAND	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	NIM				PTB			
			Measured value	u (k=1)	$x_i - \bar{x}_w$	En	Measured value	u (k=1)	$x_i - \bar{x}_w$	En
Simple pitch Diameter $1a$-D_2 / mm	16.32661	0.00051	16.3279	0.0015	0.0013	0.41	-	-	-	-
Pitch diameter $2b$-D_2 / mm	16.32647	0.00056	16.3272	0.0015	0.0007	0.22	16.3269	0.0010	0.0004	0.19
α / rad	1.047008 (59° 59′21″)	0.000364 (1′15″)	-	-	-	-	1.047886 (60°2′22″)	0.000412 (1′25″)	0.000878 (3′1″)	0.80
β / rad	0.524081 (30°1′39″)	0.000562 (1′56″)	-	-	-	-	0.522899 (29°57′36″)	0.000291 (1′0″)	-0.001182 (-4′4″)	-0.93
γ / rad	0.522927 (29° 57′41″)	0.000625 (2′9″)	-	-	-	-	0.524987 (30°4′46″)	0.000291 (1′0″)	0.002060 (7′5″)	1.49
P / mm	2.50081	0.00019	-	-	-	-	2.5012	0.00025	0.0004	0.61











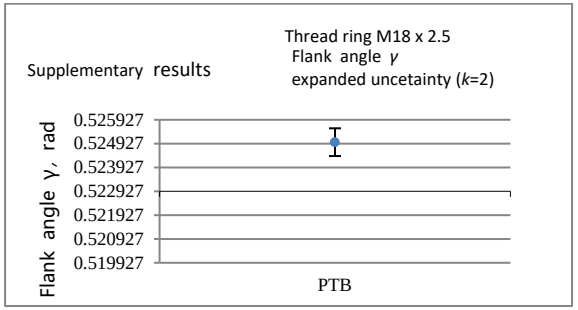
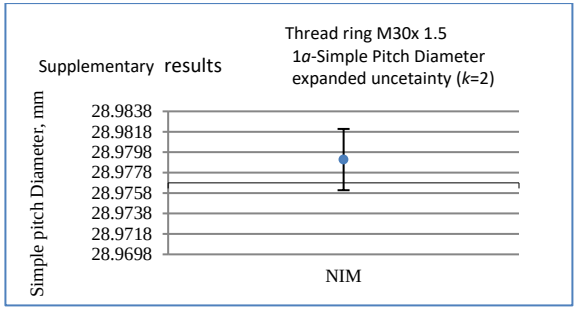
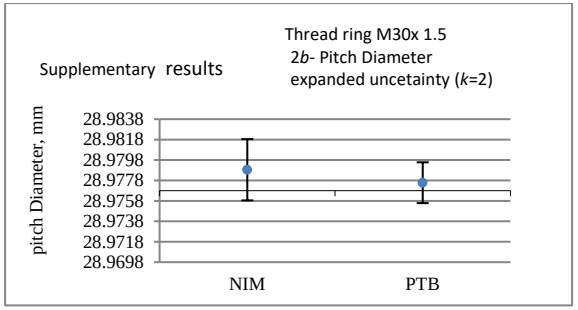
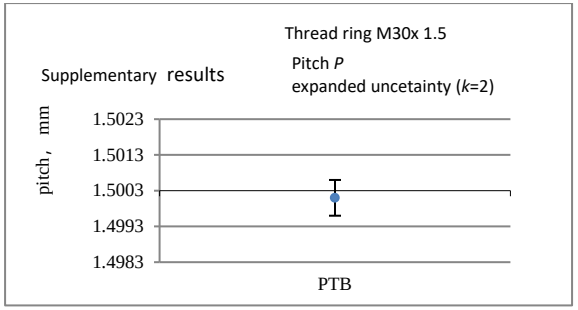


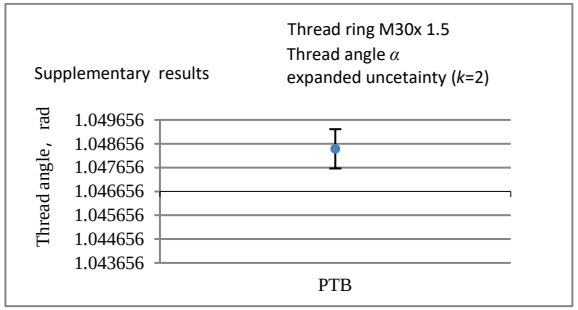
Table A- 6 Thread ring M30 x 1.5-supplementary measurement results and with respect to SRCV

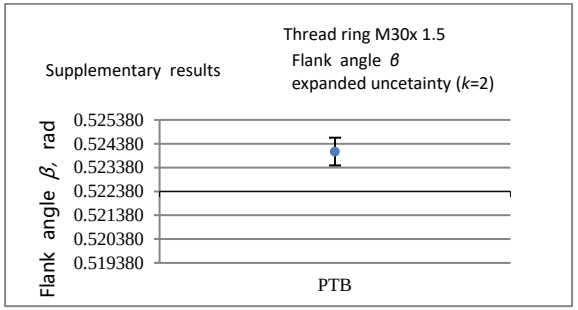
MEASURAND	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	NIM				PTB			
			Measured value	u (k=1)	$x_i - \bar{x}_w$	En	Measured value	u (k=1)	$x_i - \bar{x}_w$	En
Simple pitch Diameter $1a$-D_2 / mm	28.97682	0.00051	28.9791	0.0015	0.0023	0.72	-	-	-	-
Pitch diameter $2b$-D_2 / mm	28.97682	0.00056	28.9789	0.0015	0.0021	0.64	28.9776	0.0010	0.0008	0.34
α / rad	1.046656 (59°58′8″)	0.000406 (1′24″)	-	-	-	-	1.048443 (60°4′17″)	0.000412 (1′25″)	0.001787 (6′9″)	1.54
β / rad	0.522380 (29° 55′49″)	0.000370 (1′16″)	-	-	-	-	0.524052 (30°1′33″)	0.000291 (1′0″)	0.001672 (5′45″)	1.78
γ / rad	0.524310 (30°2′27″)	0.000343 (1′11″)	-	-	-	-	0.524391 (30°2′43″)	0.000291 (1′0″)	0.000081 (0′17″)	0.09
P / mm	1.50029	0.00019	-	-	-	-	1.5001	0.00025	-0.0002	-0.30











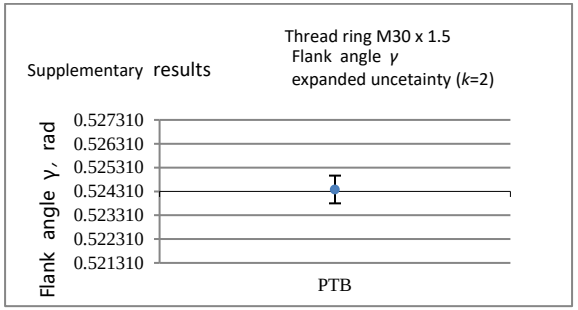
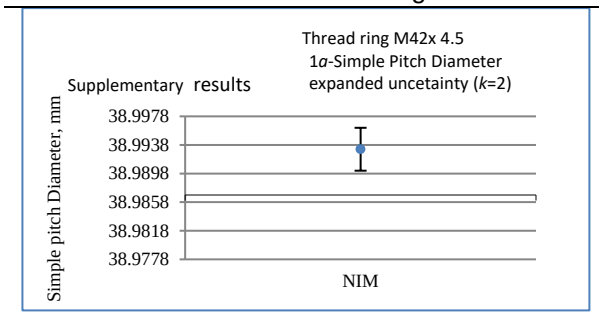
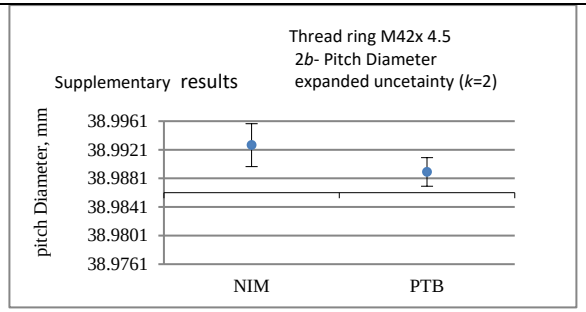
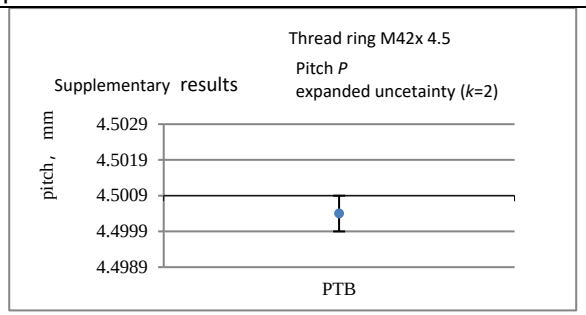


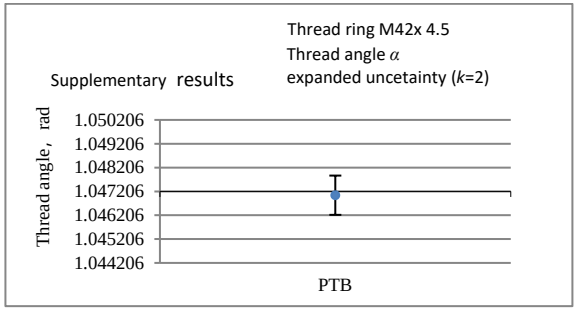
Table A- 7 Thread ring M42 x 4.5-supplementary measurement results and with respect to SRCV

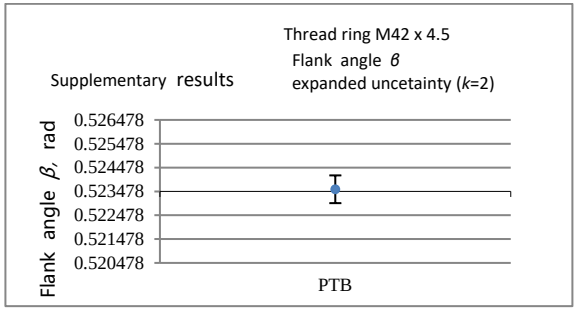
MEASURAND	$\bar{x}_w$	$u_{int(\bar{x}_w)}$	NIM				PTB			
			Measured value	u (k=1)	$x_i - \bar{x}_w$	En	Measured value	u (k=1)	$x_i - \bar{x}_w$	En
Simple pitch Diameter $1a$-D_2 / mm	38.98681	0.00057	38.9932	0.0015	0.0064	1.99	-	-	-	-
Pitch diameter $2b$-D_2 / mm	38.98606	0.00067	38.9927	0.0015	0.0067	2.04	38.9890	0.0010	0.0029	1.22
α / rad	1.047206 (60°0′2″)	0.000416 (1′26″)	-	-	-	-	1.047046 (59°59′29″)	0.000412 (1′25″)	-0.000160 (-0′33″)	-0.14
β / rad	0.523478 (29° 59′35″)	0.000348 (1′12″)	-	-	-	-	0.523568 (29°59′54″)	0.000291 (1′0″)	0.000090 (0′18″)	0.10
γ / rad	0.523724 (30°0′26″)	0.000292 (1′0″)	-	-	-	-	0.523478 (29°59′35″)	0.000291 (1′0″)	-0.000246 (-0′51″)	-0.30
P / mm	4.50090	0.00019	-	-	-	-	4.5004	0.00025	-0.0005	-0.80

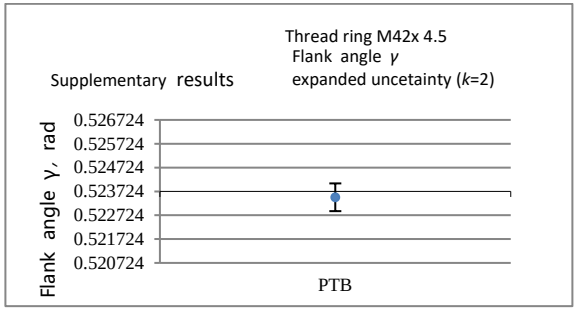

Thread ring M42x 4.5
1a-Simple Pitch Diameter
expanded uncetainty (k=2)
Supplementary results
Simple pitch Diameter, mm
38.9978
38.9938
38.9898
38.9858
38.9818
38.9778
NIM


Thread ring M42x 4.5
2b- Pitch Diameter
expanded uncetainty (k=2)
Supplementary results
pitch Diameter, mm
38.9961
38.9921
38.9881
38.9841
38.9801
38.9761
NIM
PTB


Thread ring M42x 4.5
Pitch P
expanded uncetainty (k=2)
Supplementary results
pitch, mm
4.5029
4.5019
4.5009
4.4999
4.4989
PTB


Thread ring M42x 4.5
Thread angle α
expanded uncetainty (k=2)
Supplementary results
Thread angle, rad
1.050206
1.049206
1.048206
1.047206
1.046206
1.045206
1.044206
PTB


Thread ring M42 x 4.5
Flank angle β
expanded uncetainty (k=2)
Supplementary results
Flank angle β, rad
0.526478
0.525478
0.524478
0.523478
0.522478
0.521478
0.520478
PTB


Thread ring M42x 4.5
Flank angle γ
expanded uncetainty (k=2)
Supplementary results
Flank angle γ, rad
0.526724
0.525724
0.524724
0.523724
0.522724
0.521724
0.520724
PTB