Report on GULFMET Supplementary Comparison

Measurement of gauge blocks by interferometry

GULFMET.L-S2
Final Report

Co-ordinated by: TUBİTAK UME, Turkey

D Sendogdu (UME), O Yaman (UME), T Cetin (UME),
R Hamid (UME), E Sahin (UME), C Senel (UME), M Asar (UME),
N Alqahtani (NMCC), F Alqahtani (NMCC),
Y B Talhh (NMCC), A Almutari (NMCC)

Gebze, Turkey, February, 2019
D. Sendogdu

Contents

1. Introduction

This is the report to outline the comparison that has already been finished. This comparison was on short and long gauge block length measurements by interferometry between SASO NMCC and TÜBİTAK UME, in the frame of the Project of Development and Realization Measurement and Calibration System for the National Measurement and Calibration Center (NMCC) at Saudi Standards, Metrology and Quality Organization (SASO).

It should be noted that the initial purpose of the comparison was to provide NMIs in GULFMET region an exercise in conducting and participating in an intercomparison. Later on, however, it was also suggested to have this comparison registered as a supplementary comparison to BIPM KCDB as GULFMET.L-S2. Since GULFMET region is a new RMO, this comparison will provide an improvement of the new NMIs metrological equivalence with the other RMOs.

TÜBİTAK UME is acting as the pilot laboratory. The travelling standard was provided by TÜBİTAK UME. TÜBİTAK UME is responsible for monitoring standard performance during the circulation and the evaluation and reporting of the comparison results [1].

The common way of evaluating and expressing the uncertainty of measurement is particularly important to demonstrate the degree of equivalence between the participating laboratories.

2. Organization

2.1. Participants

This bilateral comparison was planned by TÜBİTAK UME and SASO NMCC.

2.2. Participants' details

Table 1. List of participant laboratories and their contacts.

Country	Institute	Acronym	Shipping Address	Contact Person
Turkey	TÜBİTAK Ulusal Metroloji Enstitüsü	TÜBİTAK UME	TÜBİTAK Ulusal Metroloji Enstitüsü (UME) TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY	Dr. Damla Şendoğdu damla.sendogdu@tubitak.gov.tr Tel: +90 262 679 50 00
Saudi Arabia	SASO The National Measurement and Calibration Center	SASO NMCC	Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi Arabia (SASO) Riyadh 11471, P.O. Box 3437 KINGDOM of SAUDI ARABIA	Nasser M. Alqahtani n.qahtani@saso.gov.sa Tel: +966 11 252 9711

2.3. Comparison schedule

The time schedule for the comparison is given in Table 2.

The first measurement of TÜBİTAK UME was performed in the allocated time period. Then the measurement of SASO NMCC was carried out without any delay.

The time of transportation of the standards from SASO NMCC to TÜBİTAK UME was longer than expected. So the second measurement of TÜBİTAK UME was shifted about 10 days.

Table 2. Circulation Time Schedule

Acronym of Institute	Country	Planned Starting Date	Actual Measurement Dates
TÜBİTAK UME	Turkey	01.02.2017 (30 days)	31.01.2017-22.02.2017
SASO NMCC	Saudi Arabia	01.03.2017 (45 days)	03.03.2017-03.04.2017
TÜBİTAK UME	Turkey	17.04. 2017 (30 days)	04.05.2017-29.05.2017

As given in Table 2, the pilot laboratory (TÜBİTAK UME) performed the measurements at two times: at the start (first) and at the end (second). For the measurement result of the pilot laboratory, only the first measurement result was taken. The measurement results, besides being used to determine the pilot laboratory's result, can also be used as a measure of the stability of the standards.

3. Description of the standards

The package contains 12 steel gauge blocks. The gauge blocks are of the rectangular cross-section, according to the international standard ISO 3650 [2]. The thermal expansion coefficient of the gauge block was provided by the manufacturer and not confirmed value by measurement.

Table 3. List of standards

Class	Manufacturer	Identification Number	Nominal Length (mm)	α (10^{-6} K^{-1})
short, steel	KOBA	88216	2	12
	KOBA	88216	3	12
	KOBA	88216	4	12
	KOBA	88216	5	12

	KOBA	88216	6	12
	KOBA	88216	10	12
	KOBA	88216	50	12
	KOBA	88216	80	12
	KOBA	88216	100	12
long, steel	KOBA	87301	200	11,2
	KOBA	86390	500	11,4
	KOBA	87651	600	11,2

4. Measuring instructions

The gauge blocks were measured based on the standard procedure that the laboratory regularly uses for this calibration service for its customers. The "A" surface is the marked measuring face for gauge blocks with nominal length < 6 mm and the right hand measuring face for gauge blocks with a nominal length ≥ 6 mm, respectively (see Figure 1). This nomenclature was used in accordance with CCL-K1 [3]

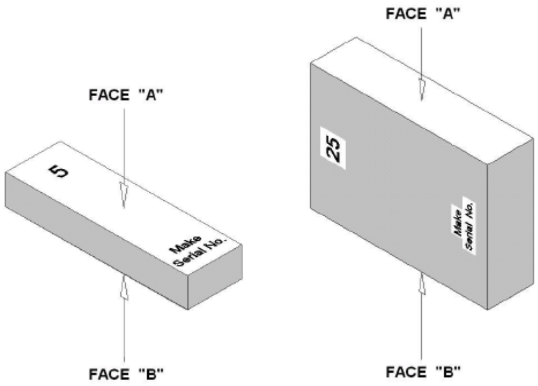


Figure 1. Nomenclature of faces

4.1. Handling of standards

The gauge blocks had to be handled by authorized persons and stored in such a way as to prevent damage. Before making the measurement, the gauge blocks had to be inspected for damage of the measurement surfaces. The scratches, rusty spots or other damage documented with a drawing using the appropriate form in the Appendix B and Appendix C of the protocol.

Laboratories had to attempt to measure all gauge blocks unless doing so would damage their equipment. If a gauge block could not be wrung readily, the laboratory had to inform the pilot about this problem, stating the respective gauge block and face. The laboratory had not to try to re-finish measuring faces by burring, lapping, stoning, or whatsoever. The measurement of the face concerned or the complete gauge block should have been omitted.

4.2. Traceability

Length measurements had to be traceable to the latest realization of the metre as set out in the current “Mise en Pratique”. Temperature measurements had to be made using the International Temperature Scale of 1990 (ITS-90).

4.3. The measurand

The principal measurand was reported was the deviation e_c of the central length l_c from the nominal length l_n of a gauge block. The arithmetic mean of the two values for wringing on both faces was considered as representative for e_c (see equation (1), the superscripts label the face wrung to the platen). In cases where only one face could be wrung the corresponding value had to be reported as the result.

$$e_\mathrm{c} = \left(e_\mathrm{c}^\mathrm{A} + e_\mathrm{c}^\mathrm{B}\right)/2 \quad \text{with} \quad e_\mathrm{c}^\mathrm{A} = l_\mathrm{c}^\mathrm{A} - l_\mathrm{n} \quad \text{and} \quad e_\mathrm{c}^\mathrm{B} = l_\mathrm{c}^\mathrm{B} - l_\mathrm{n} \tag{1}$$

4.4. Measurement Uncertainty

The uncertainty of measurement had to be estimated according to the ISO Guide to the Expression of Uncertainty in Measurement [4]. Although comparability was sacrificed by not giving an explicit model equation, the laboratories were encouraged to use their usual model for the uncertainty calculation. Examples of model equations could be found in [5,6].

All measurement uncertainties had to be stated as standard uncertainties.

For efficient evaluation, an uncertainty statement in the functional form (2) was preferred.

$$u\left(e_\mathrm{c}\right) = Q\left[a, b \cdot l_\mathrm{n}\right] = \sqrt{a^2 + \left(b \cdot l_\mathrm{n}\right)^2} \tag{2}$$

Throughout this report, expanded uncertainties were exclusively stated with an expansion factor of k=2.

$$U(x) = 2\,.\,u(x) \tag{3}$$

5. Results

5.1. Uncertainty values

$$u\left(e_\mathrm{c}\right) = Q\left[a, b \cdot l_\mathrm{n}\right] = \sqrt{a^2 + \left(b \cdot l_\mathrm{n}\right)^2} \tag{4}$$

Table 4. Uncertainty values $[u(e_c)]$ for SASO NMCC. This table corresponds to $u(x_1)$ in equation (6).

SASO NMCC	*a* / nm	*b* / 10^{-6}	Comment
Short	15,1	0,135	$(k = 1)$
Long	24,6	0,139	$(k = 1)$

Table 5. Uncertainty values $[u(e_c)]$ for TÜBİTAK UME. This table corresponds to $u(x_2)$ in equation (6).

TÜBİTAK UME	*a* / nm	*b* / 10^{-6}	Comment
Short	12,5	0,2	$(k = 1)$
Long	22,5	0,093	$(k = 1)$

TUBİTAK UME Interferometer results are stated in the key comparison EURAMET.L-K1.2011 and approved and published (as new and last revisions) in KCDB (CMC) on 22 September 2016 [7].

5.2. Degrees of equivalence and E_n values

The Degree of Equivalence [8,9], DoE, for between the measurement results by TÜBİTAK UME and SASO NMCC, is calculated as given by

$$x_1 - x_2 \tag{5}$$

where

x_1 is the laboratory's result (SASO NMCC)

x_2 is the pilot laboratory's result (TÜBİTAK UME)

Its standard uncertainty is given by

$$u(x_1 - x_2) = \sqrt{u^2(x_1) + u^2(x_2)} \tag{6}$$

For the laboratory's result, the E_n value is calculated [10].

$$E_n = \frac{x_1 - x_2}{U(x_1 - x_2)} \tag{7}$$

Where $U(x_1 - x_2)$ is the expanded uncertainty is obtained from the standard uncertainty by multiplication by k=2.

As mentioned previously, the pilot laboratory (TÜBİTAK UME) measured the standards at two times: at the start (before SASO NMCC) and at the end (after SASO NMCC). However, for the measurement result of the pilot laboratory, only the start measurement result is used (x_2).

Table 6. Pilot laboratory (TUBİTAK UME) results and uncertainties for k=1.

Nominal Length of the Block (mm)	x_2 (nm)	$u(x_2)$ (nm)
2	-133	12,5
3	19	12,5
4	-121	12,5
5	-6	12,5
6	-33	12,6
10	-71	12,7
50	-18	16,0
80	72	20,3
100	-39	23,6
200	-314	29,2
500	645	51,7
600	17	60,2

Table 7. Laboratory (SASO NMCC) results, DoE and E_n values for each of the gauge blocks

Nominal Length of the Block (mm)	x_1 (nm)	$u(x_1)$ (nm)	$x_1 - x_2$ (nm)	$u(x_1 - x_2)$ (nm)	$U(x_1 - x_2)$ (nm)	E_n	$\|E_n\|$
2	-138	15,1	-5	19,6	39,2	-0,14	0,14
3	16	15,1	-3	19,6	39,2	-0,07	0,07
4	-124	15,1	-3	19,6	39,3	-0,08	0,08
5	-6	15,1	0	19,6	39,3	0,01	0,01
6	-40	15,1	-7	19,7	39,3	-0,18	0,18
10	-57	15,2	14	19,8	39,5	0,35	0,35
50	-3	16,5	15	23,0	46,0	0,33	0,33
80	100	18,6	28	27,5	55,0	0,51	0,51
100	-13	20,3	26	31,1	62,2	0,42	0,42
200	-270	37,1	44	47,2	94,5	0,46	0,46
500	703	73,7	59	90,0	180,0	0,33	0,33
600	114	87,0	97	105,7	211,5	0,46	0,46

The graphs present the DoF with the expanded uncertainties $\boldsymbol{U}(x_1 - x_{\mathbf{2}})$ with error bars.

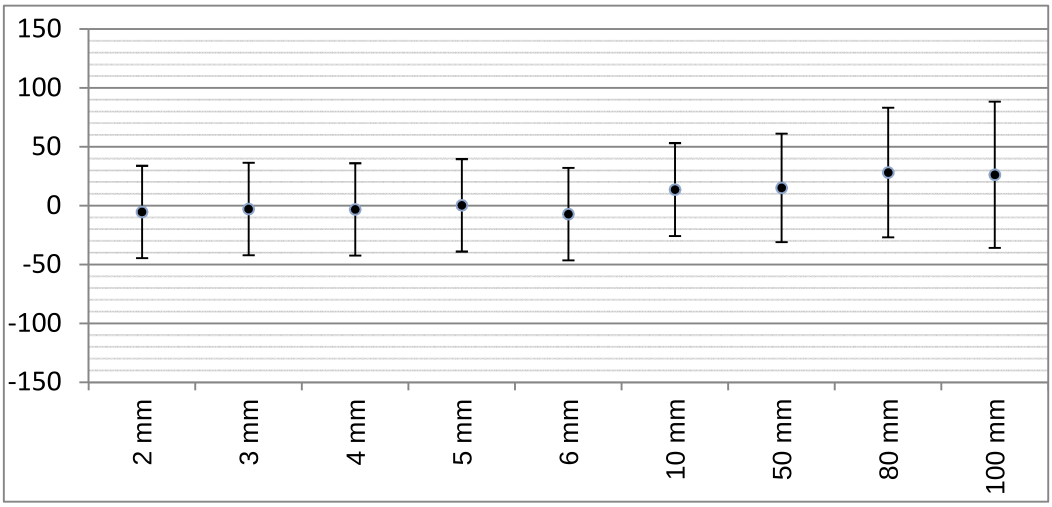


Figure 2. Degrees of Equivalence for short gauge blocks

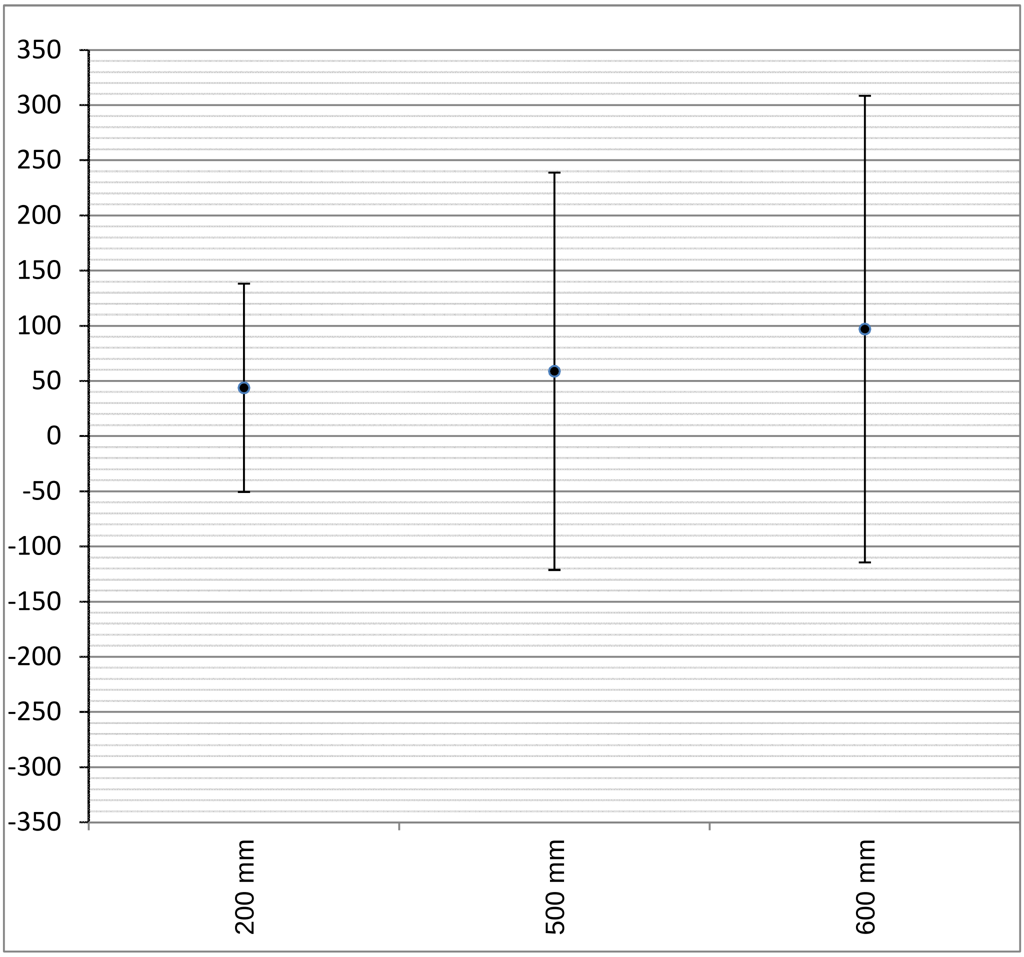


Figure 3. Degrees of Equivalence for long gauge blocks

As mentioned in 'Comparison Protocol' [1], the laboratory measurement results were utilized according to the criteria of E_n value which is given below,

If $|E_n| \leq 1$ then it is successful

If $|E_n| > 1$ then it is unsuccessful

The $|E_n|$ values for each gauge blocks are calculated and presented in table 7. For short gauges (2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 10 mm, 50 mm, 80 mm and 100 mm) and long gauges (200 mm, 500 mm and 600 mm), the $|E_n|$ values are calculated as less than 1. So the comparison results are accounted as satisfactory. However, the results can be analyzed as follows;

- Most of the E_n numbers are positive. It means that the results of SASO NMCC are larger than those of TÜBİTAK UME. Some offset might be included in the results of either and/or both laboratory.
- The E_n number generally increases with the increasing nominal length of the gauge blocks. It might be length-dependent issues (thermal measurement, thermal compensation and/or refractive index) in the results of either and/or both laboratory.

6. Stability of Standards

Pilot Laboratory, UME, made measurements according to time schedule given in table 2. At first, UME made the measurement at the start of the comparison and then SASO completed measurements. At the end of this circulation, UME made the second measurements. As mentioned before, all of these measurement results can be used as a measure of the stability of the standards.

Actually, there is no any obligation to present the stability degradation of the blocks in bilateral comparisons as mentioned in the document of Template Bilateral Report of CCL [9]. However, we prefer to show stability plots of the blocks during the comparison.

Table 8. First and second measurement results ($x_{2\ start}$, $x_{2\ end}$) by TÜBİTAK UME laboratory, measurement results (x_1) by SASO NMCC laboratory, and the uncertainties ($u(x_2)$, $u(x_1)$)

Nominal Length of the Block (mm)	$x_{2\ start}$ (nm)	x_1 (nm)	$x_{2\ end}$ (nm)	$u(x_2)$ (nm)	$u(x_1)$ (nm)
2	-133	-138	-145	12,5	15,1
3	19	16	18	12,5	15,1
4	-121	-124	-123	12,5	15,1
5	-6	-6	-13	12,5	15,1
6	-33	-40	-34	12,6	15,1
10	-71	-57	-65	12,7	15,2
50	-18	-3	-22	16,0	16,5
80	72	100	56	20,3	18,6
100	-39	-13	-61	23,6	20,3
200	-314	-270	-295	29,2	37,1
500	645	703	639	51,7	73,7
600*	17	114	-	60,2	87,0

*For 600 mm long gauge block; The first measurements as a pilot laboratory are performed at UME and the gauge blocks are sent to NMCC. After NMCC Laboratory completed measurements, the gauges are sent to UME. Before starting the measurement at UME, at the stage of detail inspection of measuring faces of 600 mm gauge, the significant surface faults are noticed and marked in the report (Appendix C). Severe scratches are seen in both of the surfaces of the block. These surfaces can not wringable anymore. A reconditioning process was not applied to the surfaces of the gauge. For this reason, the stability plot cannot be shown for 600 mm gauge block.

Figures 4(a) through 4(k) show the measurements of the UME and SASO laboratories to verify the stability of the gauge blocks central length. Uncertainty bars show standard uncertainty (k=1) [7, 11].

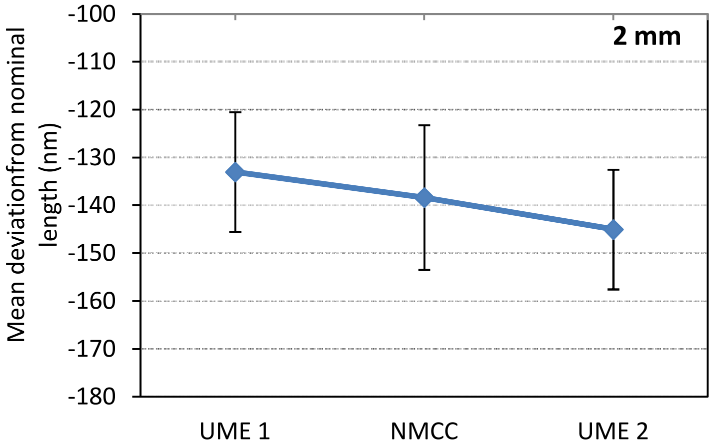


Figure 4(a). Stability of 2 mm gauge block (S/N 88216) during the comparison. Uncertainty bars show standard uncertainty (k=1).

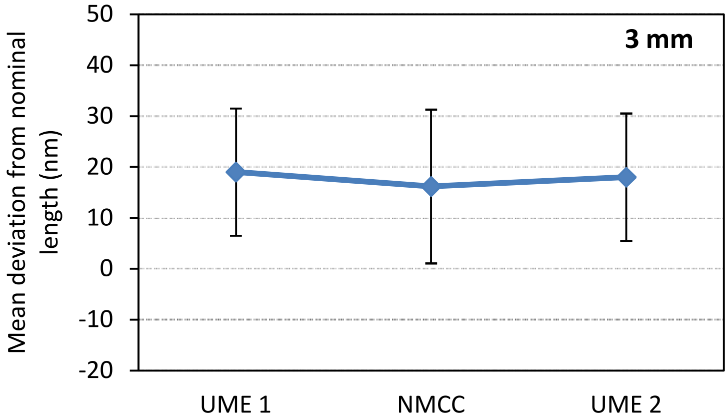


Figure 4(b). Stability of 3 mm gauge block (S/N 88216) during the comparison. Uncertainty bars show standard uncertainty (k=1).

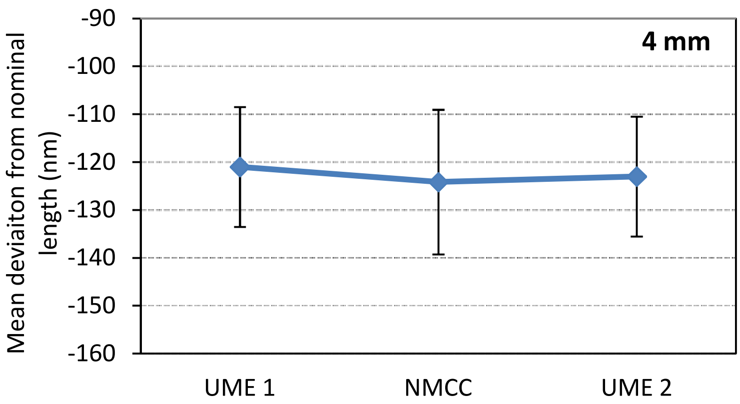


Figure 4(c). Stability of 4 mm gauge block (S/N 88216) during the comparison. Uncertainty bars show standard uncertainty (k=1).

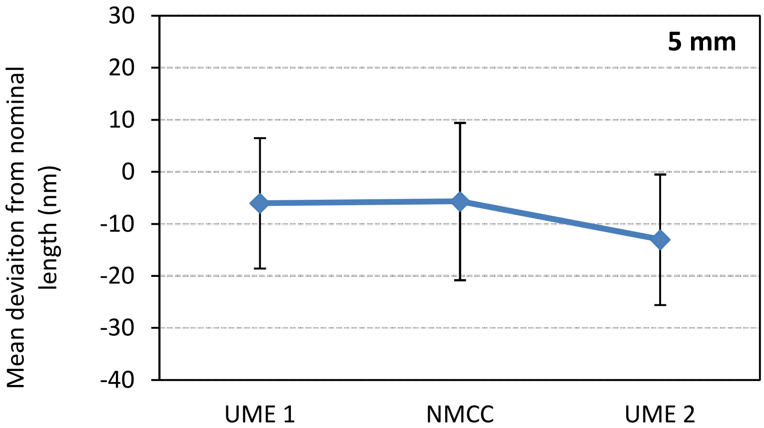


Figure 4(d). Stability of 5 mm gauge block (S/N 88216) during the comparison. Uncertainty bars show standard uncertainty (k=1).

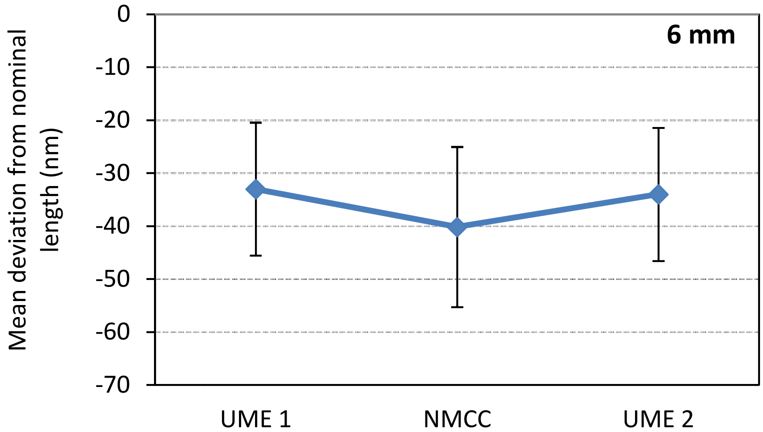


Figure 4(e). Stability of 6 mm gauge block (S/N 88216) during the comparison. Uncertainty bars show standard uncertainty (k=1).

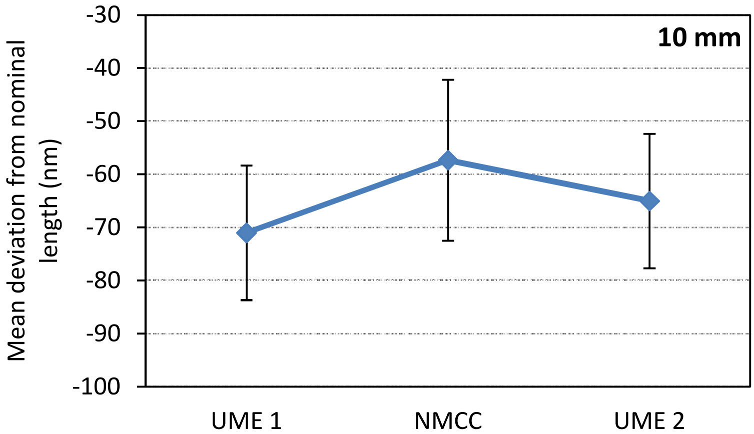


Figure 4(f). Stability of 10 mm gauge block (S/N 88216) during the comparison. Uncertainty bars show standard uncertainty (k=1).

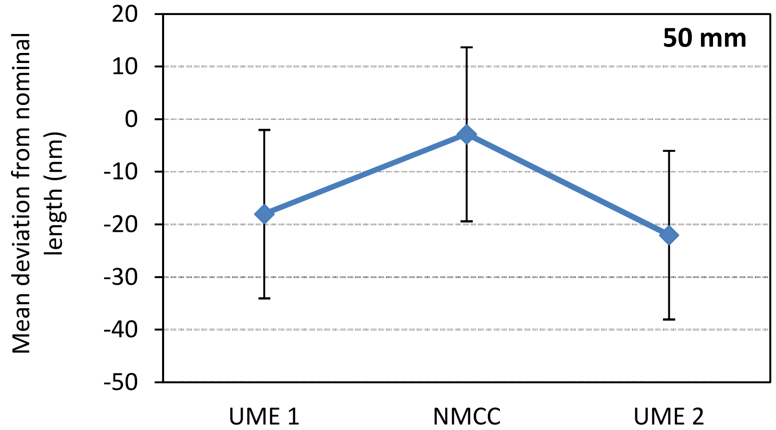


Figure 4(g). Stability of 50 mm gauge block (S/N 88216) during the comparison. Uncertainty bars show standard uncertainty (k=1).

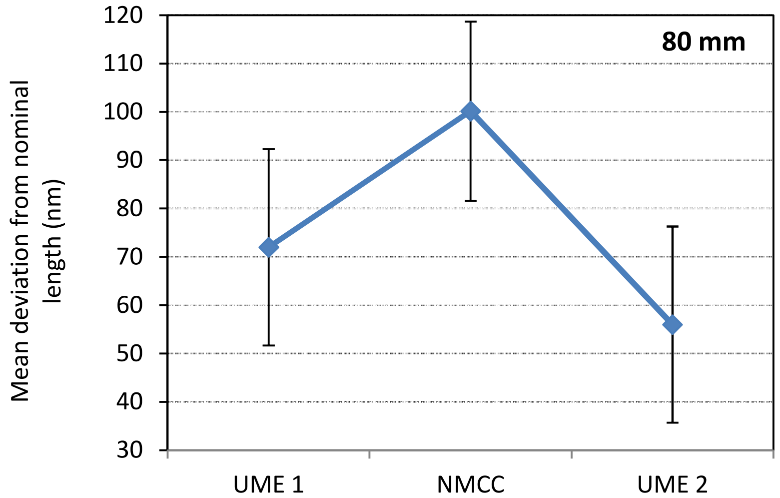


Figure 4(h). Stability of 80 mm gauge block (S/N 88216) during the comparison. Uncertainty bars show standard uncertainty (k=1).

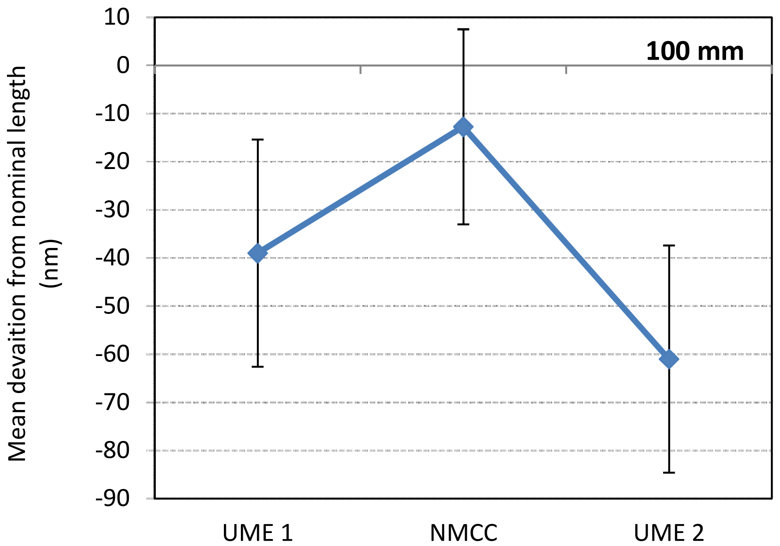


Figure 4(i). Stability of 100 mm gauge block (S/N 88216) during the comparison. Uncertainty bars show standard uncertainty (k=1).

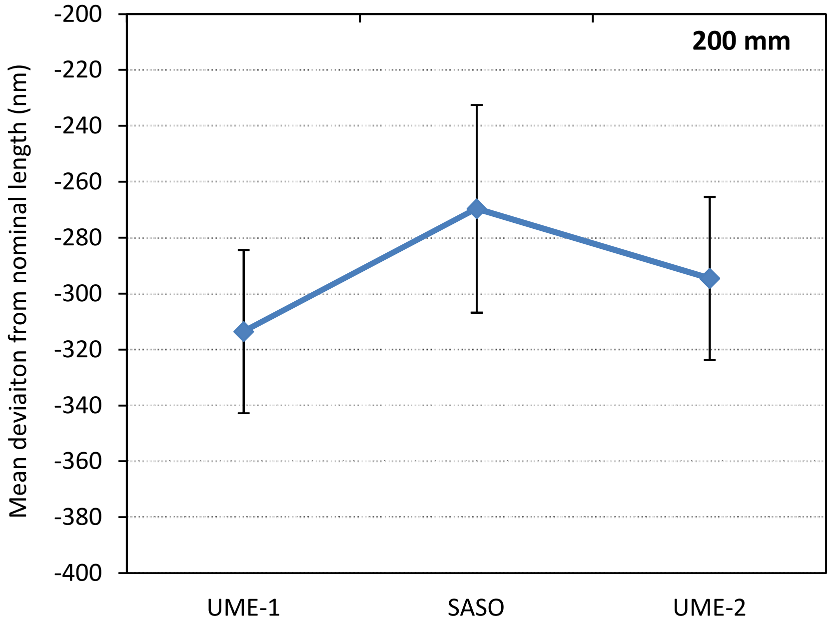


Figure 4(j). Stability of 200 mm gauge block (S/N 87301) during the comparison. Uncertainty bars show standard uncertainty (k=1).

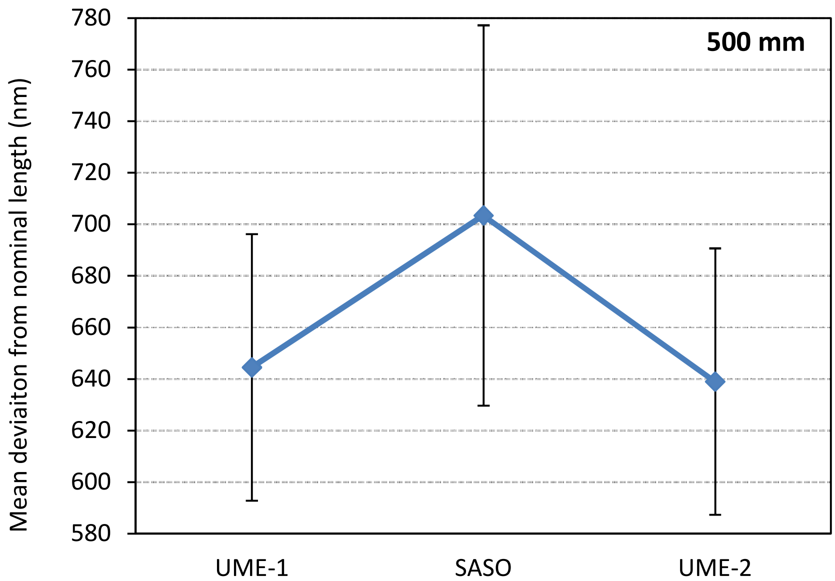


Figure 4(k). Stability of 500 mm gauge block (S/N 86390) during the comparison. Uncertainty bars show standard uncertainty (k=1).

As seen from the plots, change in length for 2 mm gauge block in Figure 4(i) is 12 nm and it can be considered to be quite small.

For all of the other blocks, there is no any drift during the comparison measurement, so these gauge blocks seemed stable. For this reason, we didn't make any drift calculations in this comparison report.

7. Conclusion

Actually, the measurements and reporting of the comparison were finished in 2017. However, because of the organizational changes in upper management of TC-L in GULFMET, the approval of the report by GULFMET TC-L and submission to the BIPM were delayed several months.

One of the gauge block, 600 mm, was damaged during the comparison. Fortunately, this damaging was occurred after completing of measurements of TUBİTAK UME and SASO NMCC laboratory. So, the results belong to 600 mm block could be reported. However, because of the second measurement of the pilot laboratory could not be performed for 600 mm gauge block, the stability graph of this block could not be plotted.

For short gauge blocks, the phase correction was measured and applied by phase stack method for both of the short gauge block interferometer systems (Appendix A). For long gauge block interferometers, no any correction was applied but the theoretical value was used in the uncertainty budget. Additionally, detailed measurement conditions of the interferometers of the participating laboratories are given in Appendix A.

It is obvious from the results that all En values are within ±1 range, with k=2. The comparison results are accounted as satisfactory and successful.

Since GULFMET region is a new RMO, this comparison will provide an improvement of the new NMIs metrological equivalence with the other RMOs. Additionally, this comparison can provide a link to the EURAMET.L-K1 Key Comparison of short and long gauge block calibration by interferometry through TÜBİTAK UME.

8. References

[1] Technical Protocol Bilateral Comparison on Calibration of Short and Long Gauge Blocks by Interferometry between TÜBİTAK UME and SASO NMCC.

[2] ISO 3650:1998(E), Geometrical Product Specification (GPS) – Length Standards – Gauge Blocks, International Organization for Standardization, Geneva, Switzerland.

[3] Viliesid M 2011 Technical Protocol document, key comparison CCL-K1

[4] Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement (GUM), JCGM 100, First edition, September 2008 (available on the BIPM website: http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf)

[5] Decker J E, Pekelsky J R 1997 Uncertainty evaluation for the measurement of gauge blocks by optical interferometry Metrologia 34 479-493

[6] Lewis A 2006 Final Report on EUROMET Key Comparison EUROMET.L-K2: Calibration of long gauge blocks *Metrologia* 43 04003

[7] Key Comparison EURAMET.L-K1.2011 Measurement of Gauge blocks by interferometry. http://iopscience.iop.org/article/10.1088/0026-1394/53/1A/04003

[8] Cox M G 2002 The evaluation of key comparison data Metrologia 39 589-95

[9] Template bilateral report, CCL-WG/-MRA-GD-3.2b

[10] ISO/IEC 17043 “Conformity assessment — General requirements for proficiency testing”, International Standardization Organization”, 2010

[11] Report template, CCL-WG/-MRA-GD-3.2

Appendix A- Measurement Conditions

Table A1. Measurement instrument and conditions reported by the participating laboratories.

For Short Interferometer;

Lab.	SASO NMCC	TUBİTAK UME
Make and type of interferometer	Twyman-Green type phase stepping interferometer	NPL TESA, Twyman-Green type interferometer
Light sources, Wavelengths	He-Ne Laser, 543 nm He-Ne/I_2, 633 nm	He-Ne Laser, 543 nm He-Ne Laser, 633 nm
Fringe fractioning method	Phase stepping (five positions) fringe fraction measurements for two wavelengths. Method of excess fractions, basing the result on the red wavelength.	According to the standard method of TESA automatic gauge block interferometer
Refractive index determination	Edlen's equation as modified by Brich and Downs with CO_2 corrections (Metrologia 31, 1994)	Edlen's equation as modified by Brich and Downs (Metrologia 31, 1994)
Temperature range/ °C	19,930 – 20,090	19,700 – 20,300
Material of reference flats	Steel	Steel
Phase correction applied	-11 nm	- 12 nm

For Long Interferometer;

Lab.	SASO NMCC	TUBİTAK UME
Make and type of interferometer	Twyman-Green type phase stepping interferometer	UME design Kösters type phase stepping interferometer
Light sources, Wavelengths	He-Ne Laser, 543 nm He-Ne/I_2,633 nm ECDL/Rb two-photon, 778 nm	Nd:YAG/I_2, 532 nm He-Ne/I_2,633 nm ECDL/Rb two-photon,778 nm
Fringe fractioning method	Phase stepping (five positions) fringe fraction measurements for three wavelengths. Method of excess fractions, basing the result on the red wavelength.	Phase stepping (five positions) fringe fraction measurements for three wavelengths. Method of excess fractions, basing the result on the red wavelength.
Refractive index determination	Edlen's equation as modified by Brich and Downs with CO_2 corrections (Metrologia 31, 1994)	Edlen's equation as modified by Brich and Downs with CO_2 corrections (Metrologia 31, 1994)
Temperature range/ °C	19,925 – 19,985	19,990 – 20,010
Material of reference flats	Steel	Steel
Phase correction applied	No correction is applied	No correction is applied

Appendix B / Appendix C - Conditions of Measuring Faces

This part includes the participant's (SASO NMCC and TÜBİTAK UME) reports "Appendix B-Condition of Measuring Faces (short GB)" and "Appendix C-Condition of Measuring Faces (long GB).

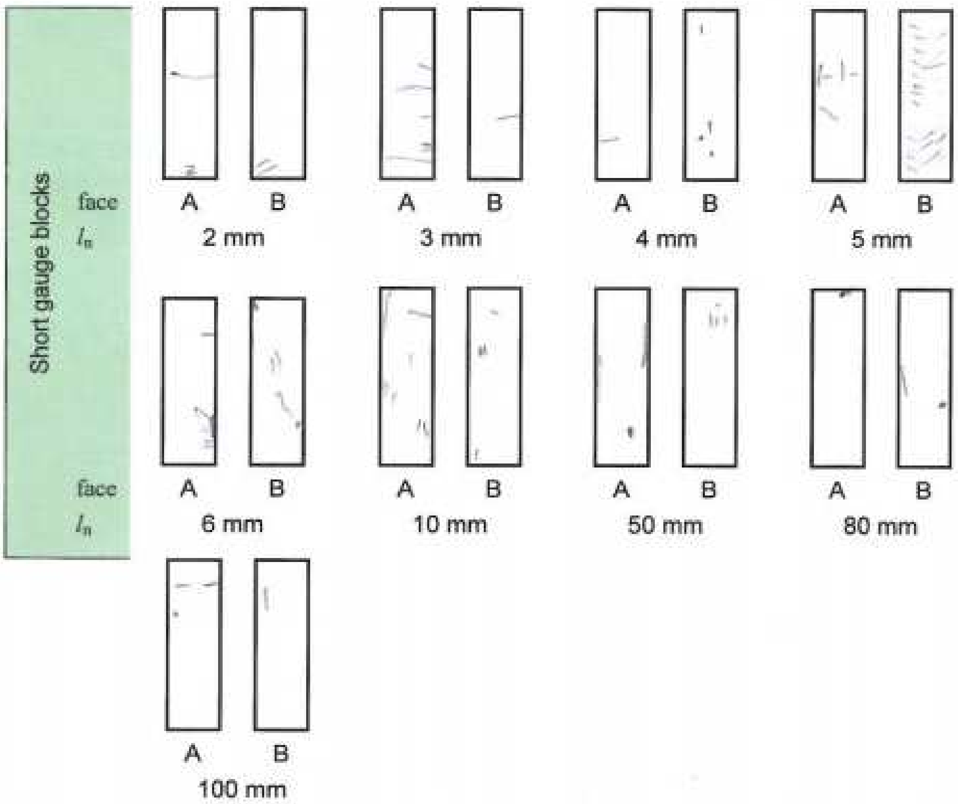
TÜBİTAK UME

GULFMET

Appendix B – Conditions of Measuring Faces (short GB)

To:	**Damla ŞENDOĞDU,** TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY Tel : +90 262 679 50 00 E-mail : damla.sendogdu@tubitak.gov.tr			
From:	NMI:	SASO - NMCC	Name:	Nasser Algahtani
	Signature:	[signature]	Date:	01.03.2017

After detailed inspection of the measuring faces of the gauge blocks these are the results. Please mark significant surface faults (scratches, indentations, corrosion, etc.)



Technical Protocol of Bilateral Comparison on Calibration of Gauge Blocks Between TÜBİTAK UME and SASO NMCC 11/15

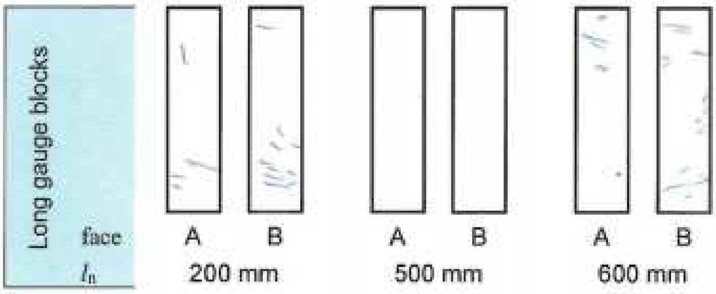
TÜBİTAK UME

GULFMET

Appendix C – Conditions of Measuring Faces (long GB)

To:	Damla ŞENDOĞDU, TÜBİTAK UME, PK:54 – 41470 Gebze-Kocaeli / TURKEY Tel: +90 262 679 50 00 e-mail: damla.sendogdu@tubitak.gov.tr			
From:	NMI:	SASO – NMCC	Name:	Nasser Alqahtani
	Signature:	[signature]	Date:	01 _ 03 _ 2017

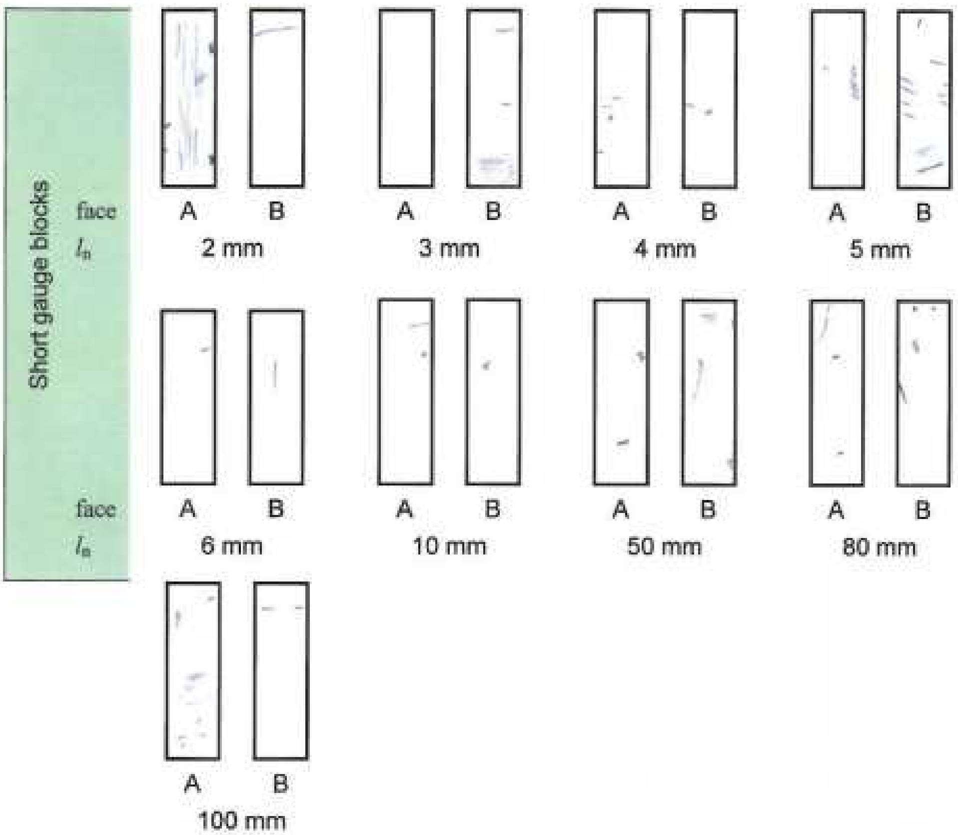
After detailed inspection of the measuring faces of the gauge blocks these are the results. Please mark significant surface faults (scratches, indentations, corrosion, etc.)



Appendix B – Conditions of Measuring Faces (short GB)

To:	**Damla ŞENDOĞDU,** TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY Tel : +90 262 679 50 00 E-mail : damla.sendogdu@tubitak.gov.tr
From:	NMI: TÜBİTAK UME .... Name: Damla Şendoğdu .... Signature: [signature] .... Date: 24.04.2017 ....

After detailed inspection of the measuring faces of the gauge blocks these are the results. Please mark significant surface faults (scratches, indentations, corrosion, etc.)



Technical Protocol of Bilateral Comparison on Calibration of Gauge Blocks Between TÜBİTAK UME and SASO NMCC 11/15

TÜBİTAK UME

GULFMET

Appendix C – Conditions of Measuring Faces (long GB)

To:	**Damla ŞENDOĞDU,** TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY Tel : +90 262 679 50 00 E-mail : damla.sendogdu@tubitak.gov.tr
From:	NMI: TÜBİTAK UME Name: Damla Şendoğdu Signature: [signature] Date: 24.04.2017

After detailed inspection of the measuring faces of the gauge blocks these are the results. Please mark significant surface faults (scratches, indentations, corrosion, etc.)