TÜBİTAK UME
National Metrology Institute of Turkey

Exercise for Intercomparison Measurements in West Balkans

Calibration of Short Gauge Blocks by Mechanical Comparison

(EURAMET Project 1237)

Final REPORT

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1. Introduction

The metrological equivalence of national measurement standards and of calibration certificates issued by National Metrology Institutes are established by a set of key and supplementary comparisons chosen and organized by the Consultative Committees of the CIPM working closely with the Regional Metrology Organizations (RMOs) [1].

At its meeting in September 1997, the Consultative Committee for Length, CCL, identified several key comparisons in the field of dimensional metrology. In particular, it decided that a key comparison on gauge block measurements shall be carried out. This key comparison, CCL-K1, and its EURAMET equivalents (EUROMET.L-K1 and subsequent comparison EUROMET.L-K1.1) have been completed and the final reports are published [2].

These key comparisons involve measurement by interferometry. Several EURAMET members perform gauge block measurements by comparison and require participation in a suitable supplementary comparison, for purposes of supporting their CMC claims. Previous supplementary comparisons, EUROMET.L-S12 and EUROMET.L-S16 completed their circulation and data was made public [2].

The *Focus Group (FG) on Facilitating National Metrology Infrastructure Development* was concerned with facilitating cooperation and acceleration of the integration process of EURAMET members and associates and WELMEC associates into existing EURAMET and WELMEC structures. Currently these activities are performed in Working Group for Capacity Building.

In the FG meeting (2010), it was decided to conduct an intercomparison on short gauge blocks by mechanical comparison with the purpose of providing new EURAMET NMIs with exercise in participating in an intercomparison. The discussion whether to register this intercomparison as an official EURAMET supplementary comparison was carried out and it was decided in FG meeting (2011) that this comparison would not be official comparison. It would be an exercise with 2 days preparatory workshop at the initialisation stage and would be piloted by TUBITAK UME.

The workshop was carried out in TUBITAK UME (Turkey) in 5-6 July 2012 with the sponsorship of PTB (National Metrology Institute of Germany) Cooperation Project. Report of the workshop was published in EURAMET website. This report gives information about the workshop and also summaries **the actions to be taken by the participants.**

Following to workshops, several problems occurred to complete the list of actions and comparison. Delay occurred. However, support was given to those NMIs that completed the exercise measurements. The deviation of their results from TUBITAK UME value with the uncertainties were shared with them so that they can take required actions when they participate to MRA comparison. This was very successful. For example, MBM has taken part in EURAMET.L-S22 [2] and had very successful results. Basically they were trained through workshop in TUBITAK UME and then had this exercise comparison to see the operator performance and their device. Later, they have applied CMC on short gauge block calibration and now they have a CMC entry on KCDB. (*https://kcdb.bipm.org/AppendixC/L/ME/L_ME.pdf*).

Other countries were directed to participate MRA comparisons as well. For instance, SASO-NMCC of Saudi Arabia (added to project at the end of the comparison), and DPM of Albania have participated in MRA comparison in GULFMET region (GULFMET.L-S1 [2]). Evaluation of this comparison is in progress.

2. Organisation

The protocol document for this comparison and this report have been based on the corresponding documents for previous comparison EUROMET.L-S12 and S16. The protocol document was issued to all participants at the start of the comparison.

2.1. Participants

The participant list attending the workshop (2012) is given below with contact address. Initially, they were supposed to participate this comparison.

Table 1. List of participant laboratories and their contacts in the workshop 2012 (TUBITAK UME)

	Pilot	**Address for shipping the items**	**Contact information**
TR	Tanfer Yandayan (Instructor) S. Aslı Akgöz Tamer Çetin	TUBITAK-UME, Anibal Cad. Gebze Yerleşkesi PK54 - 41470 Gebze-Kocaeli / **TURKEY**	Tel. +90 262 679 5000 Fax +90 262 679 5001 e-mail: tanfer.yandayan@tubitak.gov.tr asli.akgoz@tubitak.gov.tr tamer.cetin@tubitak.gov.tr

	Participants	**Address for shipping the items**	**Contact information**
AL	Vjollca Dedolli Altin Cibuku	Rruga “Sami Frasheri” Nr.33, Tirane, **ALBANIA** *(or it may change when we are moving in a new building)*	Tel: +355 4 2 233 174 Fax: +355 4 2 22 82 44 e-mail: vjollca.dedolli@dpmk.gov.al e-mail: altin.cibuku@dpmk.gov.al
MK	Biljana Atanasov Danco Pendovski	Bureau of metrology - Skopje Bul.:"Jane Sandanski" 109-a **MACEDONIA**	phone:++389 2 24 03 676 ex.030 fax: ++389 2 24 44 677 e-mail: biljana.atanasov@bom.gov.mk phone:++389 2 24 03 676 ex.021,022 fax: ++389 2 24 44 677 e-mail: pendovski.danco@bom.gov.mk
ME	Gordana Bajic Mira Karanfilovic	Bureau of Metrology, Laboratory for length Kralja Nikole 2, 81000 Podgorica, **MONTENEGRO**	el: +382 20 601 360; 601 361 fax: +382 20 634 652 gordana.bajic@metrologija.gov.me goran.vukoslavovic@metrologija.gov.me mira.karanfilovic@metrologija.gov.me
BA	Alen Bosnjakovic	Institute of Metrology of B&H Augusta Brauna 2, 71000 Sararajevo **Bosnia and Herzegovina**	Phone: +387 33 568 930 Fax: +387 33 568 909 alen.bosnjakovic@met.gov.ba alenbosnjakovic@gmail.com

The below was the original time table planned for the comparison.

Table 2 Planned time table for the comparison

Laboratory	**Country**	**Date**
TUBITAK UME	TR	9 July 2012 – 9 Aug 2012
BoM	MK	17 Sep. – 17 Oct. 2012
MBM	ME	18 Oct – 19 Nov 2012
DPM **(ATA CARNET Problem)**	AL	20 Nov – 20 Dec 2012
MBM **(Only for delivery purpose)**	ME	20 Dec 2012 – 7 Jan 2013
IMBIH	BIH	8 Jan – 8 Feb 2013
TUBITAK UME	TR	9 Feb – 9 March 2013

Due to various issues and changes, the schedule was changed and the below organisations participated to EURAMET 1237 intercomparison.

Table 3. List of participant laboratories and their contacts

COUNTRY	**CONTACT**	**ADDRESS**	**PHONE, FAX, EMAIL**
MBM	Gordana Bajić Mira Karanfilovic	Bureau of Metrology of Montenegro, Laboratory for length Kralja Nikole 2, 81000 Podgorica, **MONTENEGRO**	el: +382 20 601 360; 601 361 fax: +382 20 634 652 gordana.bajic@metrologija.gov.me goran.vukoslavovic@metrologija.gov.me mira.karanfilovic@metrologija.gov.me
IMBIH	Allen Bosnjakovic	Institute of Metrology of B&H/Laboratory for production measuring technique, Mechanical Engineering Faculty Sarajevo Augusta Brauna 2, 71000 Sararajevo **Bosnia and Herzegovina**	Phone: +387 33 568 930 Fax: +387 33 568 909 alen.bosnjakovic@met.gov.ba alenbosnjakovic@gmail.com

DPM	**Stilian Habibi**[3] Previous contacs Eda Golemi[2] Vjollca Dedoll[1] Altin Cibuku[1]	Rruga "Sami Frasheri" Nr.33, Tirane, **ALBANIA**	Tel: +355 4 2 233 174 Fax: +355 4 2 22 82 44 **e-mail: stilian.habibi@dpm.gov.al** eda.golemi@dpm.gov.al e-mail: vjollca.dedolli@dpmk.gov.al e-mail: altin.cibuku@dpmk.gov.al
SASO-NMCC	Nasser M. AlQahtani	National Measurement & Calibration Centre (SASO-NMCC) Riyadh, Saudi Arabia	e-mail: n.qahtani@saso.gov.sa
TUBITAK UME	Tanfer Yandayan	TUBITAK-UME, Anibal Cad. Gebze Yerleşkesi PK54 - 41470 Gebze-Kocaeli / **TURKEY**	Tel. +90 262 679 5000 Fax +90 262 679 5001 e-mail: tanfer.yandayan@tubitak.gov.tr

2.2. Schedule

The comparison was organised in a single loop with each laboratory allowed approximately one month in which to make its measurements and to prepare for transportation to the next participant. Some participants had problems with failure of their devices and laboratory conditions. Extension was made by the pilot to complete the exercise.

The pilot laboratory, TUBITAK UME made several measurements to check the stability of the artefacts, but only its first set of comparison measurements is reported in the main results.

Table 4. Schedule of the participants

Laboratory	Country	Date
TUBITAK UME (as UME in the graphs)	TR	01.08.2012 - 01.09.2012
MBM	ME	04.04.2013 - 08.05.2013
IMBIH	BIH	25.05.2013 - 19.07.2013
DPM	AL	01.05.2015 - 20.10.2015
SASO-NMCC (as SASO in the graphs)	SA	01.03.2017 - 28.06.2017

Remarks for the schedule and participants

Note 1: BoM (Macedonia) had problems with their GB comparator. They intend to buy new one. Since they did not have one, they did not participate.

Note 2: DPM (Albania) has moved their equipment to their new laboratories. There was also change in their staff. New staff (Eda Golemi) visited TUBITAK UME for a few days and had taken short training under this cooperation project. Then DPM has participated in comparison.

Note 3: IMBIH (Bosnia and Herzegovina) have not Gauge Block Comparator.
But they decided to use GB comparator of an organisation in Bosnia and Herzegovina. This was possible as this is an exercise intercomparison. However, IMBIH requested no to publish their results since the comparison results of IMBIH were not taken by devices in IMBIH premises. Therefore name of IMBIH was given in the graphs and tables with no results.

Note 4: SASO-NMCC (Saudi Arabia) wanted to measure the GBs. This was requested during EURAMET TC-L meeting. It was accepted and SASO-NMCC was added to the list.

2.3. Standards

The circulated artefacts were 9 gauge blocks of steel. The gauge blocks were of grade K and of rectangular cross section, nominally according to the international standard ISO 3650. The standards were supplied in a custom made transport case, fashioned from aluminium and steel, containing high density foam, sculpted to make a tight fit with the gauge blocks, to prevent any motion of the gauge blocks and generation of excessive bending forces.

Table 5. Standards used in the comparison

Identification	Nominal length (mm)	Coefficient of Thermal Expansion (CTE) (10^{-6} K^{-1})	Manufacturer
50777	0.5	10,8	Mitutoyo
50857	1	10,8	Mitutoyo
50753	2	10,8	Mitutoyo
50827	4.5	10,8	Mitutoyo
56475	10	10,8	Mitutoyo
51833	12	10,8	Mitutoyo
53564	25	10,8	Mitutoyo
52193	50	10,8	Mitutoyo
51312	100	10,8	Mitutoyo

3. Measurement instructions and reporting of results

Before calibration, the gauge blocks had to be inspected for damage to the measurement surfaces. Any scratches, rusty spots or other damages had to be documented by a drawing or sketching in the appropriate form appended to the instructions.

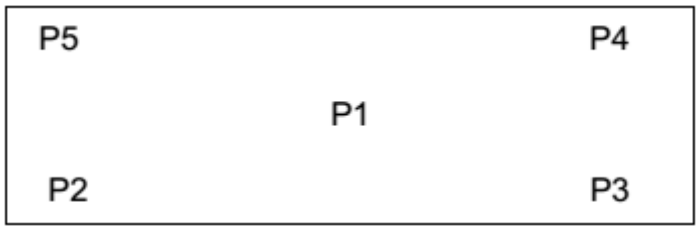
The gauge blocks had to be measured by mechanical comparison with the laboratory's reference gauge blocks, using the normal calibration procedure.

The followings are the measurands for each gauge block:

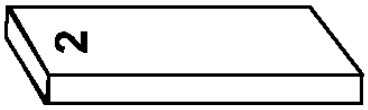
- Deviation of the central length (at P1 in figure below) from the nominal length;
- Where possible, deviation from nominal length, measured at points P2 to P5. These values will be used by the pilot to calculate f_o and f_u, for each gauge, according to ISO 3650.

The results should be recorded in first page of **Annex 1.**

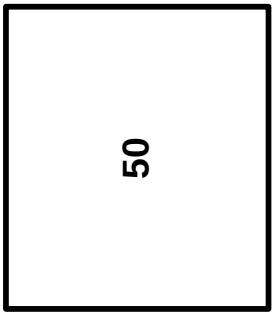
The gauges should be positioned as follows:-



0,5 – 1 – 2 – 4,5 – 5 – 10 mm gauge blocks – the measuring face with the nominal size markings should face upwards with the nominal size mark on the left side of the gauge facing the operator:



12 – 25 – 50 – 100 mm gauge blocks – the side of the gauge with the nominal size marking should be standing vertically, facing the operator with the numerals running up the gauge side:



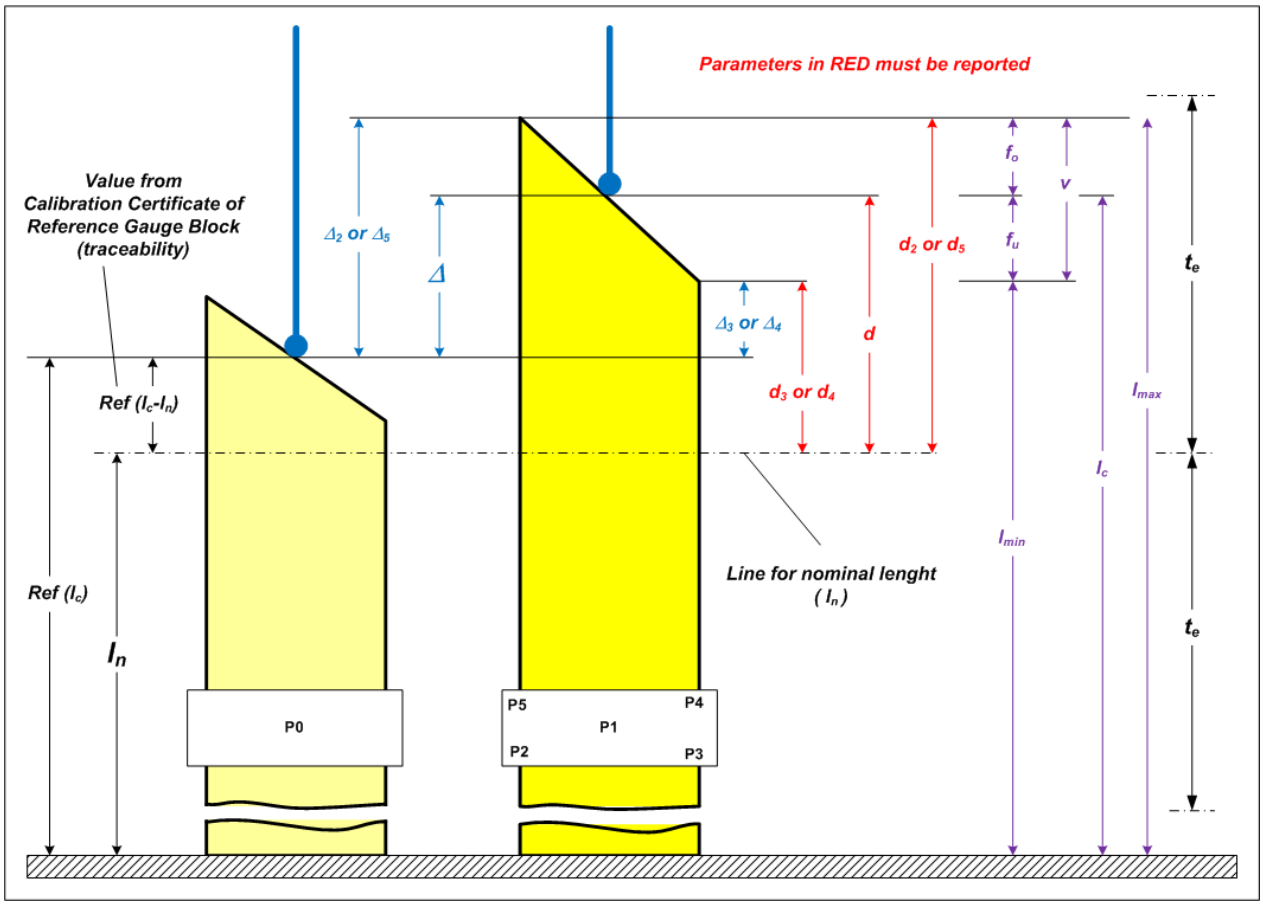


Figure 1. Explanation of the parameters to be reported

4. Stability and condition of the gauge blocks.

The pilot laboratory, TUBITAK UME, has been holding these GBs since 2006 having substantial knowledge on their stability. Besides, TUBITAK UME made several mechanical comparison calibrations before the start and during the comparison. Plotting these results for all GBs reveals that they are stable within the expanded uncertainties of the TUBITAK UME measurements. The below table shows the schedule for the stability tests.

Table 6. Schedule for stability tests

1	September 2012
2	April 2014
3	December 2014
4	December 2016
5	October2017

Figures 2(a) through 2(i) show the measurements of the pilot laboratory used to verify the stability of the gauge blocks' central length. The uncertainty bars in Figures 2(a) through 2(j) are standard uncertainties of the pilot laboratory's usual measurement technique.

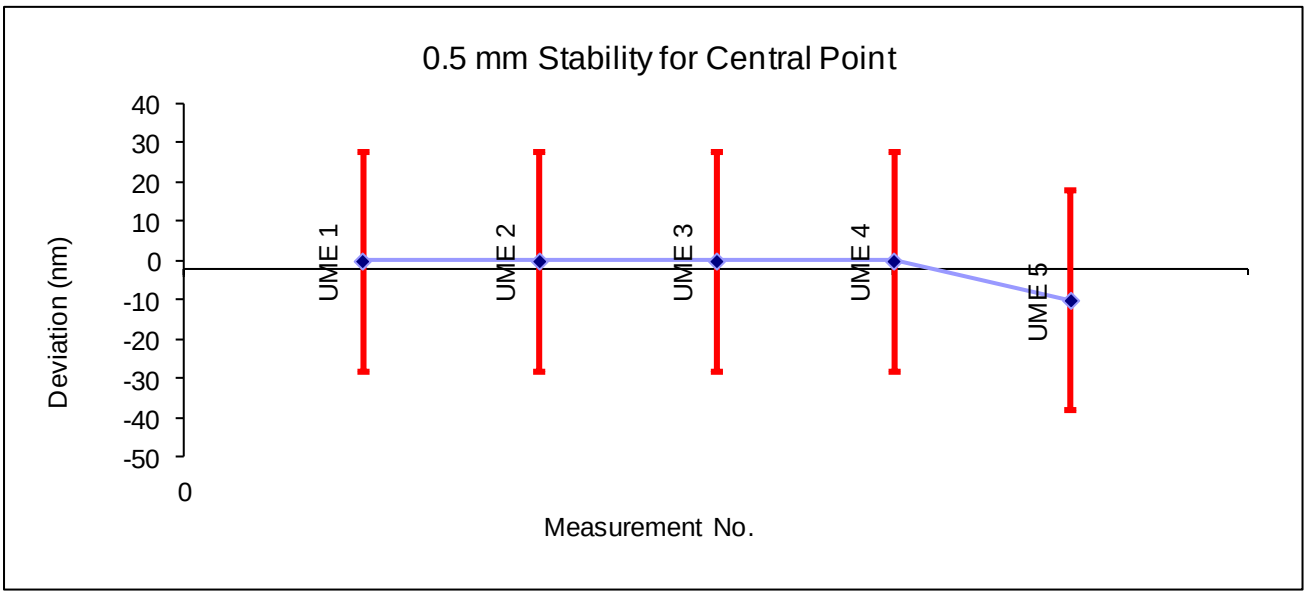


Figure 2 (a) Stability of 0.5 mm gauge block (S/N 50777) during comparison: mechanical comparison length measurements of the pilot laboratory. Uncertainty bars show standard uncertainty (*k*=1).

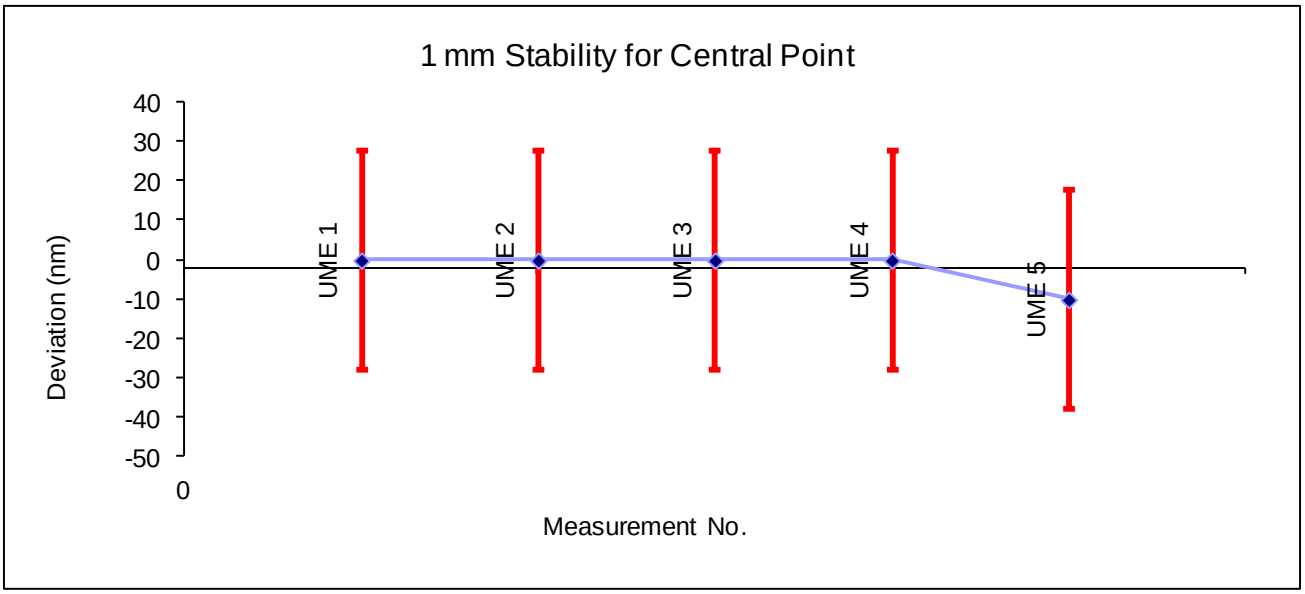


Figure 2(b) Stability of 1 mm gauge block (S/N 50857) during comparison: mechanical comparison measurements of the pilot laboratory. Uncertainty bars show standard uncertainty (*k*=1).

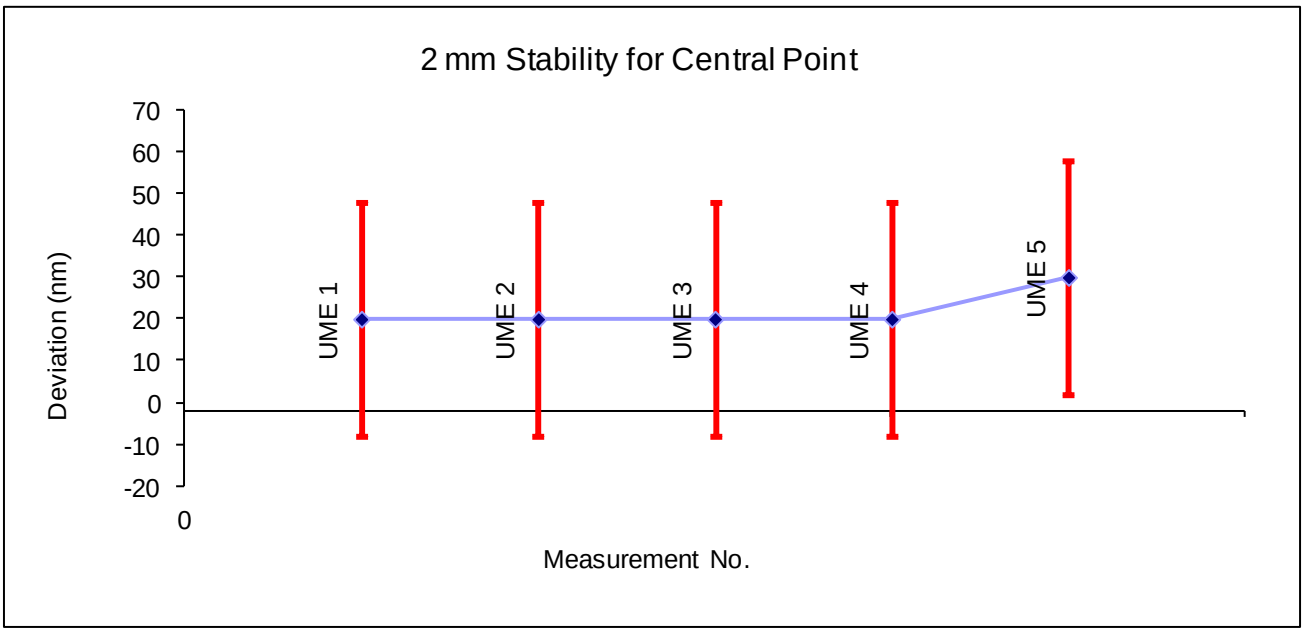


Figure 2(c) Stability of 2 mm gauge block (S/N 50753) during comparison: mechanical comparison measurements of the pilot laboratory. Uncertainty bars show standard uncertainty (*k*=1).

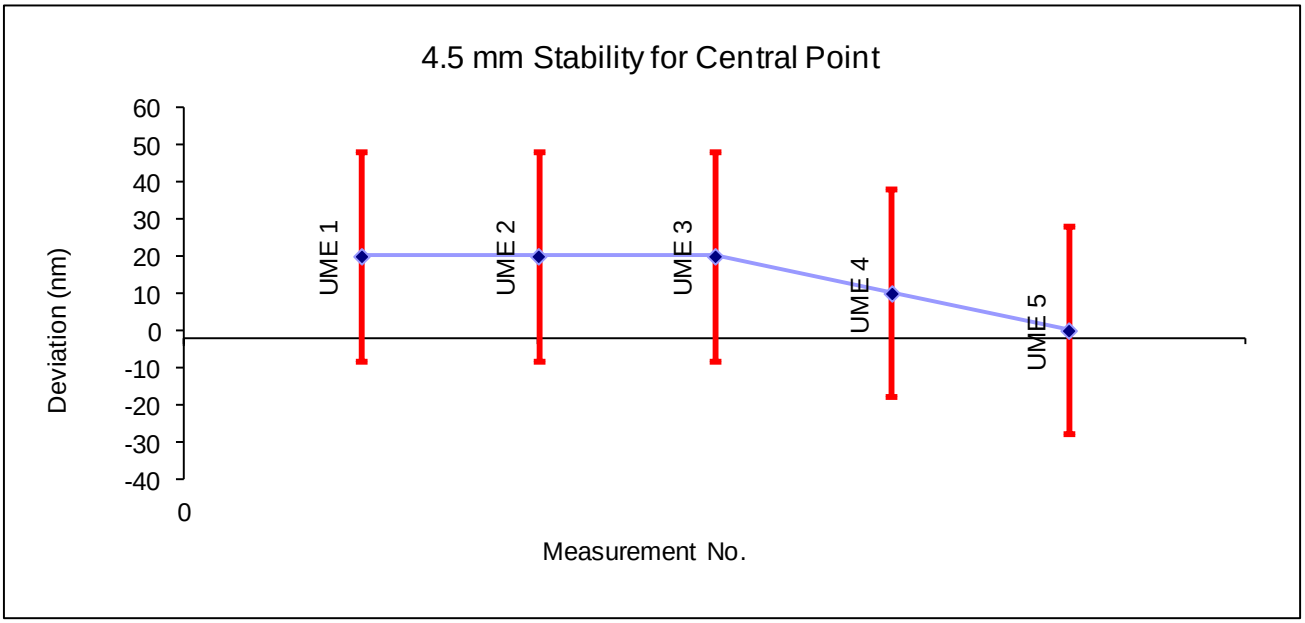


Figure 2(d) Stability of 4.5 mm gauge block (S/N 50827) during comparison: mechanical comparison measurements of the pilot laboratory. Uncertainty bars show standard uncertainty (*k*=1).

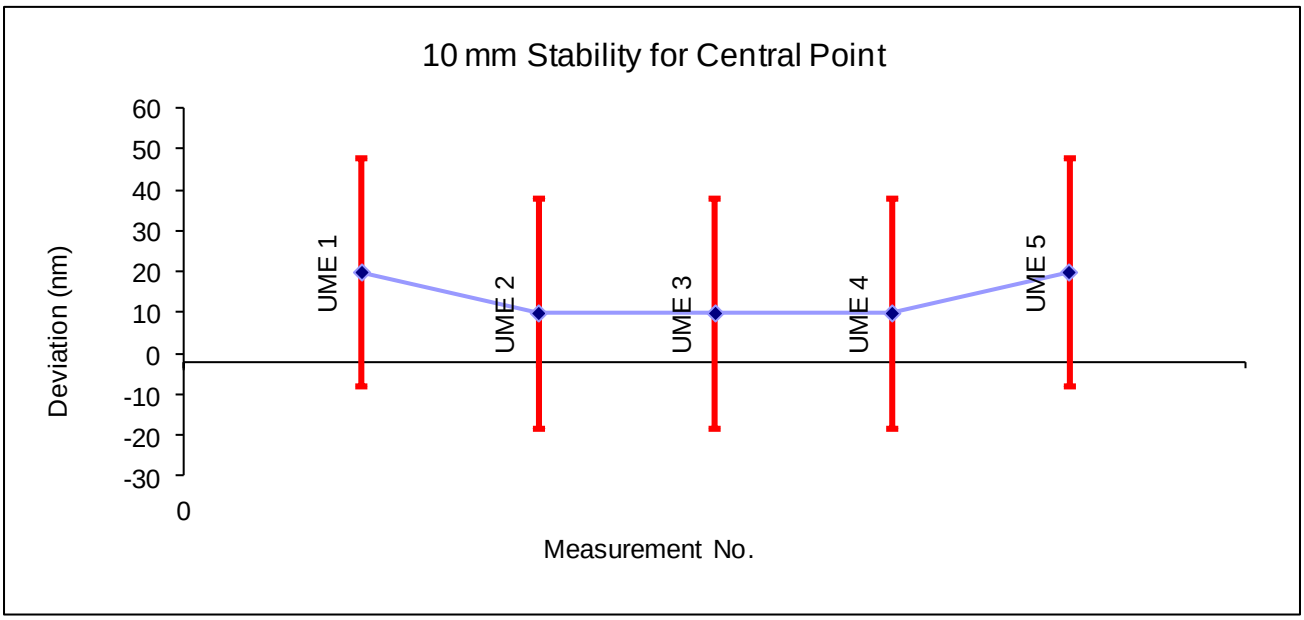


Figure 2(e) Stability of 10 mm gauge block (S/N 56475) during comparison: mechanical comparison measurements of the pilot laboratory. Uncertainty bars show standard uncertainty (*k*=1).

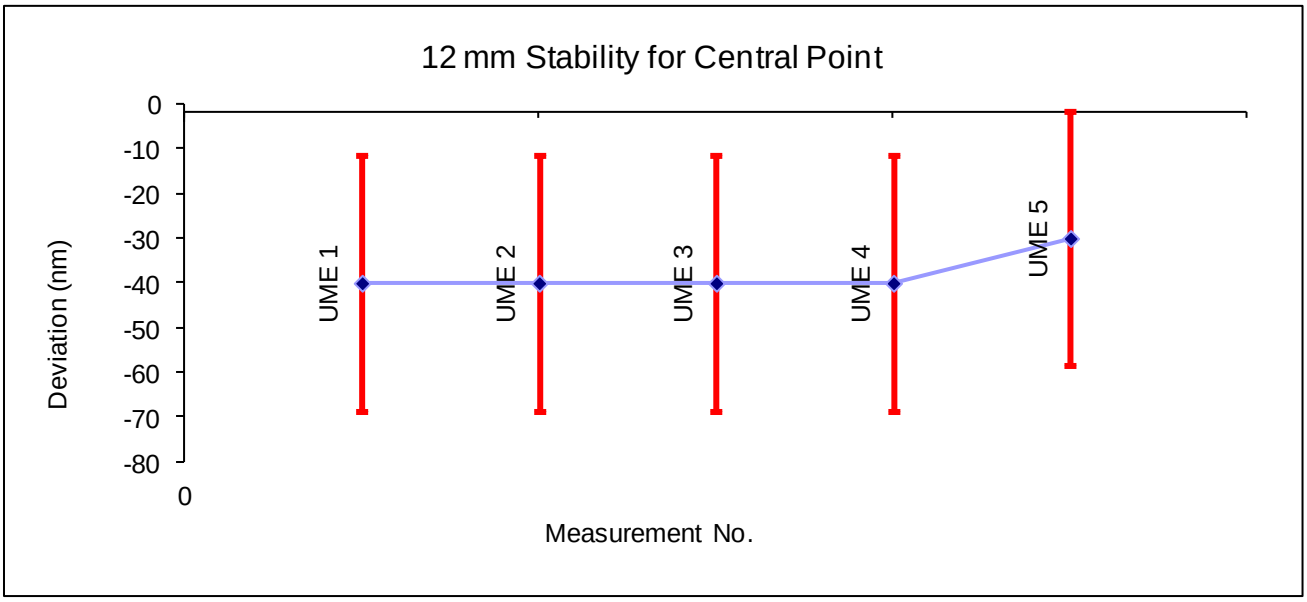


Figure 2(f) Stability of 12 mm gauge block (S/N 51833) during comparison: mechanical comparison measurements of the pilot laboratory. Uncertainty bars show standard uncertainty (k=1).

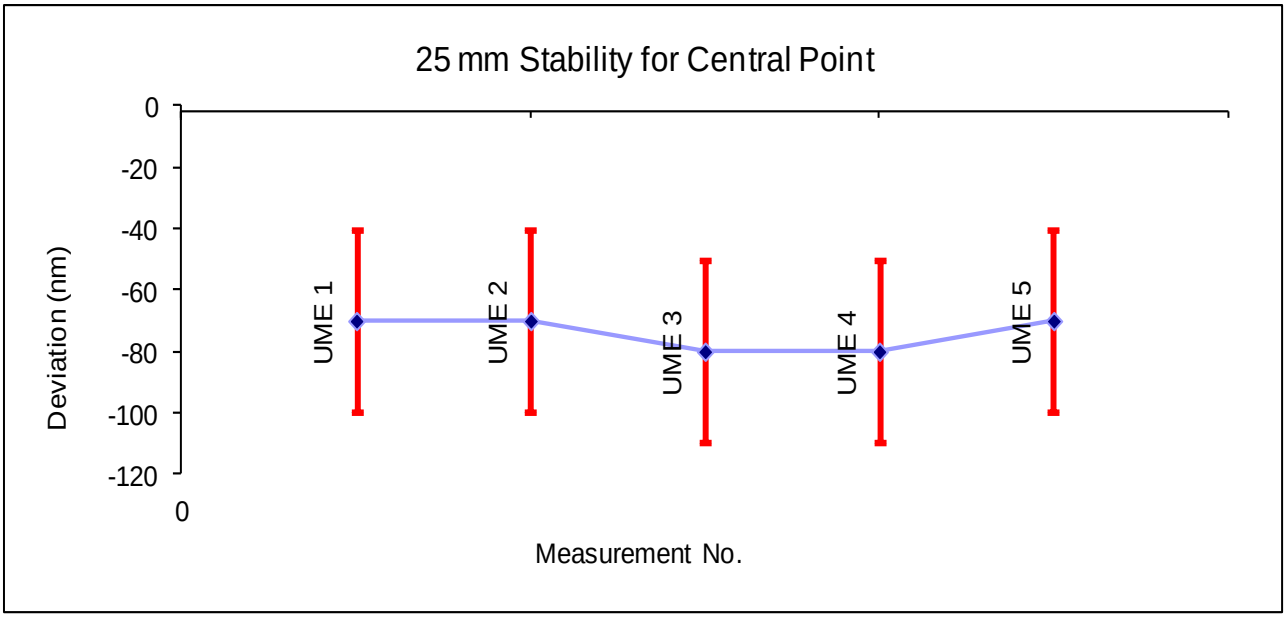


Figure 2(g) Stability of 25 mm gauge block (S/N 53564) during comparison: interferometric length measurements of the pilot laboratory. Uncertainty bars show standard uncertainty (*k*=1).

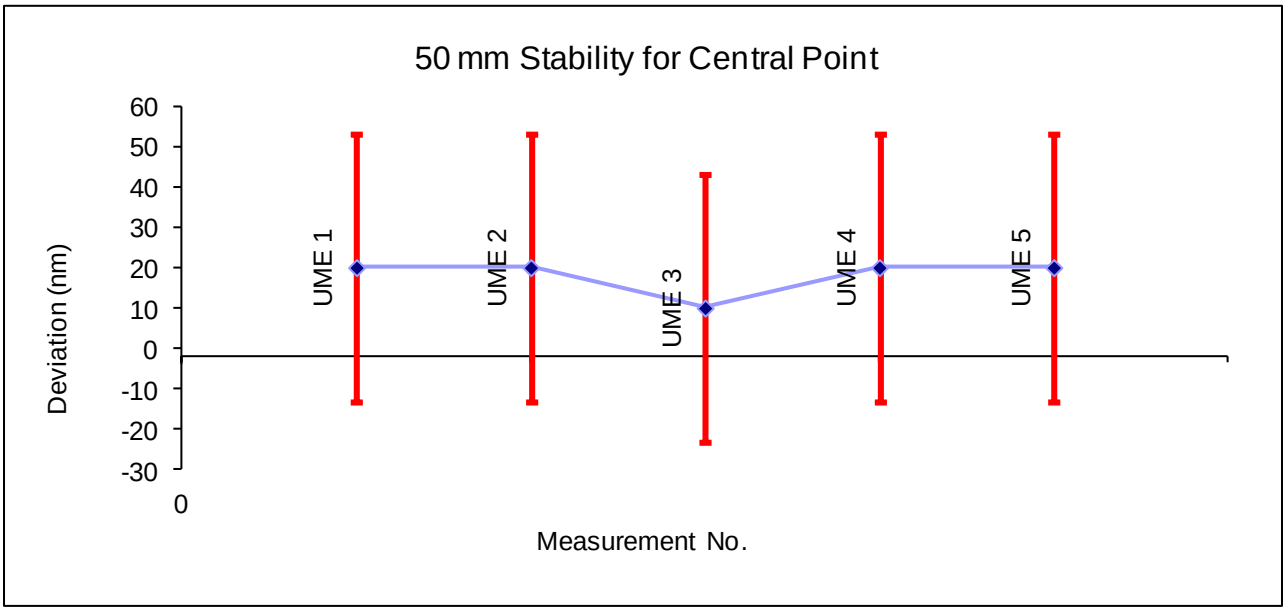


Figure 2(h) Stability of 50 mm gauge block (S/N 52193) during comparison: mechanical comparison measurements of the pilot laboratory. Uncertainty bars show standard uncertainty (*k*=1).

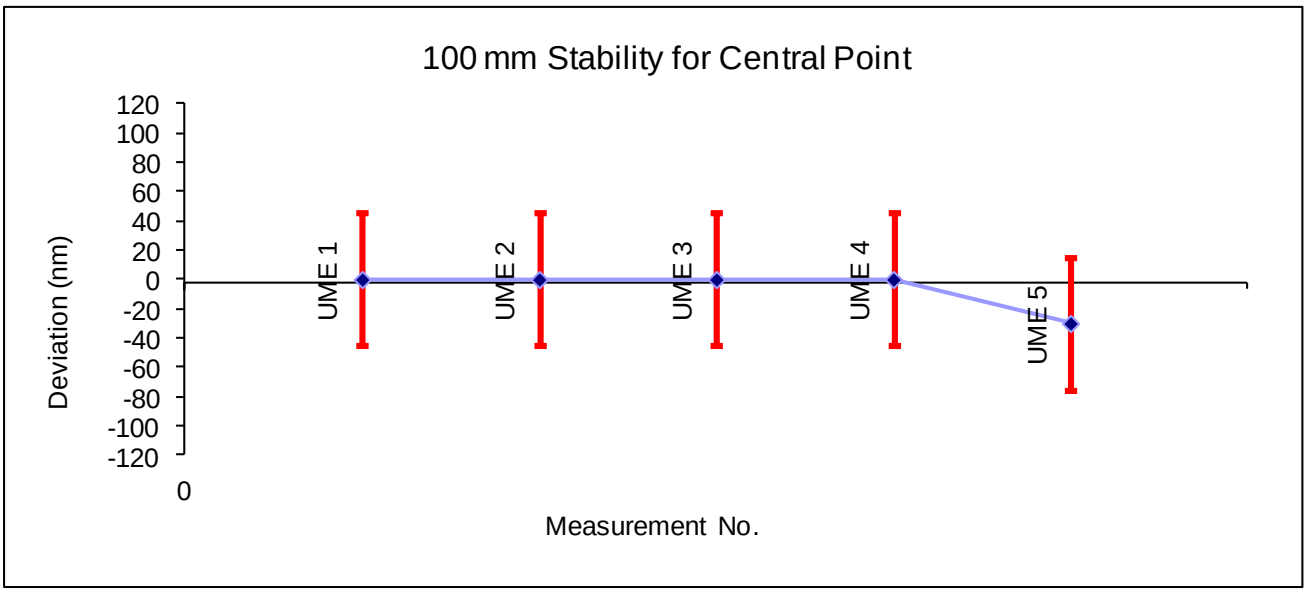


Figure 2(i) Stability of 100 mm gauge block (S/N 51312) during comparison: mechanical comparison measurements of the pilot laboratory. Uncertainty bars show standard uncertainty (*k*=1).

5. Laboratory measurements

The principal equipment used by the participants were a selection of gauge block comparators manufactured by TESA (TUBITAK UME and SASO-NMCC), Mahr (MBM) Feinmess Suhl GmbH - EMP II (DPM) and Carl Zeiss Jena EMP AW 2DH (IMBIH). The comparators of TUBITAK UME, MGM, DPM and IMBIH have resolution of 10 nm and of SASO-NMCC is 0.001 nm. The participants used steel master gauges for the measurements.

The greatest reported temperature deviation from the reference 20 °C was within +/-0.5 °C.

6. Measurement results, as reported by the participants

The results reported by the participants are given in Tables 7 through 15 and Figures 3(a) through 11(a) show the reported deviations from nominal length and Figures 3(b) through 11(b) show the reported with variation in length, standard (*k*=1) uncertainties. Using the reported results of d (d_1), d_2, d_3, d_4 and d_5, variation in length (*v*) values were calculated. Uncertainty of "*v*" values were taken as uncertainty values of d_2, d_3, d_4 and d_5.

Table 7 - 0.5 mm gauge block results

Nominal length	Central deviation from nominal,	Uncertainty (k=2)	Deviation from nominal at P2	Deviation from nominal at P3	Deviation from nominal at P4	Deviation from nominal at P5	Uncertainty (k=2)	Calculeted Variation in length	Uncertainty (k=2)
0.5 mm	d	$U(d)$	d_2	d_3	d_4	d_5	$U(d_i)$	v	$U(v)$
	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
MBM	-20	78	0	10	-60	-70	110	80	110
IMBIH									
DPM	0	96	-10	-15	-29	-44	131	44	131
SASO	-20	56	-20	-20	-20	-20	44	0	44
UME	0	56	20	10	10	0	50	20	50

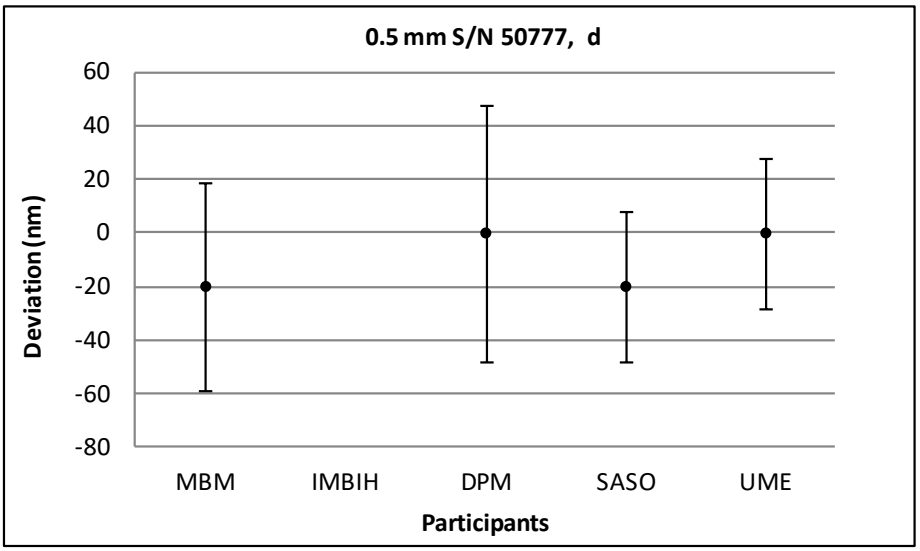


Figure 3(a) - Graph for 0.5 mm gauge block results (k = 1) (Deviation from nominal length)

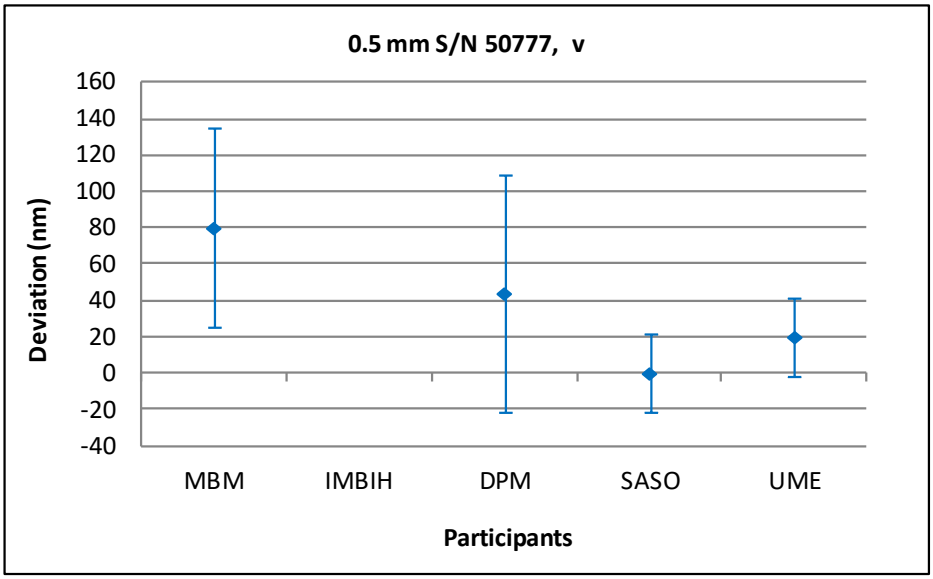


Figure 3(b) - Graph for 0.5 mm gauge block results (k = 1) (Variation in length)

Table 8 - 1 mm gauge block results

Nominal length	Central deviation from nominal,	Uncertainty (k=2)	Deviation from nominal at P2	Deviation from nominal at P3	Deviation from nominal at P4	Deviation from nominal at P5	Uncertainty (k=2)	Calculeted Variation in length	Uncertainty (k=2)
1 mm	d	$U(d)$	d_2	d_3	d_4	d_5	$U(d_i)$	v	$U(v)$
	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
MBM	-10	78	-10	-10	-80	-70	110	70	110
IMBIH									
DPM	-41	95	-93	-17	-34	-98	137	81	137
SASO	-17	56	-4	-24	-7	9	44	33	44
UME	0	56	15	-5	5	5	50	20	50

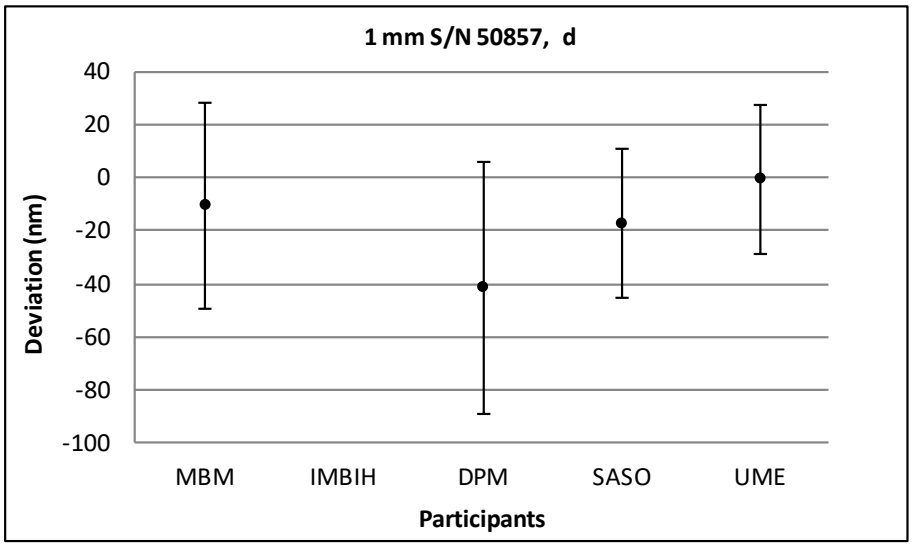


Figure 4(a) - Graph for 1 mm gauge block results (k = 1) (Deviation from nominal length)

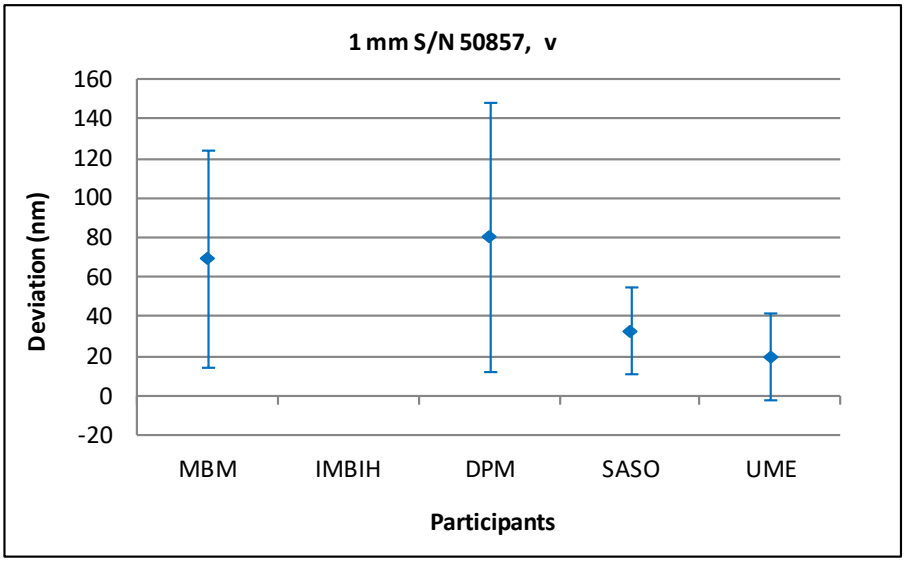


Figure 4(b) - Graph for 1 mm gauge block results (k = 1) (Variation in length)

Table 9 - 2 mm gauge block results

Nominal length	Central deviation from nominal,	Uncertainty (k=2)	Deviation from nominal at P2	Deviation from nominal at P3	Deviation from nominal at P4	Deviation from nominal at P5	Uncertainty (k=2)	Calculeted Variation in length	Uncertainty (k=2)
2 mm	d	$U(d)$	d_2	d_3	d_4	d_5	$U(d_i)$	v	$U(v)$
	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
MBM	-10	78	10	-20	10	10	110	30	110
IMBIH									
DPM	-19	95	-65	-7	4	-41	127	69	127
SASO	-4	56	-8	-4	-11	-14	44	10	44
UME	20	56	45	25	25	25	50	25	50

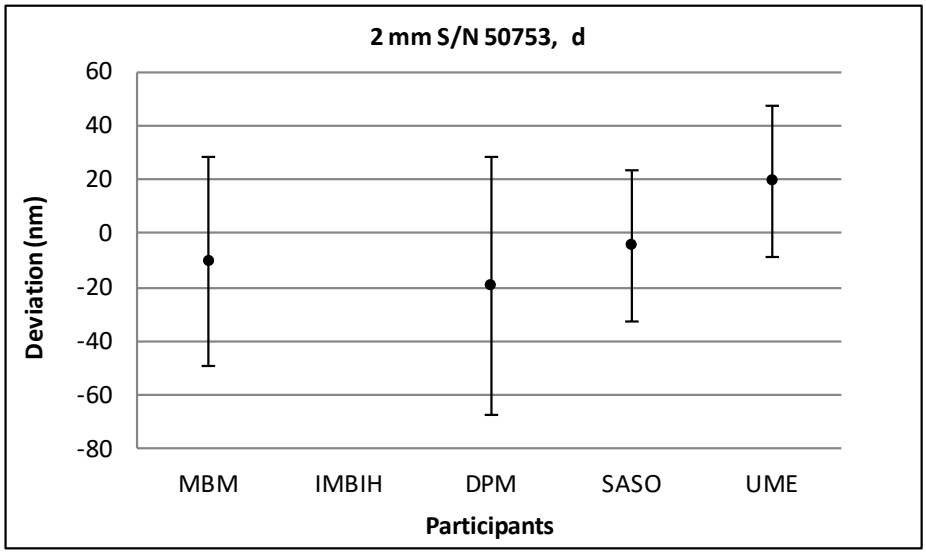


Figure 5(a) - Graph for 2 mm gauge block results (k = 1) (Deviation from nominal length)

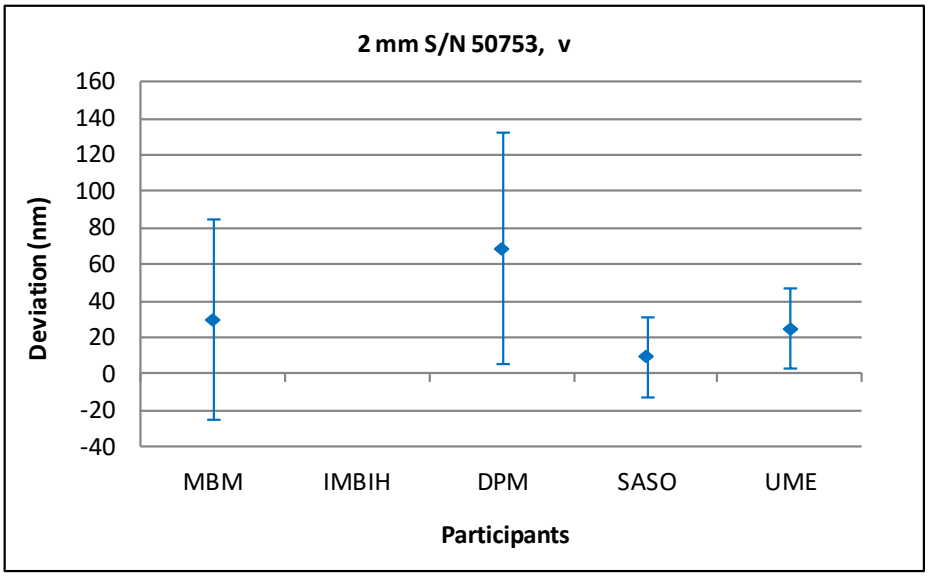


Figure 5(b) - Graph for 2 mm gauge block results (k = 1) (Variation in length)

Table 10 - 4.5 mm gauge block results

Nominal length	Central deviation from nominal,	Uncertainty (k =2)	Deviation from nominal at P2	Deviation from nominal at P3	Deviation from nominal at P4	Deviation from nominal at P5	Uncertainty (k =2)	Calculeted Variation in length	Uncertainty (k =2)
4.5 mm	d	$U(d)$	d_2	d_3	d_4	d_5	$U(d_i)$	v	$U(v)$
	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
MBM	10	79	20	30	10	20	111	20	111
IMBIH									
DPM	60	95	38	58	43	20	111	40	111
SASO	-13	56	-25	-21	-18	-21	44	12	44
UME	20	56	20	10	30	30	50	20	50

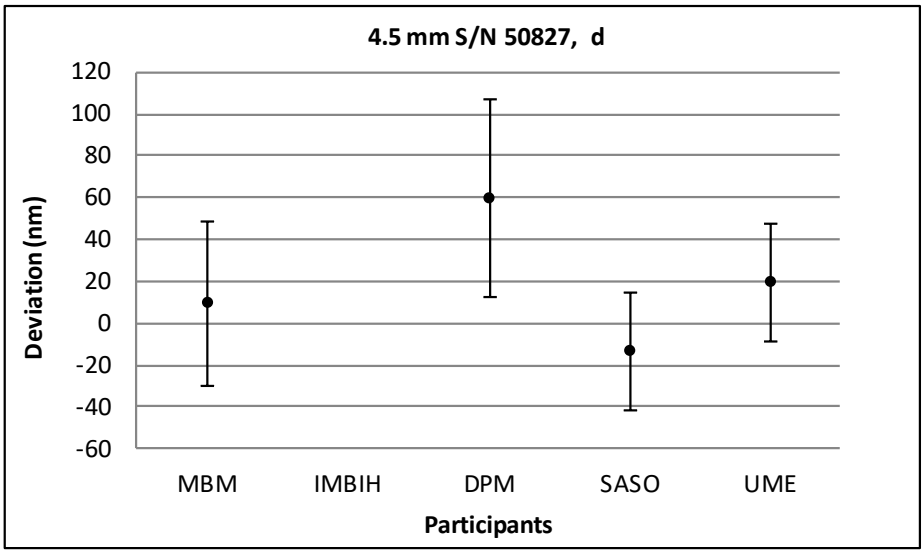


Figure 6(a) - Graph for 4.5 mm gauge block results (k = 1) (Deviation from nominal length)

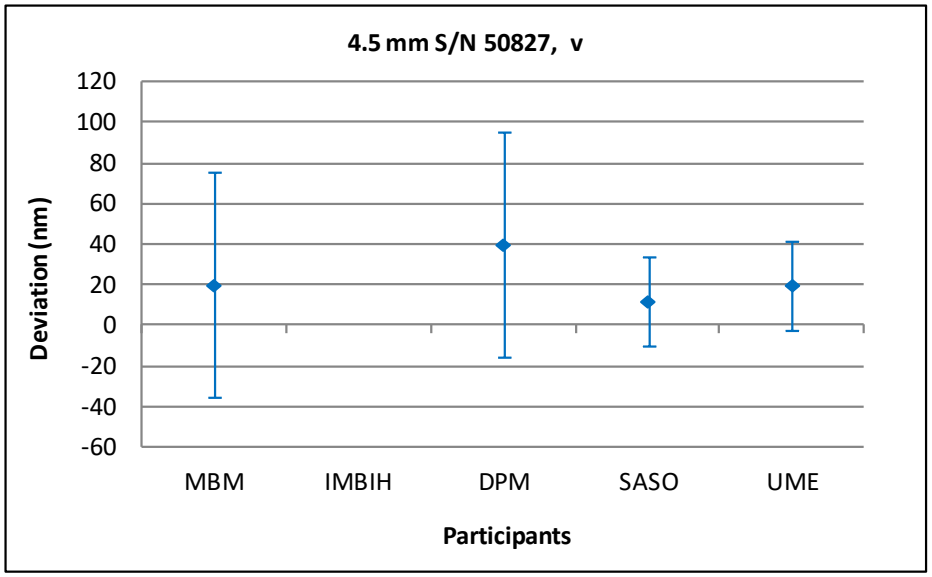


Figure 6(b) - Graph for 4.5 mm gauge block results (k = 1) (Variation in length)

Table 11 - 10 mm gauge block results

Nominal length	Central deviation from nominal,	Uncertainty (k=2)	Deviation from nominal at P2	Deviation from nominal at P3	Deviation from nominal at P4	Deviation from nominal at P5	Uncertainty (k=2)	Calculeted Variation in length	Uncertainty (k=2)
10 mm	d	$U(d)$	d_2	d_3	d_4	d_5	$U(d_i)$	v	$U(v)$
	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
MBM	0	83	-30	-30	30	10	117	60	117
IMBIH									
DPM	30	94	-15	-39	-42	-21	108	72	108
SASO	-1	56	-44	-54	-27	-27	44	53	44
UME	20	56	-20	0	0	0	50	40	50

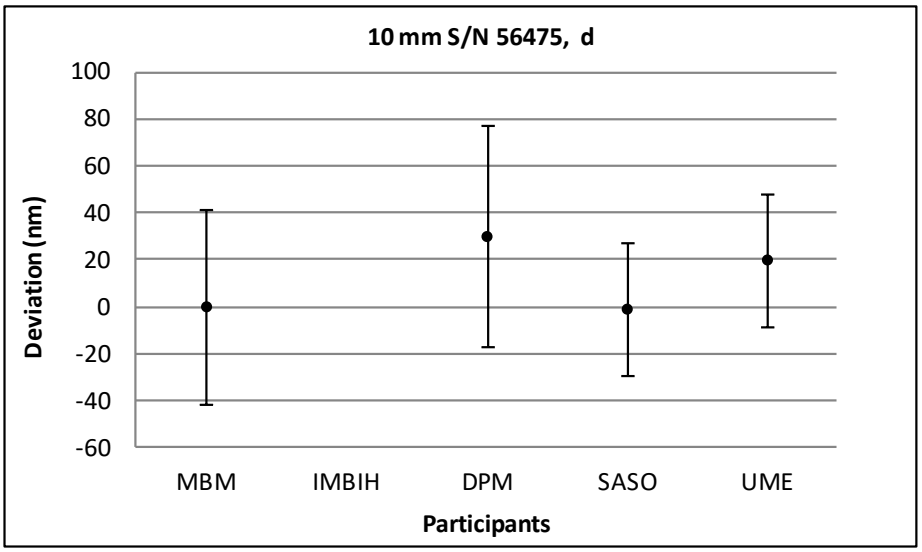


Figure 7(a) - Graph for 10 mm gauge block results (k = 1) (Deviation from nominal length)

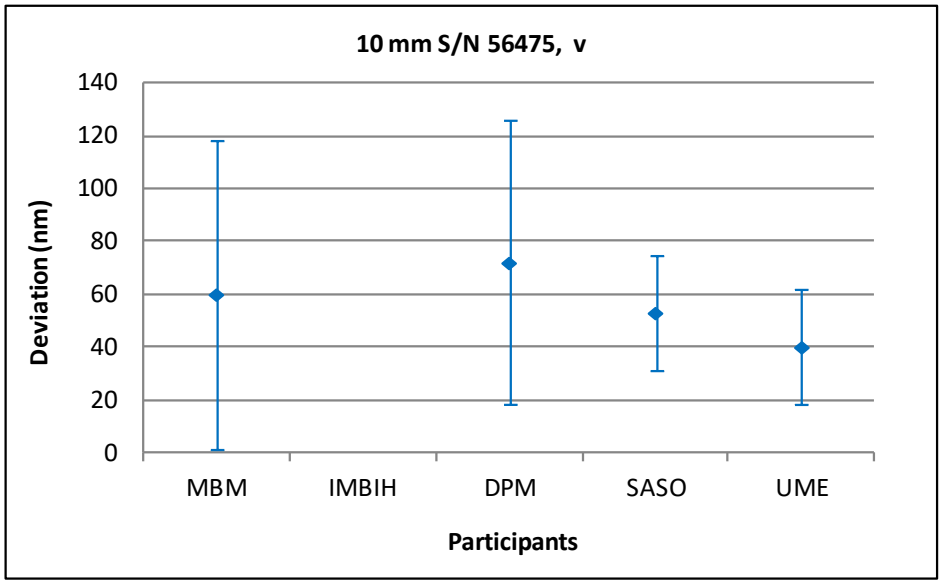


Figure 7(b) - Graph for 10 mm gauge block results (k = 1) (Variation in length)

Table 12 - 12 mm gauge block results

Nominal length	Central deviation from nominal,	Uncertainty (k=2)	Deviation from nominal at P2	Deviation from nominal at P3	Deviation from nominal at P4	Deviation from nominal at P5	Uncertainty (k=2)	Calculeted Variation in length	Uncertainty (k=2)
12 mm	d	$U(d)$	d_2	d_3	d_4	d_5	$U(d_i)$	v	$U(v)$
	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
MBM	-60	84	-50	-40	-10	-20	118	50	118
IMBIH									
DPM	-17	111	-51	-16	1	-10	134	52	134
SASO	-39	56	-59	-59	-43	-49	44	20	44
UME	-40	57	-30	-30	-40	-30	50	10	50

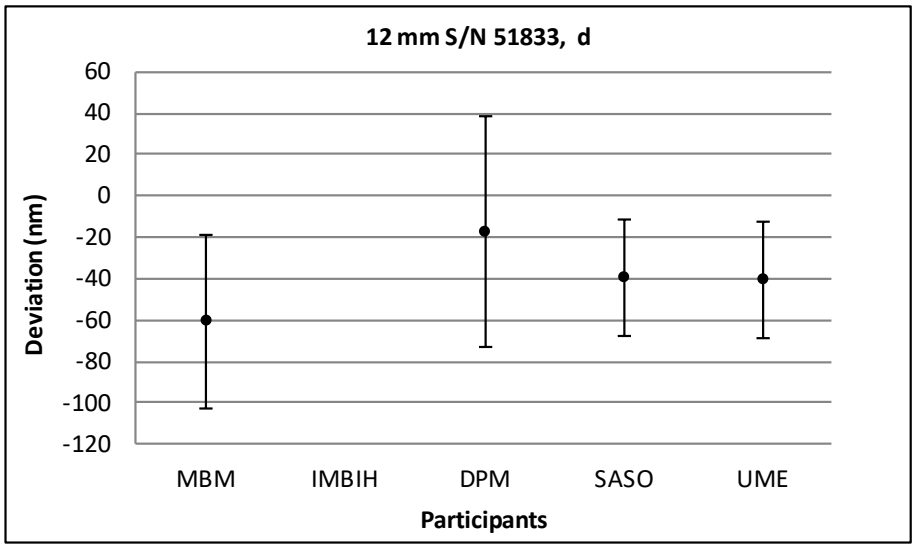


Figure 8(a) - Graph for 12 mm gauge block results (k = 1) (Deviation from nominal length)

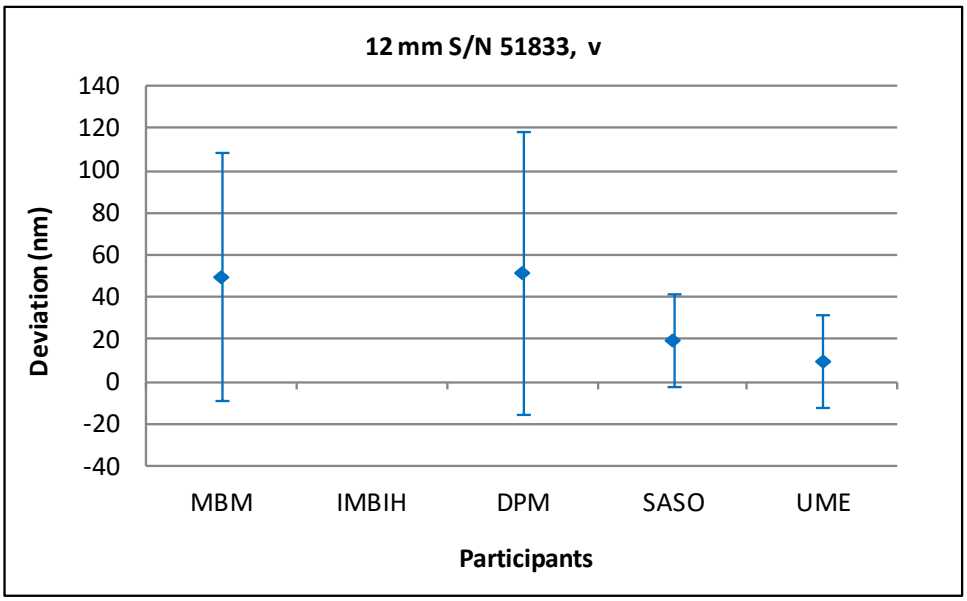


Figure 8(b) - Graph for 12 mm gauge block results (k = 1) (Variation in length)

Table 13 - 25 mm gauge block results

Nominal length	Central deviation from nominal,	Uncertainty (k=2)	Deviation from nominal at P2	Deviation from nominal at P3	Deviation from nominal at P4	Deviation from nominal at P5	Uncertainty (k=2)	Calculeted Variation in length	Uncertainty (k=2)
25 mm	d	$U(d)$	d_2	d_3	d_4	d_5	$U(d_i)$	v	$U(v)$
	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
MBM	-80	110	-80	-90	-80	-10	155	80	155
IMBIH									
DPM	-14	111	-33	-40	-16	-12	124	28	124
SASO	-98	57	-98	-128	-122	-138	44	40	44
UME	-70	59	-60	-70	-70	-80	50	20	50

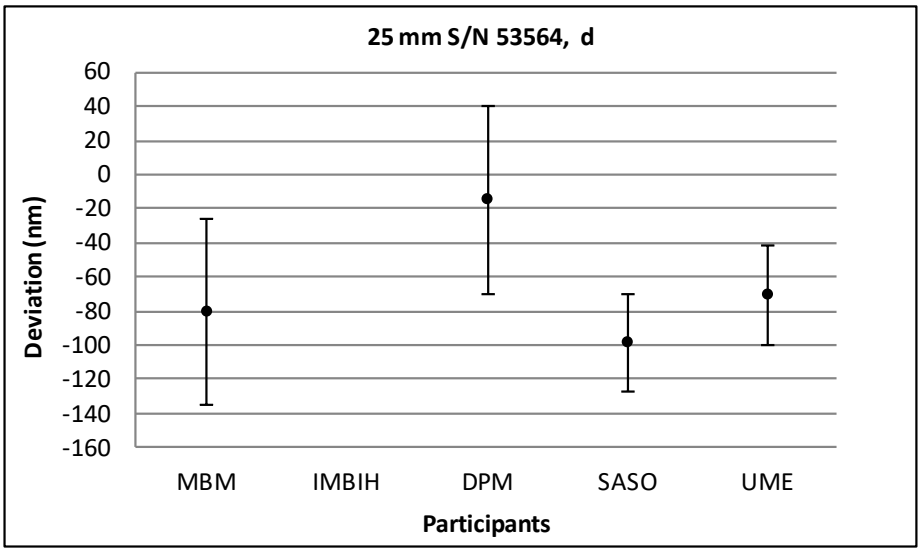


Figure 9(a) - Graph for 25 mm gauge block results (k = 1) (Deviation from nominal length)

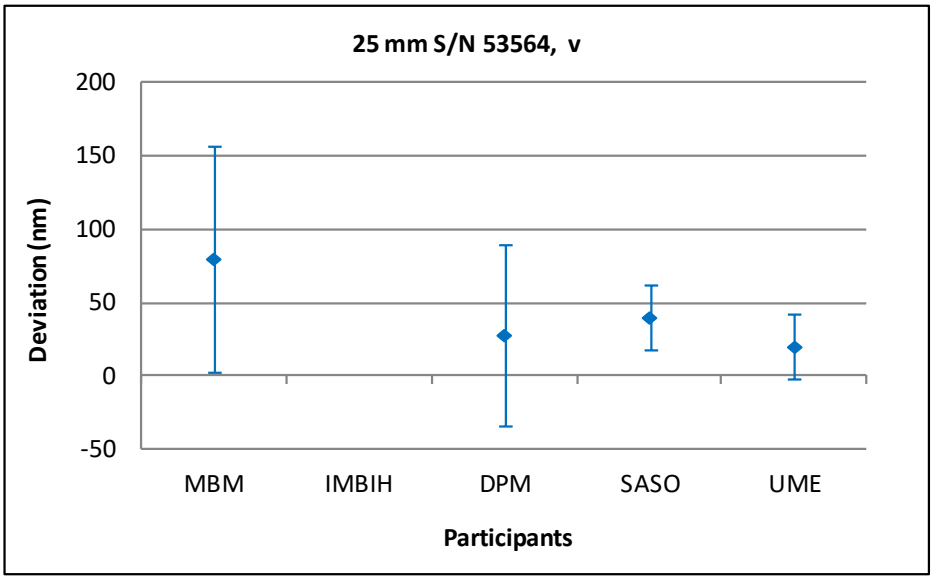


Figure 9(b) - Graph for 25 mm gauge block results (k = 1) (Variation in length)

Table 14 - 50 mm gauge block results

Nominal length	Central deviation from nominal,	Uncertainty (k=2)	Deviation from nominal at P2	Deviation from nominal at P3	Deviation from nominal at P4	Deviation from nominal at P5	Uncertainty (k=2)	Calculeted Variation in length	Uncertainty (k=2)
50 mm	d	$U(d)$	d_2	d_3	d_4	d_5	$U(d_i)$	v	$U(v)$
	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
MBM	40	121	20	40	20	10	171	30	171
IMBIH									
DPM	98	130	64	78	103	78	146	39	146
SASO	75	60	22	25	9	12	44	66	44
UME	20	66	20	-20	-10	0	50	40	50

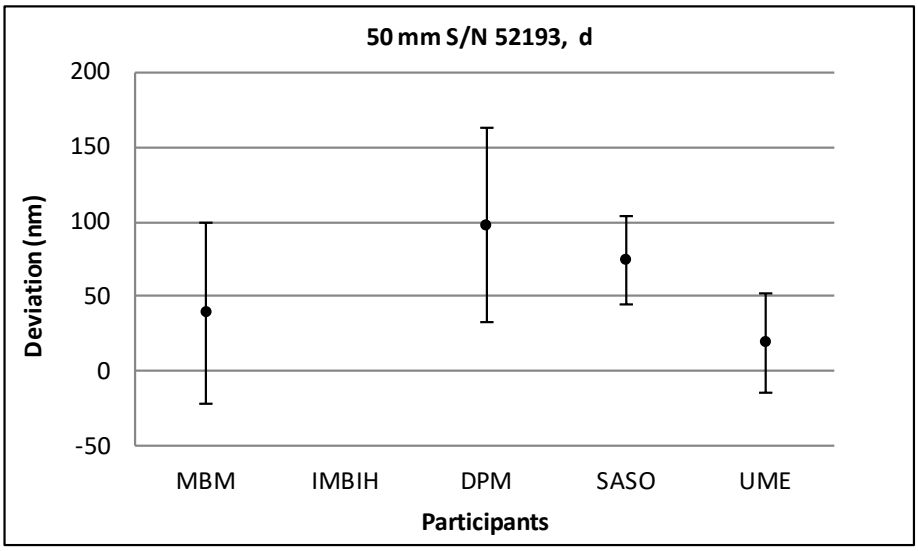


Figure 10(a) - Graph for 50 mm gauge block results (k = 1) (Deviation from nominal length)

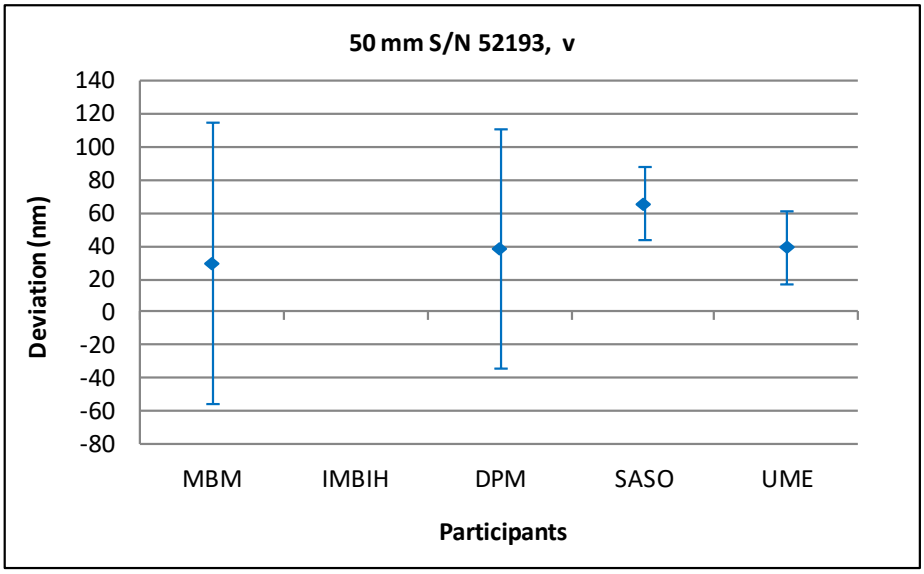


Figure 10(b) - Graph for 50 mm gauge block results (k = 1) (Variation in length)

Table 15 - 100 mm gauge block results

Nominal length	Central deviation from nominal,	Uncertainty (k=2)	Deviation from nominal at P2	Deviation from nominal at P3	Deviation from nominal at P4	Deviation from nominal at P5	Uncertainty (k=2)	Calculeted Variation in length	Uncertainty (k=2)
100 mm	d_1	$U(d1)$	d_2	d_3	d_4	d_5	$U(d_i)$	v	$U(v)$
	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
MBM	30	166	10	20	10	-10	234	40	234
IMBIH									
DPM	3	200	52	33	-94	-43	268	146	268
SASO	-27	69	-39	-32	-46	-52	44	25	44
UME	-30	90	-40	-30	-20	-30	50	20	50

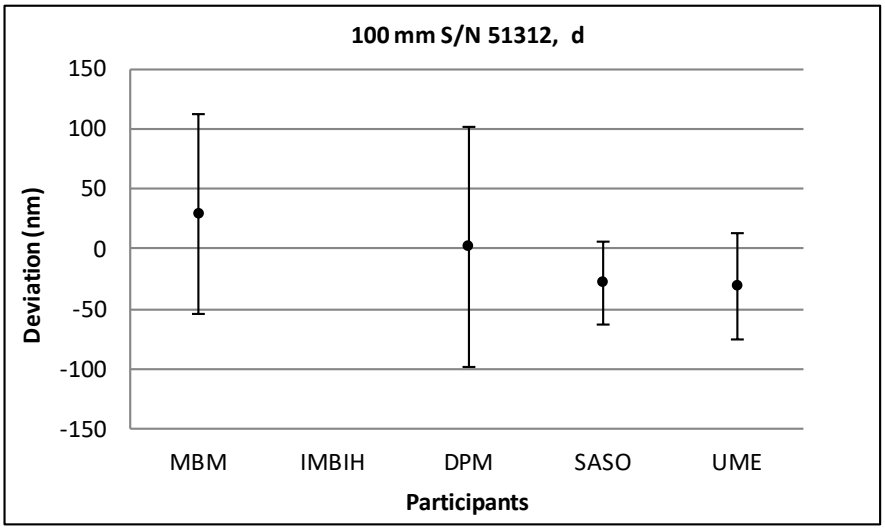


Figure 11(a) - Graph for 100 mm gauge block results (k = 1) (Deviation from nominal length)

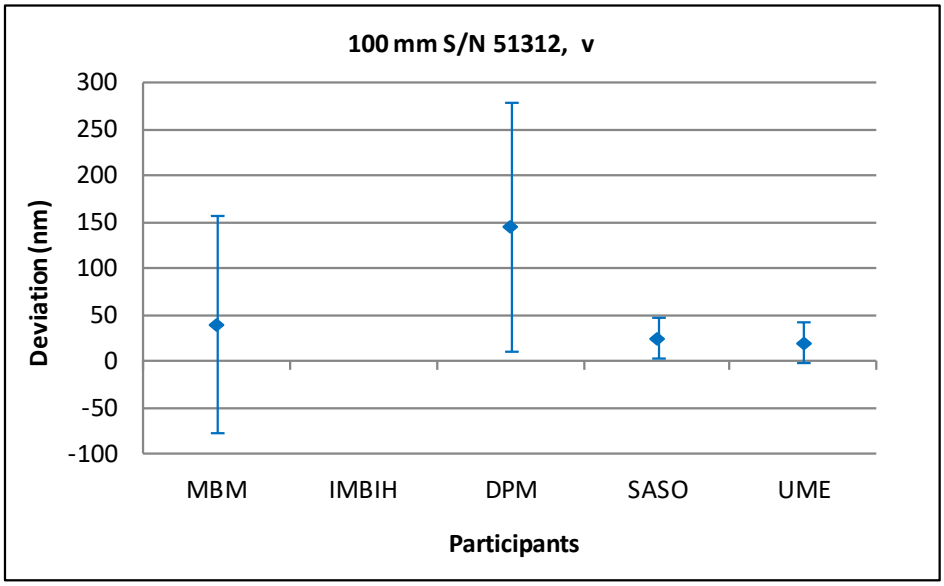


Figure 11(b) - Graph for 100 mm gauge block results (k = 1) (Variation in length)

7. Measurement uncertainties

The participants were asked to supply sample uncertainty calculations for the 2 mm and 100 mm steel gauge blocks, according to the GUM [3]. They were given for calculation of deviation from nominal length. They also provide uncertainty values for d_2 to d_5 values.

8. Analysis of the reported results

The reported measurement results are now analysed by simple statistical means to allow identification of any significant bias or outliers, and to investigate the statistical distribution of the results. From Tables 7 through 15 and Figures 3 through 11 it is clear that the uncertainties quoted by the participants are different from one participant to another, and that the uncertainties depend on the length of the gauge block being measured. Thus analysis via use of the simple arithmetic mean as an estimator of the true mean is not suitable and instead, the weighted mean should be used. This approach requires that the participants have made correct estimates of their uncertainty of measurement otherwise a too low uncertainty will place undue emphasis on the result of that particular laboratory.

8.1. Derivations

For each laboratory, *i*, which measures each gauge block, *j*, let the measured deviation from nominal size (after making all required corrections) be denoted x_{ij}. The number of laboratories, *I*, is 4 and the number of gauge blocks, *J*, is 9. Since the 9 gauge blocks are 9 physically different length artefacts with 9 different lengths, thermal expansion coefficients, material properties *etc*, it is reasonable to expect that the data x_{ij} come from 9 separate populations (one per gauge block) and so analysis should be on a gauge-by-gauge

Thus, for a particular gauge block, *j* :

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

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

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

where the normalising factor, *C*, is given by:

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

Then the weighted mean, $\overline{x}_w$, is given by:

$$\overline{x}_w = \sum_{i=1}^{I} w_i . x_i \tag{3}$$

The uncertainty of the weighted mean can be calculated as either the so-called internal or external standard deviation $u_{int}(\overline{x}_w)$ and $u_{ext}(\overline{x}_w)$, respectively. The internal standard deviation is based on the estimated uncertainties $u(x_i)$ as reported by the participants, whereas the external standard deviation is the standard deviation of the spread of the actual results, x_i, weighted by the uncertainties $u(x_i)$:

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

$$u_{ext}(\overline{x}_w) = \sqrt{\frac{1}{I-1} \cdot \frac{\sum_{i=1}^{I} w_i \cdot (x_i - \overline{x}_w)^2}{\sum_{i=1}^{I} w_i}} \tag{5}$$

Substituting (1) into (5) gives:

$$u_{ext}(\overline{x}_w) = \sqrt{\frac{1}{I-1} \cdot \frac{\sum_{i=1}^{I} \frac{1}{[u(x_i)]^2} \cdot (x_i - \overline{x}_w)^2}{\sum_{i=1}^{I} \frac{1}{[u(x_i)]^2}}} \tag{6}$$

After deriving the weighted mean and its associated uncertainty, the deviation of each laboratory's result from the weighted mean is determined simply as $x_i - x_w$. 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. In this case, the uncertainty of the weighted mean is taken as $u_{int}(\overline{x}_w)$. The uncertainty of the deviation from the weighted mean is given by equation (7), 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).

$$u(x_i - \overline{x}_w) = \sqrt{[u(x_i)]^2 - [u_{int}(\overline{x}_w)]^2} \tag{7}$$

Values for the weighted mean, internal standard deviation, deviation from weighted mean and its corresponding uncertainty are calculated for each gauge block, and reported in section 8.4.

8.2. Analysis using En values

A check for statistical consistency of the results with their associated uncertainties can be made by calculating the *En* value for each laboratory, where E_n is defined as the ratio of the deviation from the

weighted mean, divided by the uncertainty of this deviation:

$$E_n = \frac{x_i - \overline{x}_w}{\sqrt{[u(x_i)]^2 - [u_{int}(\overline{x}_w)]^2}} \tag{8}$$

8.3. Birge ratio test

The statistical consistency of a comparison can also be investigated by the so-called Birge ratio R_B [17], which compares the observed spread of the results with the spread expected from the individual reported uncertainties.

The application of least squares algorithms and the χ2-test leads to the Birge ratio:

$$R_B = \frac{u_{ext}(\overline{x}_w)}{u_{int}(\overline{x}_w)} \tag{9}$$

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

$$R_B < \sqrt{1 + \sqrt{8/(I-1)}} \tag{10}$$

where I is the number of laboratories.

8.4. Results of all participants

8.4.1. Deviation from Nominal length

Tables 16 through 24 present the analysis of the results of deviations from nominal length for the nine gauge blocks, as described in sections 8.1 through 8.3, with displayed values rounded to the nearest nanometre.

Table 16 - analysis for results of deviation from nominal length for 0.5 mm

0.5 mm **(Nominal Length)**

LAB	d_1	$u(d_1)$	w_i	x_i-x_w	$u(x_i-x_w)$	$E_n(k=2)$
MBM	-20.00	39.00	0.180296633	-9.40	35.31	-0.13
IMBIH						
DPM	0.00	47.78	0.120147694	10.60	44.81	0.12
SASO	-20.00	28.00	0.349784668	-9.40	22.58	-0.21
UME	0.00	28.00	0.349771005	10.60	22.58	0.23
weighted mean, x_w	-10.60					
C	274.2311795					
$u_{int}(x_w)$	16.5599					
$u_{ext}(x_w)$	5.763044512					
R_B	0.35					

Table 17 - analysis for results of deviation from nominal length for 1 mm

1 mm **(Nominal Length)**

LAB	d_1	$u(d_1)$	w_i	x_i-x_w	$u(x_i-x_w)$	$E_n(k=2)$
MBM	-10.00	39.00	0.180267708	2.68	35.31	0.04
IMBIH						
DPM	-41.00	47.74	0.120329828	-28.32	44.77	-0.32
SASO	-17.00	28.00	0.34972855	-4.32	22.58	-0.10
UME	0.00	28.00	0.349673914	12.68	22.58	0.28
weighted mean, x_w	-12.68					
C	274.1871835					
$u_{int}(x_w)$	16.5586					
$u_{ext}(x_w)$	7.315512172					
R_B	0.44					

Table 18 - analysis for results of deviation from nominal length for 2 mm

2 mm **(Nominal Length)**

LAB	d_1	$u(d_1)$	w_i	x_i-x_w	$u(x_i-x_w)$	$E_n(k=2)$
MBM	-10.00	39.00	0.180238047	-11.50	35.31	-0.16
IMBIH						
DPM	-19.00	47.67	0.120638348	-20.50	44.70	-0.23
SASO	-4.00	28.00	0.349671006	-5.50	22.58	-0.12
UME	20.00	28.01	0.349452599	18.50	22.59	0.41
weighted mean, X_w	1.50					
C	274.1420691					
$u_{int}(X_w)$	16.5572					
$u_{ext}(X_w)$	8.260597843					
R_B	0.50					

Table 19 - analysis for results of deviation from nominal length for 4.5 mm

4.5 mm **(Nominal Length)**

LAB	d_1	$u(d_1)$	w_i	x_i-x_w	$u(x_i-x_w)$	$E_n(k=2)$
MBM	10.00	39.50	0.176530334	-1.52	35.84	-0.02
IMBIH						
DPM	60.00	47.53	0.121946484	48.48	44.53	0.54
SASO	-13.00	28.00	0.35131563	-24.52	22.55	-0.54
UME	20.00	28.04	0.350207552	8.48	22.61	0.19
weighted mean, X_w	11.52					
C	275.431454					
$u_{int}(X_w)$	16.5961					
$u_{ext}(X_w)$	13.20890037					
R_B	0.80					

Table 20 - analysis for results of deviation from nominal length for 10 mm

10 mm (Nominal Length)

LAB	d_i	$u(d_i)$	w_i	$x_i - x_w$	$u(x_i - x_w)$	$E_n(k=2)$
MBM	0.00	41.50	0.163505442	-10.50	37.96	-0.14
IMBIH						
DPM	30.00	47.24	0.126211976	19.50	44.15	0.22
SASO	-1.00	28.10	0.356628269	-11.50	22.54	-0.26
UME	20.00	28.22	0.353654314	9.50	22.69	0.21
weighted mean, X_w	10.50					
C	281.5972472					
$u_{int}(X_w)$	16.7809					
$u_{ext}(X_w)$	6.954613844					
R_B	0.41					

Table 21- analysis for results of deviation from nominal length for 12 mm

12 mm (Nominal Length)

LAB	d_i	$u(d_i)$	w_i	$x_i - x_w$	$u(x_i - x_w)$	$E_n(k=2)$
MBM	-60.00	42.00	0.166581188	-19.22	38.34	-0.25
IMBIH						
DPM	-17.00	55.70	0.094713993	23.78	53.00	0.22
SASO	-39.00	28.10	0.372144749	1.78	22.27	0.04
UME	-40.00	28.31	0.366560071	0.78	22.53	0.02
weighted mean, X_w	-40.78					
C	293.8492151					
$u_{int}(X_w)$	17.1420					
$u_{ext}(X_w)$	6.231593473					
R_B	0.36					

Table 22 - analysis for results of deviation from nominal length for 25 mm

25 mm **(Nominal Length)**

LAB	d_i	$u(d_i)$	w_i	x_i-x_w	$u(x_i-x_w)$	$E_n(k=2)$
MBM	-80.00	55.00	0.108247611	-3.56	51.94	-0.03
IMBIH						
DPM	-14.00	55.40	0.106690112	62.44	52.36	0.60
SASO	-98.00	28.45	0.404556476	-21.56	21.95	-0.49
UME	-70.00	29.34	0.380505801	6.44	23.09	0.14
weighted mean, X_w	-76.44					
C	327.4490233					
$u_{int}(X_w)$	18.0956					
$u_{ext}(X_w)$	14.38937932					
R_B	0.80					

Table 23 - analysis for results of deviation from nominal length for 50 mm

50 mm **(Nominal Length)**

LAB	d_i	$u(d_i)$	w_i	x_i-x_w	$u(x_i-x_w)$	$E_n(k=2)$
MBM	40.00	60.50	0.106845531	-13.66	57.18	-0.12
IMBIH						
DPM	98.00	65.00	0.092577877	44.34	61.91	0.36
SASO	75.00	29.75	0.441868631	21.34	22.23	0.48
UME	20.00	33.02	0.358707962	-33.66	26.44	-0.64
weighted mean, X_w	53.66					
C	391.0813551					
$u_{int}(X_w)$	19.7758					
$u_{ext}(X_w)$	16.42749604					
R_B	0.83					

Table 24 - analysis for results of deviation from nominal length for 100 mm

100 mm (Nominal Length)

LAB	d_i	$u(d_i)$	w_i	$x_i - x_w$	$u(x_i - x_w)$	$E_n(k=2)$
MBM	30.00	83.00	0.091420247	50.84	79.12	0.32
IMBIH						
DPM	3.00	100.08	0.062885045	23.84	96.88	0.12
SASO	-27.00	34.40	0.532208356	-6.16	23.53	-0.13
UME	-30.00	44.82	0.313486352	-9.16	37.14	-0.12
weighted mean, x_w	-20.84					
C	629.7940806					
$u_{int}(x_w)$	25.0957					
$u_{ext}(x_w)$	10.30425608					
R_B	0.41					

8.4.2. Variation in Length

Tables 25 through 33 present the analysis of the results of variation in length for the nine gauge blocks, as described in sections 8.1 through 8.3, with displayed values rounded to the nearest nanometre.

Table 25 - analysis for results of variation in length for 0.5 mm

0.5 mm (Nominal Length)

LAB	v	u(v)	w_i	$x_i - x_w$	$u(x_i - x_w)$	$E_n(k=2)$
MBM	80.00	55.00	0.077981263	63.79	52.81	0.60
IMBIH						
DPM	44.00	65.50	0.054983584	27.79	63.67	0.22
SASO	0.00	21.95	0.489605843	-16.21	15.68	-0.52
UME	20.00	25.00	0.377429311	3.79	19.73	0.10
weighted mean, x_w	16.21					
C	235.8933192					
$u_{int}(x_w)$	15.3588					
$u_{ext}(x_w)$	12.83035151					
R_B	0.84					

Table 26 - analysis for results of variation in length for 1 mm

1 mm **(Nominal Length)**

LAB	v	u(v)	w_i	x_i-x_w	$u(x_i-x_w)$	En(k=2)
MBM	70.00	55.00	0.078321306	36.59	52.80	0.35
IMBIH						
DPM	81.00	68.25	0.050862768	47.59	66.49	0.36
SASO	33.00	21.95	0.491740807	-0.41	15.65	-0.01
UME	20.00	25.00	0.37907512	-13.41	19.70	-0.34
weighted mean, X_w	33.41					
C	236.92195					
$u_{int}(X_w)$	15.3923					
$u_{ext}(X_w)$	9.803132005					
R_B	0.64					

Table 27 - analysis for results of variation in length for 2 mm

2 mm **(Nominal Length)**

LAB	v	u(v)	w_i	x_i-x_w	$u(x_i-x_w)$	En(k=2)
MBM	30.00	55.00	0.077705739	9.36	52.82	0.09
IMBIH						
DPM	69.00	63.49	0.058322513	48.36	61.61	0.39
SASO	10.00	21.95	0.487875969	-10.64	15.71	-0.34
UME	25.00	25.00	0.376095779	4.36	19.75	0.11
weighted mean, X_w	20.64					
C	235.0598616					
$u_{int}(X_w)$	15.3317					
$u_{ext}(X_w)$	8.278238242					
R_B	0.54					

Table 28 - analysis for results of variation in length for 4.5 mm

4.5 mm (Nominal Length)

LAB	v	u(v)	w_i	x_i-x_w	$u(x_i-x_w)$	En(k=2)
MBM	20.00	55.50	0.075037647	2.33	53.38	0.02
IMBIH						
DPM	40.00	55.36	0.075417652	22.33	53.23	0.21
SASO	12.00	21.95	0.479729164	-5.67	15.83	-0.18
UME	20.00	25.00	0.369815537	2.33	19.85	0.06

weighted mean, X_w	17.67
C	231.1347107
$u_{int}(X_w)$	15.2031
$u_{ext}(X_w)$	4.298963015
R_B	0.28

Table 29 - analysis for results of variation in length for 10 mm

10 mm (Nominal Length)

LAB	v	u(v)	w_i	x_i-x_w	$u(x_i-x_w)$	En(k=2)
MBM	60.00	58.50	0.067761339	9.83	56.48	0.09
IMBIH						
DPM	72.00	53.88	0.079894916	21.83	51.68	0.21
SASO	53.00	21.95	0.481309755	2.83	15.81	0.09
UME	40.00	25.00	0.371033989	-10.17	19.83	-0.26

weighted mean, X_w	50.17
C	231.8962433
$u_{int}(X_w)$	15.2281
$u_{ext}(X_w)$	5.380580392
R_B	0.35

Table 30 - analysis for results of variation in length for 12 mm

12 mm (Nominal Length)

LAB	v	u(v)	w_i	x_i-x_w	$u(x_i-x_w)$	En(k=2)
MBM	50.00	59.00	0.068626521	30.06	56.94	0.26
IMBIH						
DPM	52.00	66.93	0.053327884	32.06	65.12	0.25
SASO	20.00	21.95	0.495823326	0.06	15.59	0.00
UME	10.00	25.00	0.382222269	-9.94	19.65	-0.25
weighted mean, x_w	19.94					
C	238.8889181					
$u_{int}(x_w)$	15.4560					
$u_{ext}(x_w)$	7.178454042					
R_B	0.46					

Table 31 - analysis for results of variation in length for 25 mm

25 mm (Nominal Length)

LAB	v	u(v)	w_i	x_i-x_w	$u(x_i-x_w)$	En(k=2)
MBM	80.00	77.50	0.040594829	46.94	75.91	0.31
IMBIH						
DPM	28.00	62.10	0.063225303	-5.06	60.10	-0.04
SASO	40.00	21.95	0.506063564	6.94	15.43	0.22
UME	20.00	25.00	0.390116304	-13.06	19.52	-0.33
weighted mean, x_w	33.06					
C	243.8226903					
$u_{int}(x_w)$	15.6148					
$u_{ext}(x_w)$	7.788398212					
R_B	0.50					

Table 32 - analysis for results of variation in length for 50 mm

50 mm (Nominal Length)

LAB	v	u(v)	w_i	x_i-x_w	$u(x_i-x_w)$	En(k=2)
MBM	30.00	85.50	0.034271014	-23.07	84.02	-0.14
IMBIH						
DPM	39.00	72.81	0.047258194	-14.07	71.07	-0.10
SASO	66.00	22.00	0.517623305	12.93	15.28	0.42
UME	40.00	25.00	0.400847487	-13.07	19.35	-0.34
weighted mean, x_w	53.07					
C	250.5296795					
$u_{int}(x_w)$	15.8281					
$u_{ext}(x_w)$	7.801898912					
R_B	0.49					

Table 33 - analysis for results of variation in length for 100 mm

100 mm (Nominal Length)

LAB	v	u(v)	w_i	x_i-x_w	$u(x_i-x_w)$	En(k=2)
MBM	40.00	117.00	0.019250043	15.04	115.87	0.06
IMBIH						
DPM	146.00	133.99	0.014677722	121.04	133.00	0.46
SASO	25.00	22.00	0.544450087	0.04	14.85	0.00
UME	20.00	25.00	0.421622148	-4.96	19.01	-0.13
weighted mean, x_w	24.96					
C	263.5138422					
$u_{int}(x_w)$	16.2331					
$u_{ext}(x_w)$	8.751503912					
R_B	0.54					

8.5. Results revision or withdrawal

Macedonia cancelled its participation due to equipment failure.

Bosnia and Herzegovina requested not to publish their results since the results were not taken by their own devices in their premises.

No labs revised their results.

8.6. Analysis of results, outliers excluded from weighted mean

No results were excluded from calculation of the weighted mean. All were included during calculation of weighted mean apart from results of IMBIH.

9. Conclusions

From the EURAMET project, Exercise for Intercomparison Measurements in West Balkans

"Calibration of Short Gauge Blocks by Mechanical Comparison", the following conclusions can be drawn:

From the start of the comparison, several problems occurred causing sometimes long time delays:

- Delays
- Equipment and standards (lack of equipment)
- Staff (lack of staff and staff lost)
- Laboratory conditions
- Movement of Lab to new premises
- Delivery of the items (ATA CARNET and Custom problems)
- Bad treatment of standards/failure of comparison (prevented by workshop in EURAMET 1237)
- Filling of the forms and preparation of the report by NMIs (improved by workshop)

However required feedback was given to participants to proceed them to new MRA comparison on the same subject.

For example, Montenegro (MBM) has taken part in MRA comparison EURAMET.L-S22 and had very successful results. Before their participation, they were trained through workshop in TUBITAK UME and then had this exercise comparison to see their performance and then participated to MRA comparison (EURAMET.L-S22) as aimed in the project. Later, they have applied CMC on short gauge block calibration and now they have a CMC entry on KCDB. (*https://kcdb.bipm.org/AppendixC/L/ME/L_ME.pdf*)

Macedonia cancelled its participation due to equipment failure. Despite the guidelines provided by TUBITAK UME for fixing and then re-placement of their gauge block comparator with new one, Macedonia could not get the device due to various reasons and could not measure the gauges at the end of the comparison either.

Bosnia and Herzegovina (IMBIH) used the device of an organisation in their country and they perform the measurements in organisation premises. It was a good exercise for them to participate and become ready for further MRA comparisons when they will have an equipment. They have fully participated at each stage during the reports Draft A, B and Final. But we decided not to publish any of their results since the equipment of another organisation were used.

The gauge blocks were still in good condition.

Overall, the comparison exercise has been very successful. No outliers are observed.

NMIs are now aware of the importance of the custom issues and has started cooperation with their departments doing custom clearance in advance.

NMIs understand the procedure for correction of their results during stages of draft A and B: Which kind of corrections, how to show the mistakes to the pilots with proofs.

Improvements for their process and precise determination of their uncertainty budgets.

SASO-NMCC of Saudi Arabia, and DPM of Albania have participated in MRA comparison in GULFMET region (GULFMET.L-S1 [2]). Evaluation of this comparison is in progress.

It may be concluded that the project achieved its purpose and new NMIs were prepared to be able participate MRA comparisons on Gauge calibration by mechanical comparison.

10. Acknowledgements

Acknowledgement to TUBITAK UME and PTB for their support during the workshop before starting the comparison measurements.

11. References

[1] BIPM, Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes, 1999, BIPM

[2] The BIPM key comparison database, https://kcdb.bipm.org/

[3] ISO/IEC 2008 Uncertainty of measurement: part 3. Guide to the Expression of Uncertainty in Measurement ISO/IEC Guide 98-3