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SIM.L-S2.2n01

Gauge Block by Mechanical Comparison

SUPPLEMENTARY COMPARISON

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Supplementary Comparison

Calibration of Gauge Block by Mechanical Comparison

Final Report

(October 2025)

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1. Document control

Version Draft A	Issued on May 2024.
2nd Version Draft A	Issued on October 2024.
3rd Version Draft A	Issued on November 2024
Version Draft B	Issued on November 2024
2nd Version Draft B	Issued on September2025
Final report	Issued on October 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 SIM TC for Length decided in June 2019 upon a supplementary comparison on short gauge blocks (GB) (length ≤ 100 mm) calibration by mechanical comparison, named SIM.L-S7.2019, with INTI as the pilot laboratory, CENAM as the co-pilot laboratory and NRC as a non-participant viewer. The SIM comparison was registered in October 2019, and measurements started in January 2020.

Reference values from the deviation of central length measured by interferometry were provided by INTI and NIST. INTI performed three interferometric measurements: one before the circulation of the GB started (2019), one as intermediate check at the middle of the exercise (2021), and a last one once the GB returned to Argentina (2024). NIST performed one interferometric measurement along with the mechanical comparison measurement (2020).

Reference values from f_o and f_u were provided by CENAM. They were determined by Mechanical Comparison (the variations between readings at the center and at the four corners of the measuring faces, approximately 1.5 mm from the side faces). CENAM took three f_o and f_u measurements: one at the beginning of the comparison, one intermediate check, and a last one before sending the GB to PAI (NMI of Kuwait).

The procedures outlined in the SIM.L-S7 Protocol document covered the technical procedure to be followed during the measurements. A goal of the SIM supplementary comparisons is to demonstrate the equivalence of routine calibration services offered by NMIs to clients, as listed in Appendix C of the Mutual Recognition Arrangement (MRA). To this end, participants in this comparison agree to use the same apparatus and methods as routinely applied to client artifacts.

Fifteen SIM and one GULFMET laboratories participated in the comparison: TTBS (Trinidad and Tobago), CENAM (México), INEN (Ecuador), CENAME (Guatemala), DICTUC (Chile), IBMETRO (Bolivia), LATU(Uruguay), INM (Colombia), INTI (Argentina), CENAMEP (Panamá), INMETRO (Brazil), LACOMET (Costa Rica), BSJ (Jamaica), INACAL (Perú), NIST (United States), PAI (Kuwait).

The comparison followed the guidelines for CIPM key comparisons (CIPM MRA-G-11).

3. Organization

3.1 Participants

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Table 1 – Participants

3.2 Circulation

The comparison started with INTI, as the pilot laboratory measuring the (GB) by interferometry, then CENAM measured f_o and f_u by mechanical comparison, followed by all the participants, including an intermediate check by INTI, and finished with INTI for verification of either drift or damage to the artifacts. During their turn, NIST also carried out their interferometric measurements.
Each laboratory had one month (4 weeks) to perform the calibration and to ship the GB to the next laboratory.

There were several important delays from the initial schedule established in the measurement protocol. The first delay occurred after the DICTUC concluded their measurements and was due to the Covid-19 Pandemic and some of the following participants closed their operations. The initial schedule was changed to allow the laboratories, which were not closed, to perform their measurements. The second delay was due to customs clearance at INMETRO before the GB came back to Argentina to perform intermediate interferometric measurements. Further delays occurred at customs when the GB were shipped from INEN to INM, and finally, another important delay occurred at customs in Peru (when arriving and leaving Peru) when the GB were going from IBMETRO to INACAL and from INACAL to CENAM.
The final circulation schedule is shown in Table 2.

Region	**Laboratory**	**Measurement Date**
SIM	CENAM	January 2020
	LATU	February 2020
	DICTUC	March 2020
	LACOMET	August - Sept 2020
	NIST	October 2020
	CENAMEP	January 2021
	CENAM (intermediate f_o and f_u)	February 2021
	INTI (mechanical)	August 2021
	INTI (intermediate check)	September 2021
	INEN	February 2022
	INM	May 2022
	BSJ	June 2022
	TTBS	July 2022
	INMETRO	September 2022
	CENAME	November 2022
	IBMETRO	January 2023
	INACAL	June 2023
	CENAM (f_o and f_u final)	August 2023
GULFMET	PAI	September 2023
SIM	INTI (final check)	January 2024

Table 2 – Final circulation schedule

4. Description of artifacts

A set of six steel GB was selected for this comparison, with nominal lengths of 0.5, 2.5, 10, 25, 60 and 100 mm. They are shown inside their shipping casing in figure 1.

Figure 1 – Gauge blocks

A thermal expansion coefficient of 11.5 (10^{-6} K^{-1}), stated by the manufacturer should be used for all corrections.

5. Measurement Instructions

5.1 Definitions

The main measurand is the deviation of the central length of the GB with respect to its nominal length, as defined in ISO 3650. The central length is determined by mechanical comparison by comparing against the laboratory reference gauge block by means of an appropriate GB comparator. If capable, participants shall also determine a second measurand used to calculate the variation in length across the surface of each gauge by measuring at five points on the surface of each GB, the four corners and the center, and determining afterwards f_o and f_u as defined in ISO 3650.

The GB should be measured by mechanical comparison against the laboratory's reference GB, applying the regular calibration procedure used for their customers.

The measurands for each gauge block are the following:

1) Deviation of the central length d (P1 in figure 2) is the difference between the measured central length lc and the nominal length ln, calculated as:

$$d = lc - ln \qquad (1)$$

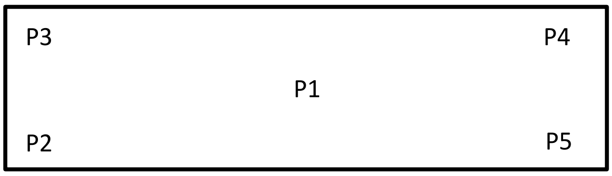

Figure 2 - Measuring points

2) If the participant is capable, points P2 to P5 (figure 2) must be measured. These values are then used to calculate f_o and f_u, for each gauge by the participants, according to ISO 3650.

f_o is calculated as follows:

$$f_o = l_{max} - lc \qquad (2)$$

f_u is calculated as follows:

$$f_u = lc - l_{min} \qquad (3)$$

where l_{max} and l_{min} are the maximum and the minimum measured lengths from points P2 through P5 as shown in Figure 3.

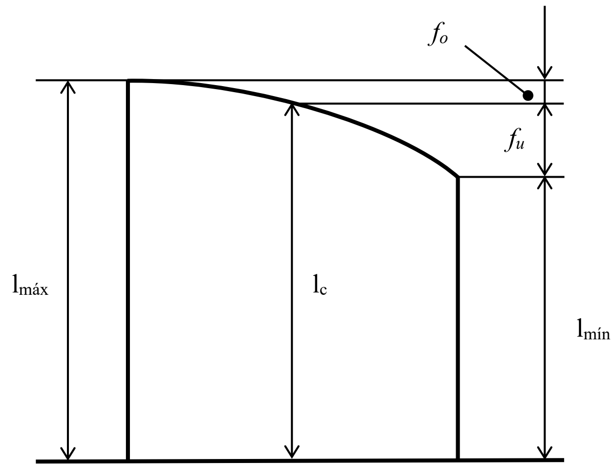

Figure 3 - Definitions according to ISO 3650

5.2 Measurement methods

The participants were requested to measure the GB by applying the regular procedure the laboratory uses in their calibration service. We identify as “Face A” the measuring face showing the inscriptions of nominal length, identification number and manufacturer for GBs with nominal length < 6 mm; and those marked with these inscriptions on the righthand side for longer GB (see Figures 4 and 5). The other face is identified as “Face B”.

To perform their measurements the GB should be positioned as indicated in figures 4 and 5:

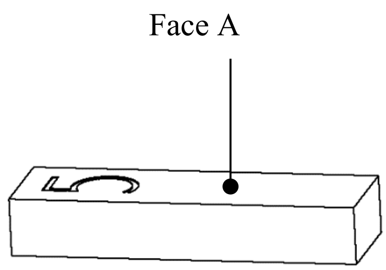

Figure 4 - Gauge Block with nominal length < 6 mm

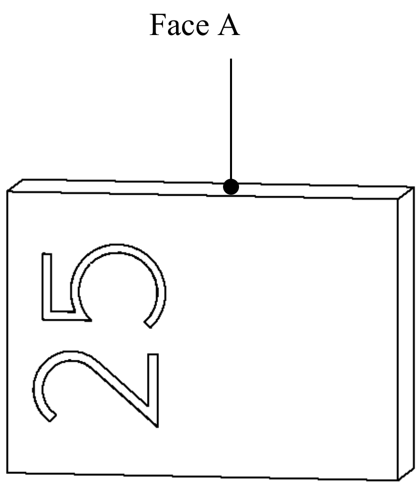

Figure 5 - Gauge block with nominal length ≥ 6 mm

6. Measurement uncertainties

The uncertainty of measurement was reported by the participants according to the ISO Guide for the Expression of Uncertainty in Measurement. The detailed uncertainty budget of the participants was also requested, and they appear in Annex D.

7. Instrument used, traceability and CMC entry by the participants

Table 3 shows a brief description of the instrument used, how is traceability of measurement achieved, and the CMC stated uncertainty by the participants.

Participant	Instrument and Reference GB	Traceability	CMC Quoted Uncertainty	KCDB Uncertainty
CENAM	TESA upd 525 mm GB double probe comparator, 2 nm resolution. Measurement span 25 mm Steel gauge blocks calibrated by interferometry	CENAM	Q[21, 0.49L] nm L in mm *k*=2	Q[29, 0.94L] nm L in mm *k*=2
LATU	Mahr 100 mm gauge block comparator, model 826, Steel gauge blocks calibrated by interferometry	PTB CENAM	Q[61, 0.89L] nm L in mm (*k*=2)	Q[65, 0.89L] nm L in mm (*k*=2)
DICTUC	Double probe Tesa UPC 100 mm gauge block comparator Steel Gauge blocks calibrated by interferometry	PTB calibrated gauge blocks PTB calibration	60 nm + 0.6 * 10-6 L (*k*=2)	60+0.6L nm L in mm (*k*=2)
LACOMET	Tesa Mechanical gauge block comparator Ceramic gauge blocks calibrated by interferometry	CENAM CENAM	Q[0.041 µm, $0.42x10^{-6}$L] (*k*=2)	-----

NIST	Two contact point 100 mm Mahr / Federal comparator, model 130B-24	Master blocks measured on a continuous cycle by interferometry at NIST. Traceability to the SI unit of length, m, is through the vacuum wavelength of the 633 nm He-Ne laser calibrated periodically against the NIST Iodine stabilized laser	13.4+0.14L [nm] L in mm (*k*=1)	25+0.35L [nm] L in mm (*k*=2)
CENAMEP	Mitutoyo GBCD 100 mm gauge block comparator Ceramic gauge block set calibrated by interferometry	Probe adjustments CENAM	(0.0024L+0.0022) µm L[mm] (*k*=2)	-----
INTI	Double inductive TESA probing system, with vacuum pump for probe lifting, mounted in a anti vibrating table. All the measuring system is inside an isolating plastic thermal box. One thermistor temperature sensor for gauge blocks under 20 mm (measures the table temperature) and 2 thermistor temperature sensors for gauge blocks from 20 mm up to 100 mm Steel gauge blocks calibrated by interferometry	Argentinian realization of the meter and interferometric calibration of GB	Q[40;0.92L] nm L[mm] (*k*=2)	Q[40;0.92L] nm L[mm] (*k*=2)
INEN	Mahr 175 mm double probe differential comparator Steel gauge blocks calibrated by interferometry	Tungsten carbide gauge blocks calibrated at CENAM CENAM Calibration	Q[21.4;0.6L] nm L[mm] (*k*=1)	-----
INM	Tesa UPD 500 mm gauge block comparator	CENAM calibration	Q[40,0.87L] nm L[mm] (*k*=2)	0.03 +0.001L µm L in mm (*k*=2)

	KOBA steel gauge blocks (1, 5, 10, 15, 20, 25, 50, 75, 100) mm calibrated by interferometry Fluke Chub-E4 digital thermometer	PTB calibration Internal calibration		
BSJ	Mahr, Mechanical Gauge Block Comparator, model 2247386 (130B-24) No information about reference GB	Mahr calibration No information about traceability of GB	Not informed	-----
TTBS	Gauge block comparator Grade K Steel gauge blocks calibrated by interferometry	PTB NPL	Q[21, 0.2L] [nm] L in mm (*k*=1)	-----
INMETRO	Tesa 100 mm double probe electromechanical comparator Thermometer Steel gauge blocks calibrated by interferometry	LAINT – INMETRO LATER – INMETRO LAMED - INMETRO	Q[55, 0.9L] [nm] L in mm (*k*=2)	Q[55, 0.9L] [nm] L in mm (*k*=2)
CENAME	Mahr 826 PC 170 mm Gauge blocks comparator Grade 0 Steel Gauge blocks (universal measuring machine calibrated) Thermometer	Mahr Opus metrology / assicontrol CENAME	(0.0025+0.000144 L) µm L in mm	-----
IBMETRO	STEINMEYER 100 mm gauge block comparator Grade k steel gauge block set calibrated by interferometry Material Thermometer	INTI JCSS - Mitutoyo LATU	67+0.29 L nm (L in mm) (k =2)	-----
INACAL	Mahr 100 mm Gauge block comparator Steel grade k gauge blocks calibrated by interferometry Thermometer	INACAL CEM INACAL	Q[45;0.6$10^{-6}$L] (*k*=1)	Q[74, 0.61L] nm L in mm (*k*=2)
PAI	Ferinmess Suhl GMBH Gauge block ceramic grade 0 0.5 and 60 mm gauge block steel grade k 2.5, 10, 25 and 100 mm gauge block calibrated by mechanical comparison	TUKAK (UME)	0.09 µm+0.7x10^{-6} L (L in mm) (*k*=2)	-----

Table 3 - Measurement methods and instrument used by the participants

8. Stability of Artifacts

The six GB used for the comparison are property of INTI and were manufactured more than twenty years ago, therefore, it is assumed they are stable. However, the stability during the circulation was verified by INTI by measuring the deviation of the central length by interferometry, at the start, at the middle and at the end of the circulation of the GB. To check stability of f_0 and f_u, CENAM also measured these parameters at the beginning, at the middle and at the end of the comparison.

8.1 Deviation of the central length stability

In order to check a possible change in the values of the deviation of the central length, the maximum difference measured by INTI by the interferometric method is calculated.

Table 4 shows the apparent changes and the standard uncertainties.

Nominal length /mm	**Apparent change /nm**	$\boldsymbol{u}$ **/nm (*k*=1)**
0.5	4	11
2.5	7	11
10	7	11
25	7	13
60	28	19
100	13	28

Table 4 – Deviation of the central length apparent changes

From table 4 the apparent change in the deviation of the central length is between the informed uncertainty, so these apparent changes are considered not significant.

Figures 6 to 11 show the opening, intermediate and closing measurements with their respective standard uncertainties for the deviation of the central length.

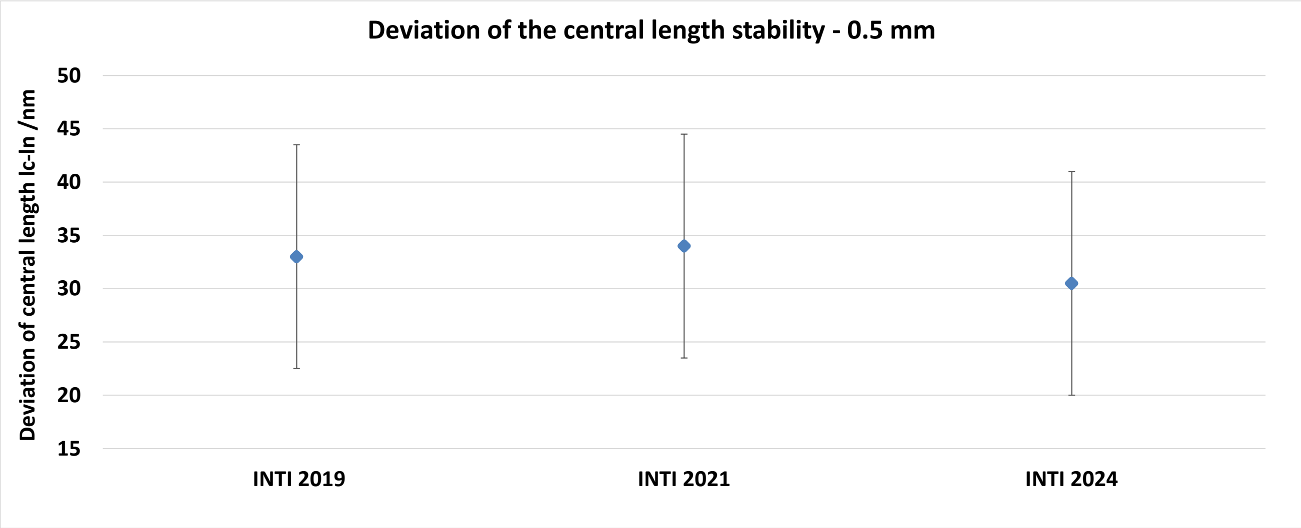

Figure 6 – 0.5 mm nominal length gauge block

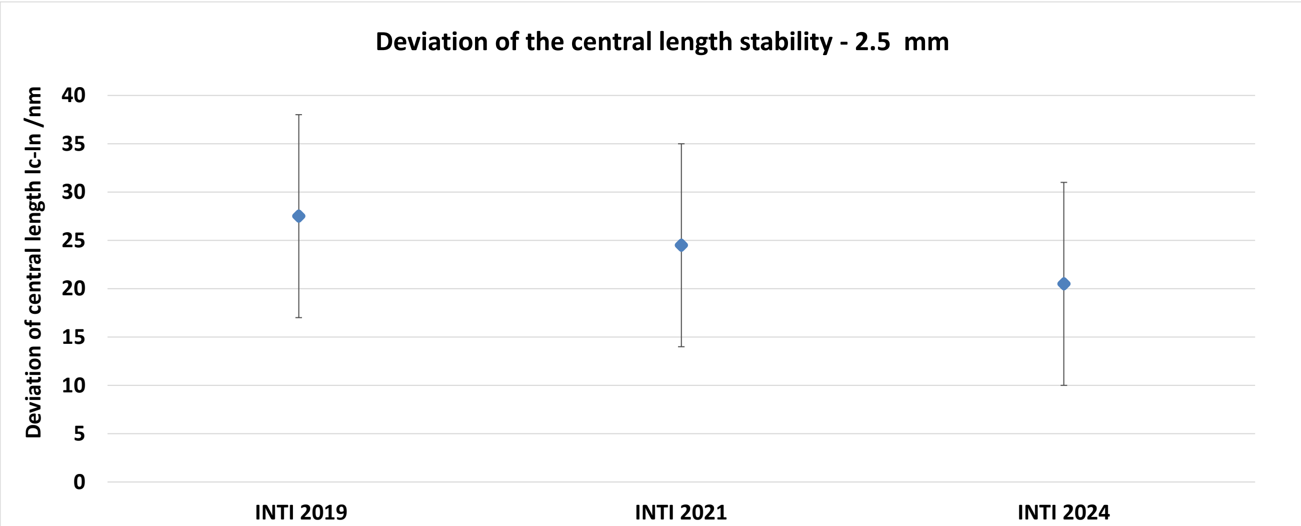

Figure 7 – 2.5 mm nominal length gauge block

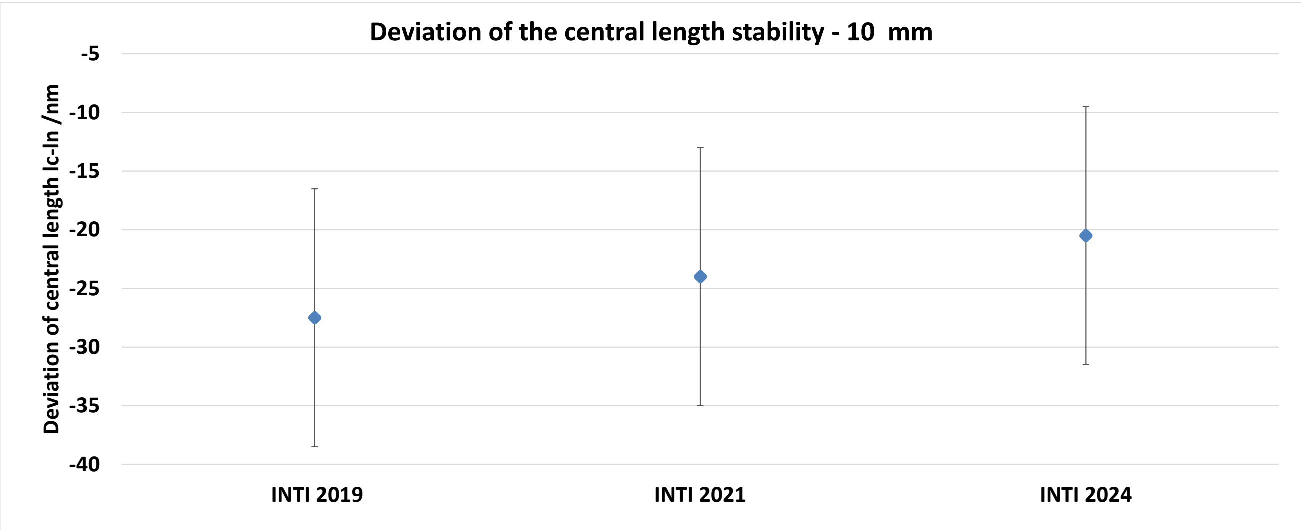

Figure 8 – 10 mm nominal length gauge block

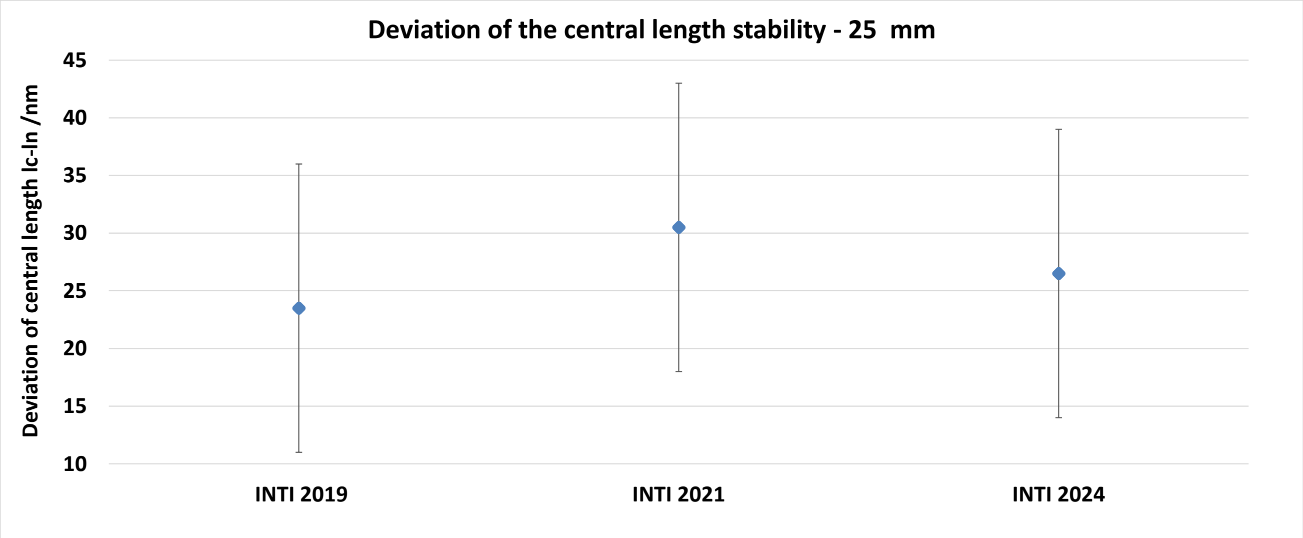

Figure 9 – 25 mm nominal length gauge block

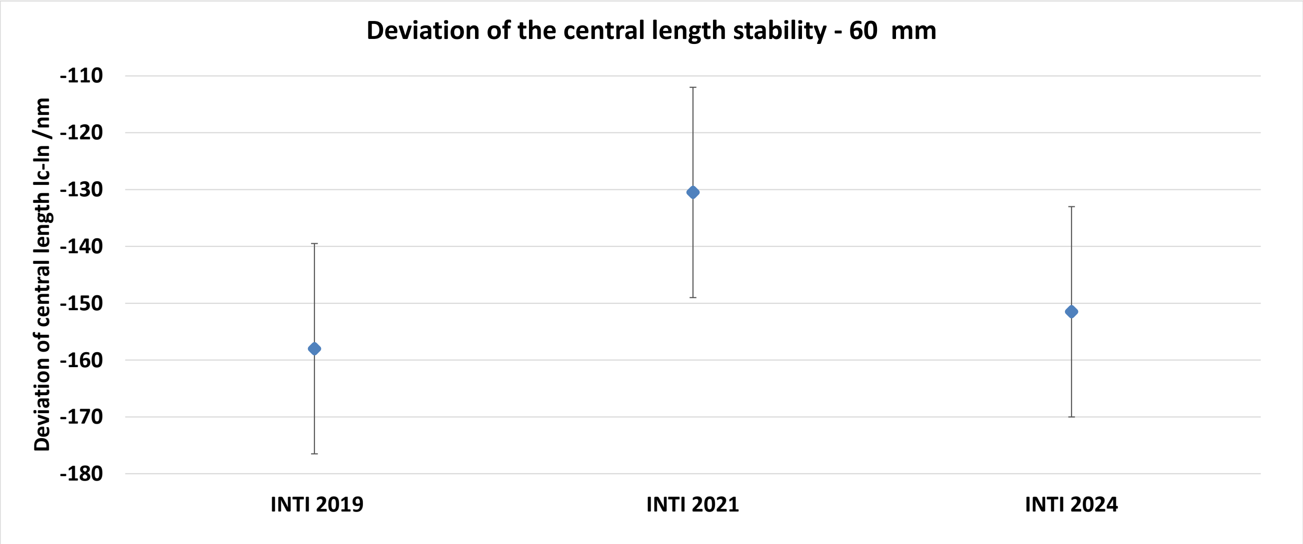

Figure 10 – 60 mm nominal length gauge block

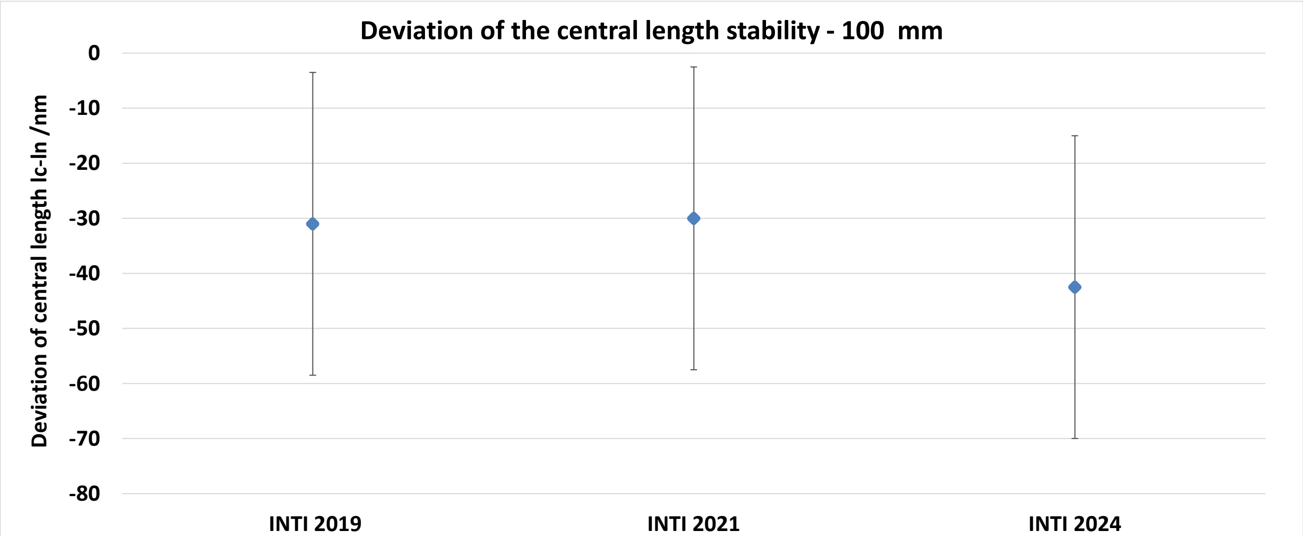

Figure 11 – 100 mm nominal length gauge block

8.2 f_o stability

In order to check a possible change in the value of f_o, the maximum difference of the measured values by CENAM are calculated. Table 5 shows the apparent changes and the standard uncertainties.

Nominal length /mm	Apparent change /nm	u /nm (*k*=1)
0.5	2	9
2.5	1	9
10	0	9
25	1	9
60	0	9
100	2	9

Table 5 – f_o apparent change

From table 5 the apparent change in the deviation from central length are between the informed uncertainty, so these apparent changes are considered not significant.

Figures 12 to 17 show the opening, intermediate and closing measurements with their respective standard uncertainties for f_o.

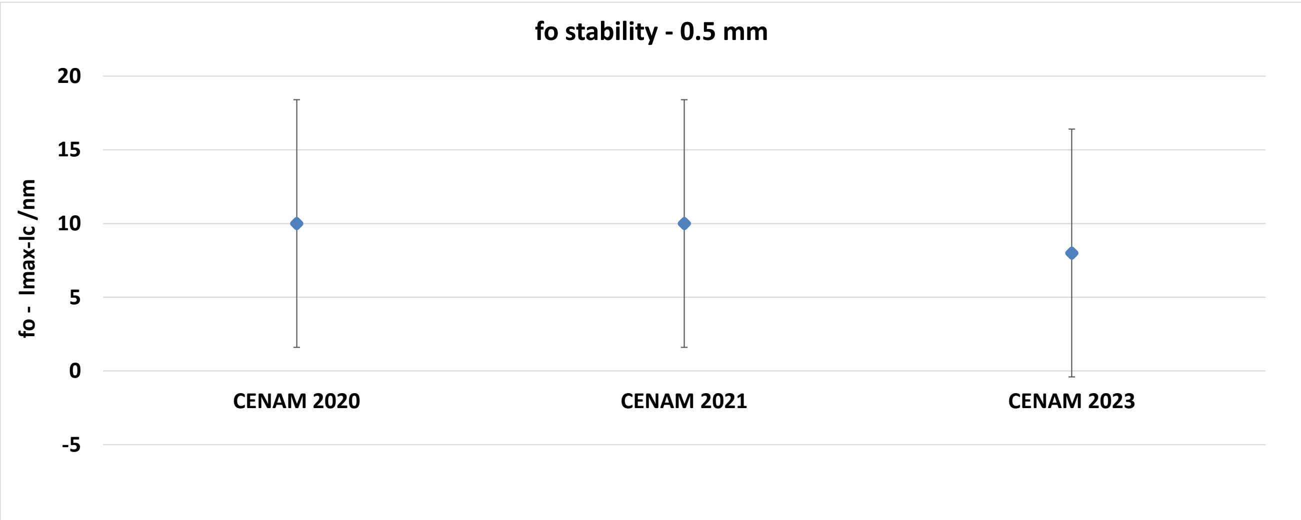

Figure 12 – 0.5 mm nominal length gauge block

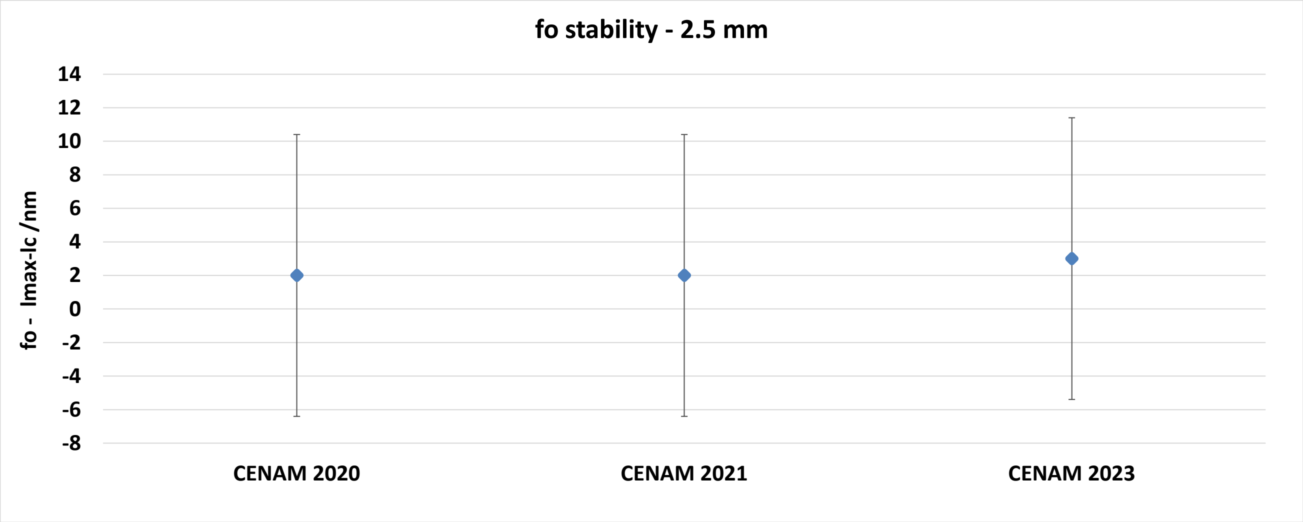

Figure 13 – 2.5 mm nominal length gauge block

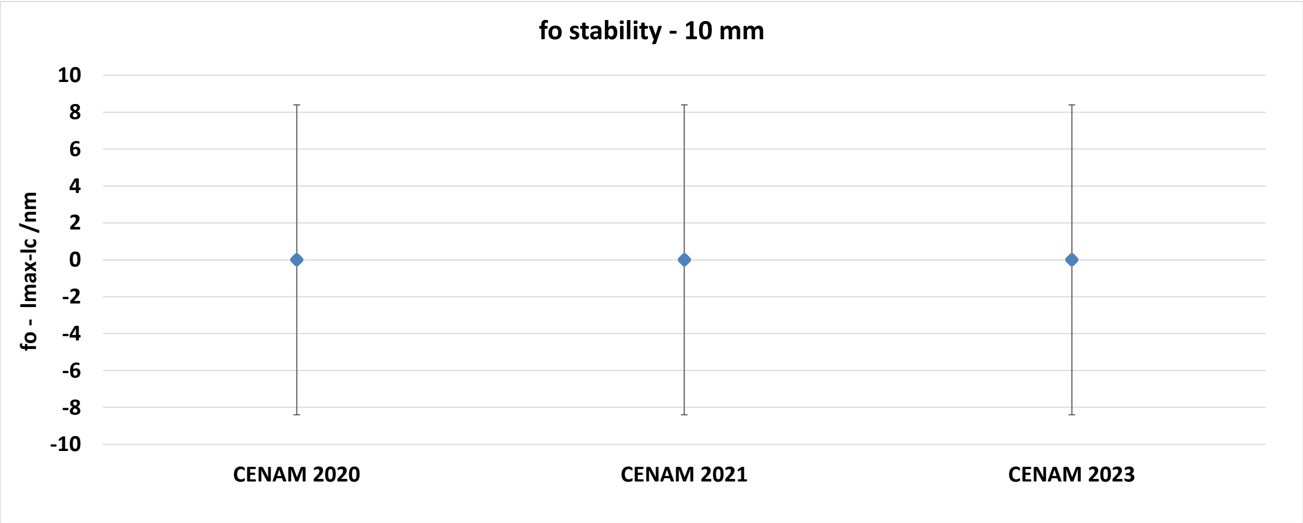

Figure 14 – 10 mm nominal length gauge block

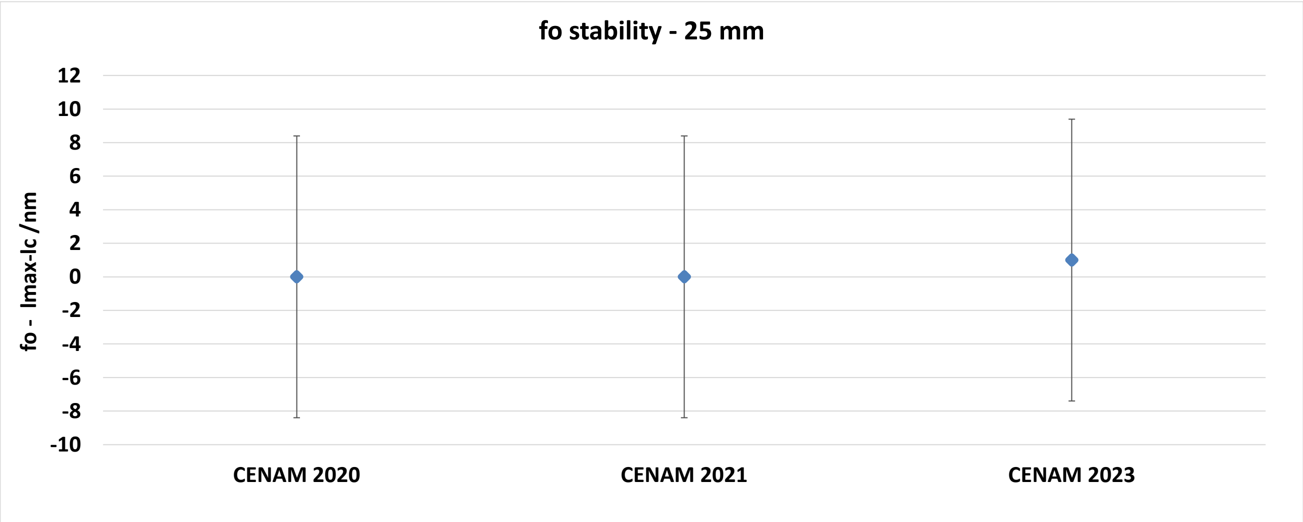

Figure 15 – 25 mm nominal length gauge block

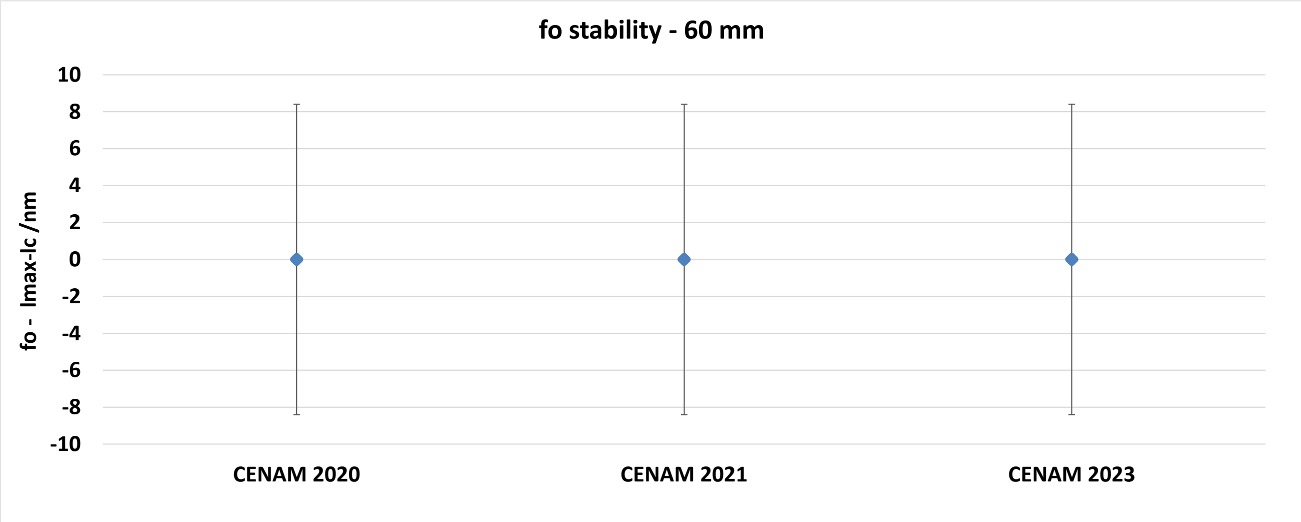

Figure 16 – 60 mm nominal length gauge block

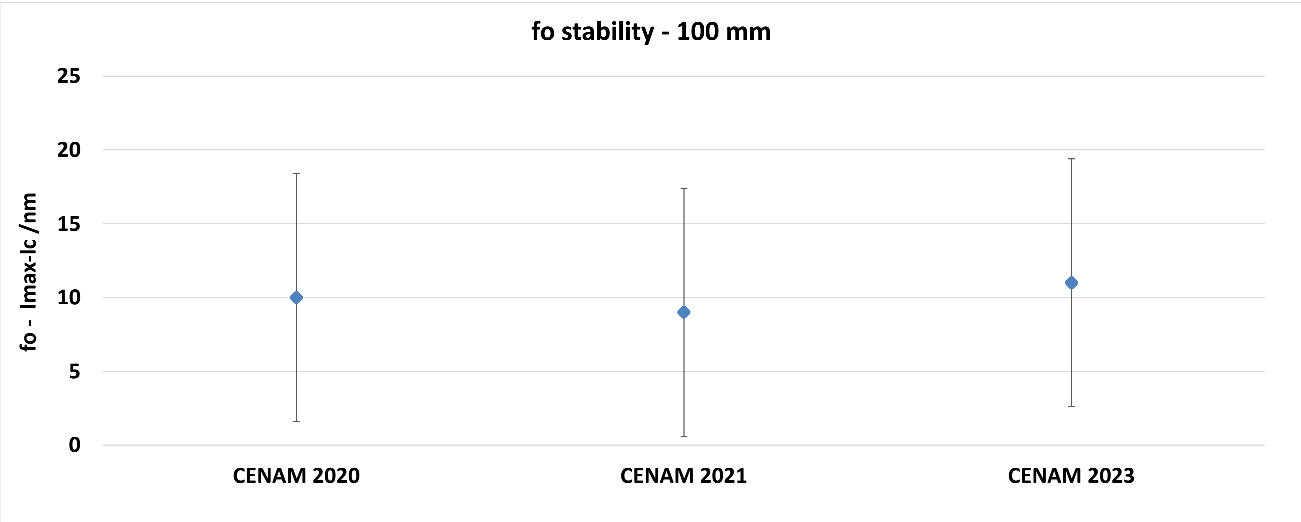

Figure 17 – 100 mm nominal length gauge block

8.3 f_u stability

To check a possible change in the value of f_u, the maximum difference of the measured values by CENAM are calculated. Table 6 shows the apparent changes and the standard uncertainties.

Nominal length /mm	Apparent change /nm	u /nm (*k*=1)
0.5	5	9
2.5	5	9
10	6	9
25	2	9
60	2	9
100	6	9

Table 6 –f_u apparent change

From table 6 the apparent change in the deviation from central length are between the informed uncertainty, so these apparent changes are considered not significant. Figures 18 to 23 show the opening, intermediate and closing measurements with their respective standard uncertainties for f_u.

Figure 18 – 0.5 mm nominal length gauge block

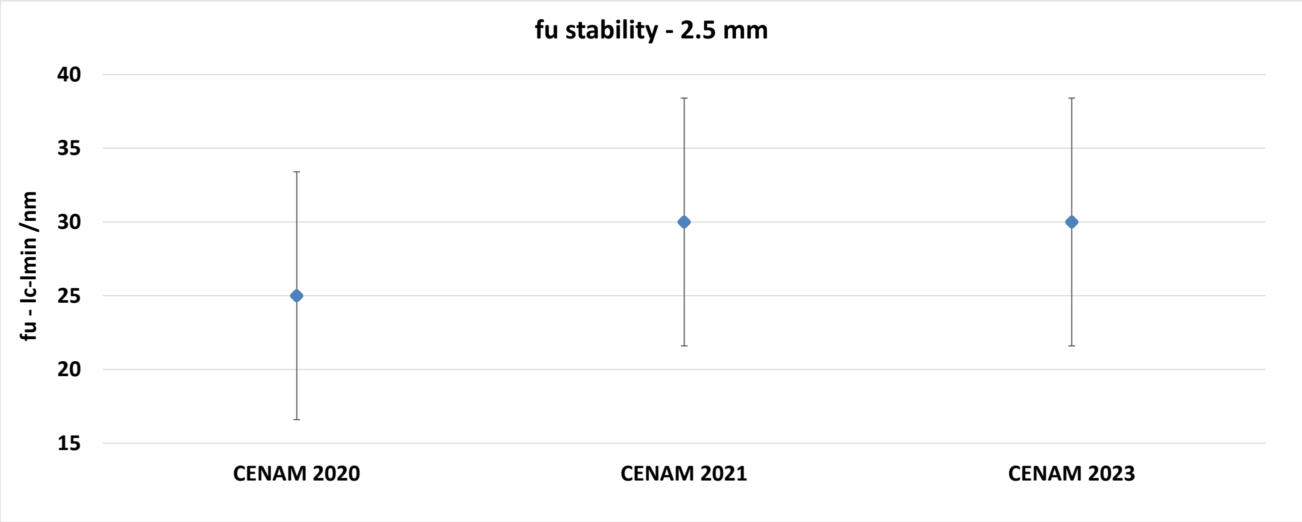

Figure 19 – 2.5 mm nominal length gauge block

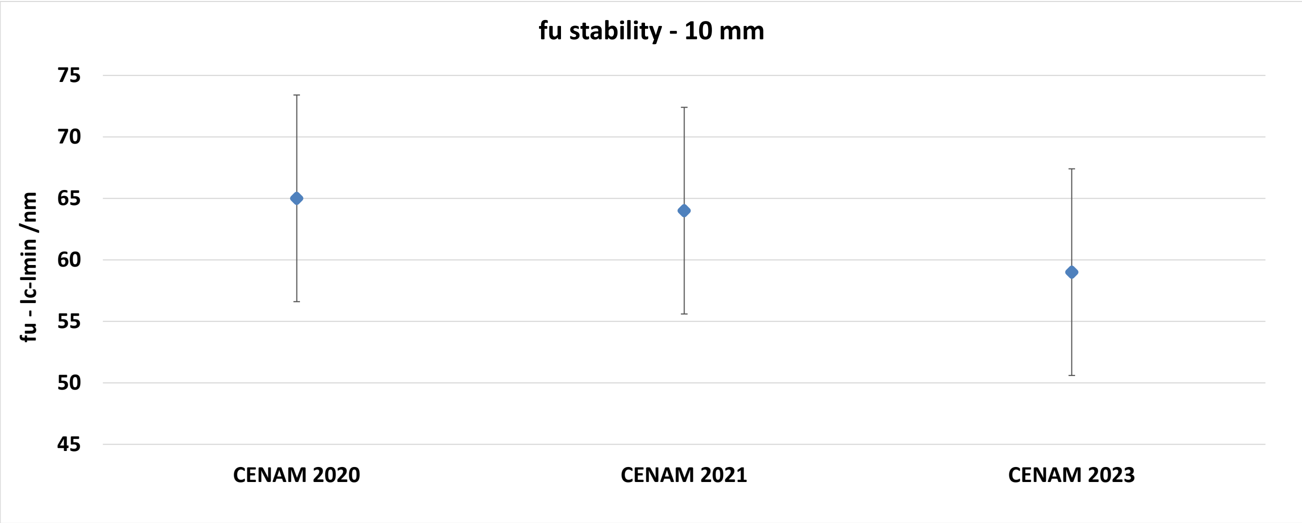

Figure 20 – 10 mm nominal length gauge block

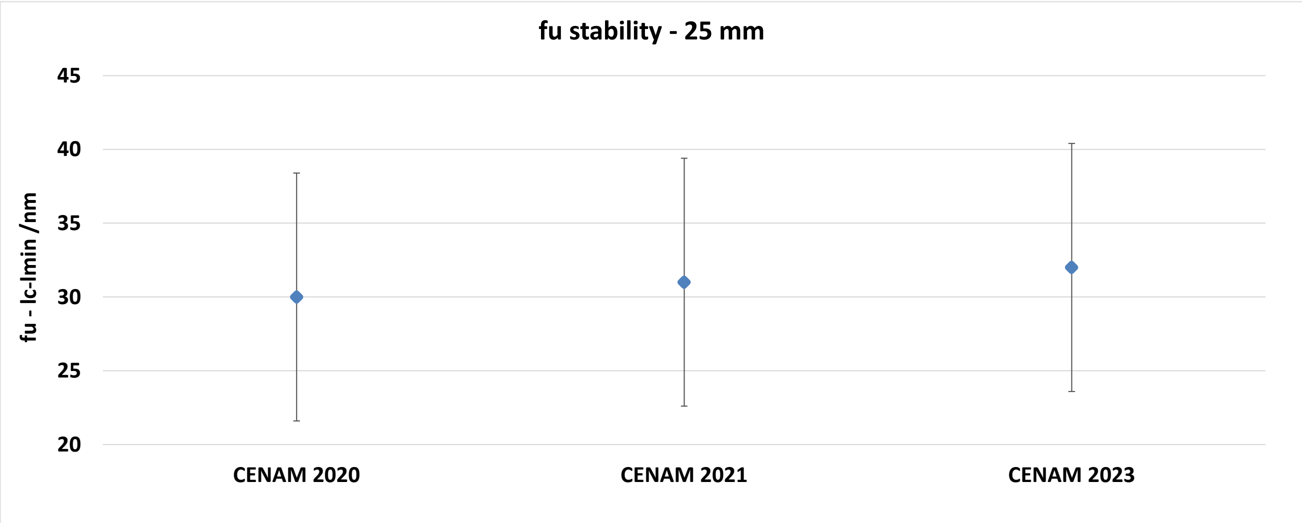

Figure 21 – 25 mm nominal length gauge block

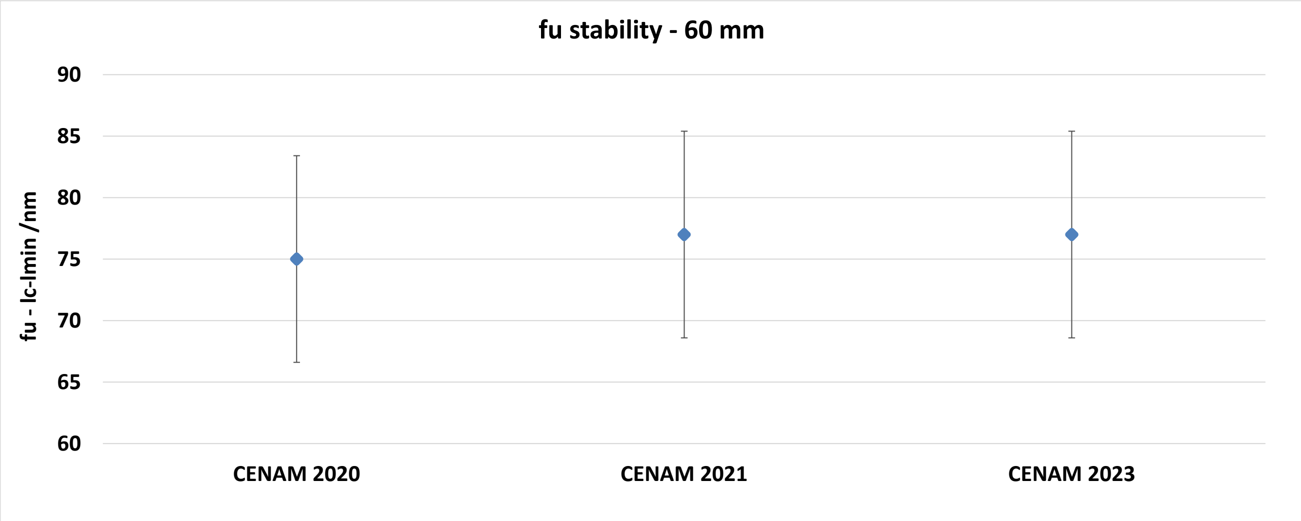

Figure 22 – 60 mm nominal length gauge block

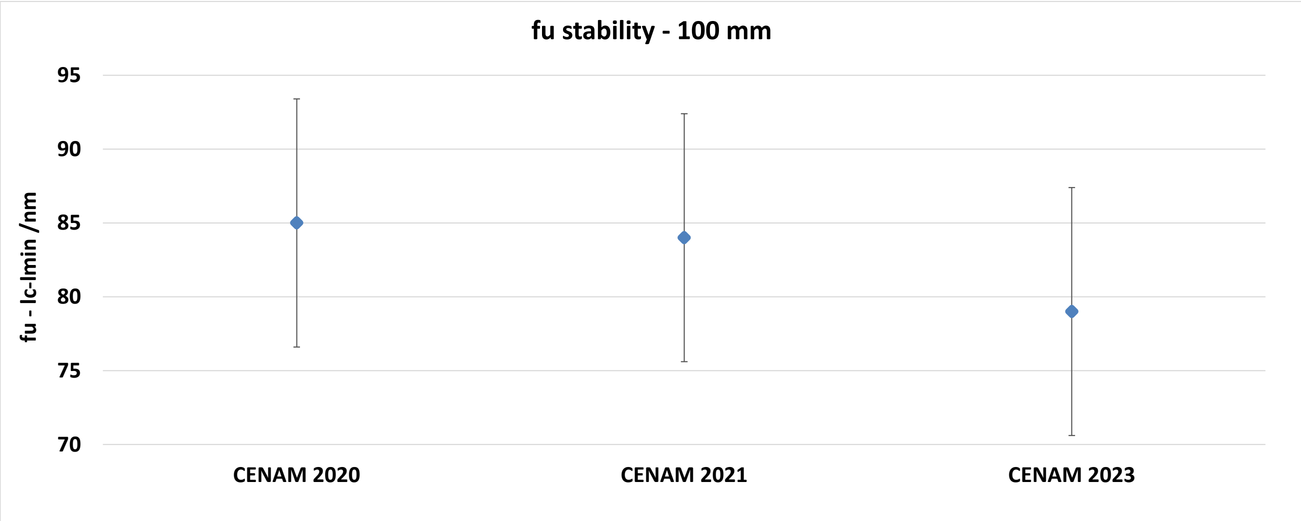

Figure 23 – 100 mm nominal length gauge block

9. Reporting of results

9.1 Deviation of the central length

The submitted results are indicated in tables 7 to 12 for each gauge block for the deviation of central length, while $u(x_i)$ is the standard uncertainty.

NMI	Deviation of the central length /nm	$u(x_i)$ (k=1) /nm
CENAM	44	11
LATU	35	24
DICTUC	30	31
INACAL	0	46
INMETRO	31	30
CENAMEP	46	15
INTI	46	20
NIST	44	14
TTBS	10	21
BSJ	43	20
LACOMET	79	38
CENAME	0	43
IBMETRO	47	30
INEN	70	22
INM	22	20
PAI	180	30

Table 7 – 0.5 mm gauge block deviation of the central length results

NMI	Deviation of the central length /nm	$u(x_i)$ (k=1) /nm
CENAM	33	11
LATU	39	24
DICTUC	20	31
INACAL	0	46
INMETRO	69	30
CENAMEP	37	15
INTI	49	20
NIST	39	14
TTBS	20	21
BSJ	28	13
LACOMET	46	41
CENAME	0	43
IBMETRO	34	30
INEN	50	22
INM	2	20
PAI	60	28

Table 8 – 2.5 mm gauge block deviation of the central length results

NMI	Deviation of the central length /nm	$u(x_i)$ (k=1) /nm
CENAM	-7	11
LATU	-22	27
DICTUC	-40	31
INACAL	0	46
INMETRO	12	30
CENAMEP	2	20
INTI	47	21
NIST	-20	15
TTBS	0	21
BSJ	-13	21
LACOMET	31	50
CENAME	0	43
IBMETRO	-10	35
INEN	10	22
INM	-56	20
PAI	20	28

Table 9 – 10 mm gauge block deviation of the central length results

NMI	Deviation of the central length /nm	$u(x_i)$ (k=1) /nm
CENAM	29	12
LATU	44	26
DICTUC	20	31
INACAL	0	48
INMETRO	80	31
CENAMEP	12	37
INTI	49	23
NIST	25	17
TTBS	30	22
BSJ	2	40
LACOMET	114	70
CENAME	0	53
IBMETRO	34	35
INEN	0	26
INM	-2	23
PAI	80	29

Table 10 – 25 mm gauge block deviation of the central length results

NMI	Deviation of the central length /nm	$u(x_i)$ (k=1) /nm
CENAM	-153	18
LATU	-119	34
DICTUC	-160	32
INACAL	0	59
INMETRO(1)	--	--
CENAMEP	-241	84
INTI	-110	34
NIST	-159	22
TTBS	-130	24
BSJ	-139	76
LACOMET	-50	115
CENAME	0	44
IBMETRO	-147	40
INEN	-140	42
INM	-175	30
PAI	600	40

Table 11 – 60 mm gauge block deviation of the central length results

NMI	Deviation of the central length /nm	u(xi) (*k*=1) /nm
CENAM	-33	27
LATU	-71	56
DICTUC	-50	34
INACAL	0	77
INMETRO	-30	48
CENAMEP	-198	131
INTI	-24	50
NIST	-35	27
TTBS	-110	29
BSJ	-42	150
LACOMET	157	167
CENAME	0	91
IBMETRO	-61	40
INEN	-20	64
INM	-46	48
PAI	220	45

Table 12 – 100 mm gauge block deviation of the central length results

9.2 f_o and f_u results

The submitted results are indicated in tables 13 to 18 for each gauge block for f_o and f_u, while $u(X_i)$ is the standard uncertainty.

NMI	f_o /nm	f_u /nm	u(xi) (*k*=1) /nm
LATU	31	16	28
DICTUC	10	0	25
INACAL	0	0	24
INMETRO	10	8	42
CENAMEP	45	31	22
INTI	10	4	25
NIST(2)	--	--	--
TTBS	20	0	30
BSJ(2)	--	--	--
LACOMET	400	2990	38
CENAME	16	12	4
IBMETRO	23	3	30
INEN	10	80	17
INM	10	20	17
PAI	10	10	19

Table 13 – 0.5 mm gauge block f_o and f_u results

NMI	f_o /nm	f_u /nm	u(x_i) (k=1) /nm
LATU	0	43	22
DICTUC	0	50	25
INACAL	0	0	24
INMETRO	3	3	42
CENAMEP	0	26	8
INTI	3	27	25
NIST(2)	--	--	--
TTBS	0	40	30
BSJ(2)	--	--	--
LACOMET	290	-150	41
CENAME	8	10	4
IBMETRO	3	10	30
INEN	20	20	17
INM	0	30	17
PAI	0	20	19

Table 14 – 2.5 mm gauge block f_o and f_u results

NMI	f_o /nm	f_u /nm	u(x_i) (k=1) /nm
LATU	0	62	19
DICTUC	20	30	25
INACAL	0	0	24
INMETRO	0	49	42
CENAMEP	0	81	24
INTI	2	54	25
NIST(2)	--	--	--
TTBS	0	40	30
BSJ(2)	--	--	--
LACOMET	-28	-110	50
CENAME	22	56	5
IBMETRO	2	45	30
INEN	0	100	17
INM	0	50	17
PAI	0	30	19

Table 15 – 10 mm gauge block f_o and f_u results

NMI	f_o /nm	f_u /nm	u(x_i) (k=1) /nm
LATU	0	49	19
DICTUC	20	40	25
INACAL	0	0	25
INMETRO	0	25	44
CENAMEP	0	26	8
INTI	3	29	25
NIST(2)	--	--	--
TTBS	20	30	31
BSJ(2)	--	--	--
LACOMET	120	-80	70
CENAME	20	42	4
IBMETRO	23	30	30
INEN	0	70	17
INM	0	30	17
PAI	0	50	19

Table 16 – 25 mm gauge block f_o and f_u results

NMI	f_o /nm	f_u /nm	u(x_i) (k=1) /nm
LATU	0	87	21
DICTUC	40	60	25
INACAL	0	0	31
INMETRO(1)	--	--	--
CENAMEP	0	73	21
INTI	3	74	25
NIST(2)	--	--	--
TTBS	40	50	34
BSJ(2)	--	--	--
LACOMET	100	110	115
CENAME	49	81	7
IBMETRO	0	63	30
INEN	0	110	17
INM	0	80	17
PAI	0	50	19

Table 17 – 60 mm gauge block f_o and f_u results

NMI	f_o /nm	f_u /nm	u(x$_i$) (k=1) /nm
LATU	23	46	39
DICTUC	60	20	25
INACAL	0	0	41
INMETRO	24	76	67
CENAMEP	5	99	30
INTI	12	86	25
NIST(2)	--	--	--
TTBS	20	110	41
BSJ(2)	--	--	--
LACOMET	360	-280	167
CENAME	53	41	15
IBMETRO	68	35	30
INEN	0	100	17
INM	30	120	17
PAI	10	30	19

Table 18 – 100 mm gauge block f_o and f_u results

(1) INMETRO do not have a 60 mm reference gauge block
(2) These NMI´s did not informed f_o and f_u

10. Analysis of results

The supplementary comparison reference value for the deviation of the central length is calculated for each GB as the weighted mean of the interferometric measurements performed by INTI and NIST (INTI reference value is calculated as the average value of the three measurements performed by INTI). The degree of equivalence for each laboratory and each artifact with respect to the reference values are evaluated using E_N values. For the interferometric submitted results, the weighted mean X_W of the n submitted values X_i is:

$$X_w = \sum_{i=1}^{n=2} W_i X_i \qquad (4)$$

where the weight W_i of each value is given by:

$$W_i = C \frac{1}{[u(X_i)]^2} \;, i = 1,2 \qquad (5)$$

with the normalizing factor C:

$$C = \frac{1}{\sum_{i=1}^{n=2} \left[\frac{1}{u(X_i)}\right]^2} \qquad (6)$$

The uncertainty of the weighted mean X_W is given by the internal (submitted uncertainties) and external (spread of results) standard uncertainty:

$$u_{int}(X_w) = \sqrt{\frac{1}{\sum_{i=1}^{n}\left[\frac{1}{u(X_i)^2}\right]}} \quad (7)$$

$$u_{ext}(X_w) = \sqrt{\frac{1}{(n-1)}\frac{\sum_{i=1}^{n} W_i (X_i - X_w)^2}{\sum_{i=1}^{n} W_i}} \quad (8)$$

The consistency of each result with the weighted mean X_W and their corresponding uncertainties is calculated by E_n:

$$E_n = \frac{X_i - X_w}{\sqrt{u(X_i)^2 + u_{int}(X_w)^2}} \quad (9)$$

E_n values less than 2.0 (superior $E_{n\ limit\ (k=1)}$) and higher than -2.0 (inferior $E_{n\ limit\ (k=1)}$) are expected with a coverage factor *k*=1.

The supplementary comparison reference value for f_o and f_u is calculated on a gauge-per-gauge basis as the mean measurements results performed by CENAM (opening, intermediate and closing measurements).

10.1 Deviation of the central length results

Table 19 shows the weighted mean X_W, the internal and external standard deviation.

The Table 20 shows the differences of the submitted results from the calculated CRV (the weighted mean X_W) and the E_n values for *k* = 1.

The interferometric values of INTI contribute only once to the calculation of the reference values, with the mean of the interferometric measurements.

Figures 24 to 29 show the submitted results with the standard uncertainties and the weighted mean X_W ± the internal uncertainty u_{int} (X_W)

REFERENCE VALUE			
Nominal length /mm	**X_w /nm**	**u_{int} (X_w) /nm**	**u_{ext} (X_w) /nm**
0.5	37.9	7.5	5.5
2.5	26.8	7.5	2.7
10	-24.5	7.9	0.5
25	23.2	8.9	3.7
60	-159.6	11.8	10.7
100	-40.0	15.3	3.7

Table 19 – Deviation from central length reference value

DEGREE OF EQUIVALENCE FOR EACH LABORATORY								
Nominal length /mm	**CENAM**		**LATU**		**DICTUC**		**INACAL**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	6.1	0.5	-2.9	-0.1	-7.9	-0.2	-37.9	-0.8
2.5	6.2	0.5	12.2	0.5	-6.8	-0.2	-26.7	-0.6
10	17.5	1.3	2.5	0.1	-15.5	-0.5	24.5	0.5
25	5.8	0.4	20.8	0.8	-3.2	-0.1	-23.2	-0.5
60	6.6	0.3	40.6	1.1	-0.4	0.0	159.5	2.7
100	7.0	0.2	-31.0	-0.5	-10.0	-0.3	40.0	0.5
Nominal length /mm	**INMETRO**		**CENAMEP**		**INTI**		**NIST**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	-6.9	-0.2	7.8	0.5	8.1	0.4	6.1	0.4
2.5	42.2	1.4	10.4	0.6	22.2	1.0	12.2	0.8
10	36.5	1.2	26.1	1.2	71.5	3.2	4.5	0.3
25	56.8	1.8	-11.6	-0.3	25.8	1.0	1.8	0.1
60	--	--	-80.9	-1.0	49.6	1.4	0.6	0.0
100	10.0	0.2	-158.0	-1.2	16.0	0.3	5.0	0.2
Nominal length /mm	**TTBS**		**BSJ**		**LACOMET**		**CENAME**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	-27.9	-1.2	5.1	0.2	41.1	1.1	-37.9	-0.9
2.5	-6.8	-0.3	1.2	0.1	19.2	0.5	-26.8	-0.6
10	24.5	1.1	11.5	0.5	55.5	1.1	24.5	0.6
25	6.8	0.3	-21.2	-0.5	90.8	1.3	-23.2	-0.4
60	29.6	1.1	20.6	0.3	109.6	0.9	159.6	3.5
100	-70.0	-2.1	-2.0	0.0	197.0	1.2	40.0	0.4
Nominal length /mm	**IBMETRO**		**INEN**		**INM**		**PAI**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	9.1	0.3	32.1	1.4	-15.9	-0.7	142.1	4.6
2.5	7.2	0.2	23.2	1.0	-24.8	-1.2	33.2	1.1
10	14.5	0.4	34.5	1.5	-31.5	-1.5	44.5	1.5
25	10.8	0.3	-23.2	-0.8	-25.2	-1.0	56.8	1.9
60	12.6	0.3	19.6	0.5	-15.4	-0.5	759.6	18.1
100	-21.0	-0.5	20.0	0.3	-6.0	-0.1	260.0	5.5

Table 20 – Deviation from central length degree of equivalence

E_n values that are higher than 2.0 (superior $E_{n\ limit\ (k=1)}$) and less than -2.0 (inferior $E_{n\ limit\ (k=1)}$) are colored in red

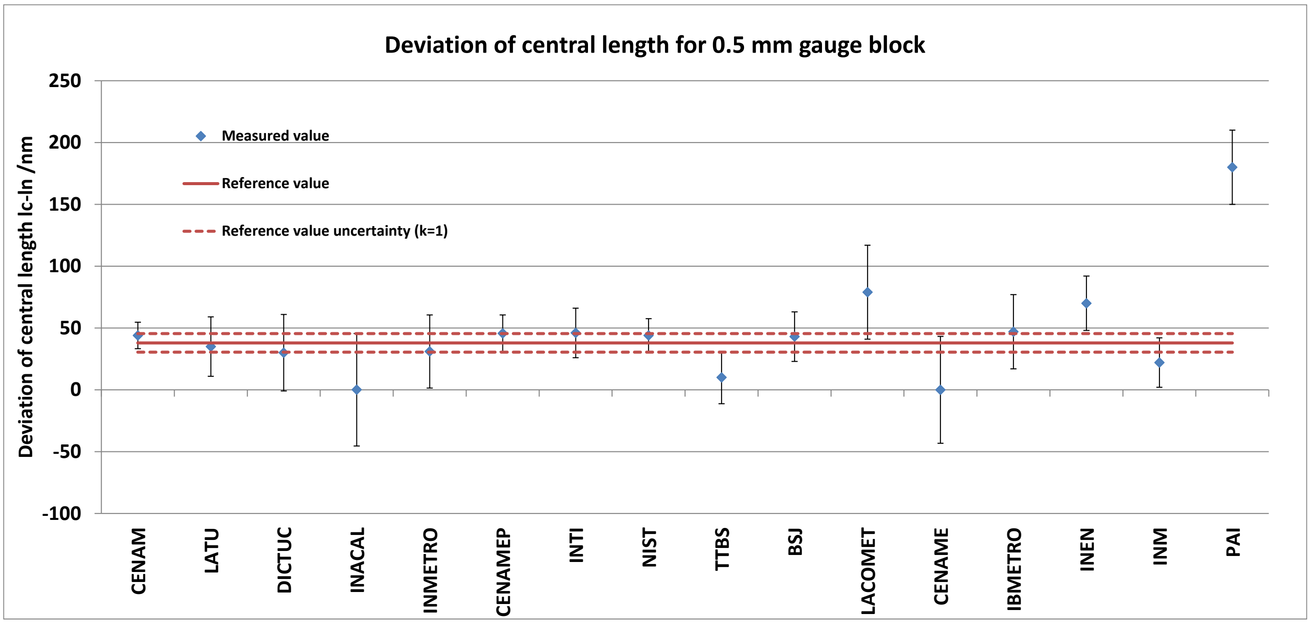

Figure 24 – Deviation from central length submitted results and ($X_W \pm u_{int}$), 0.5 mm gauge block

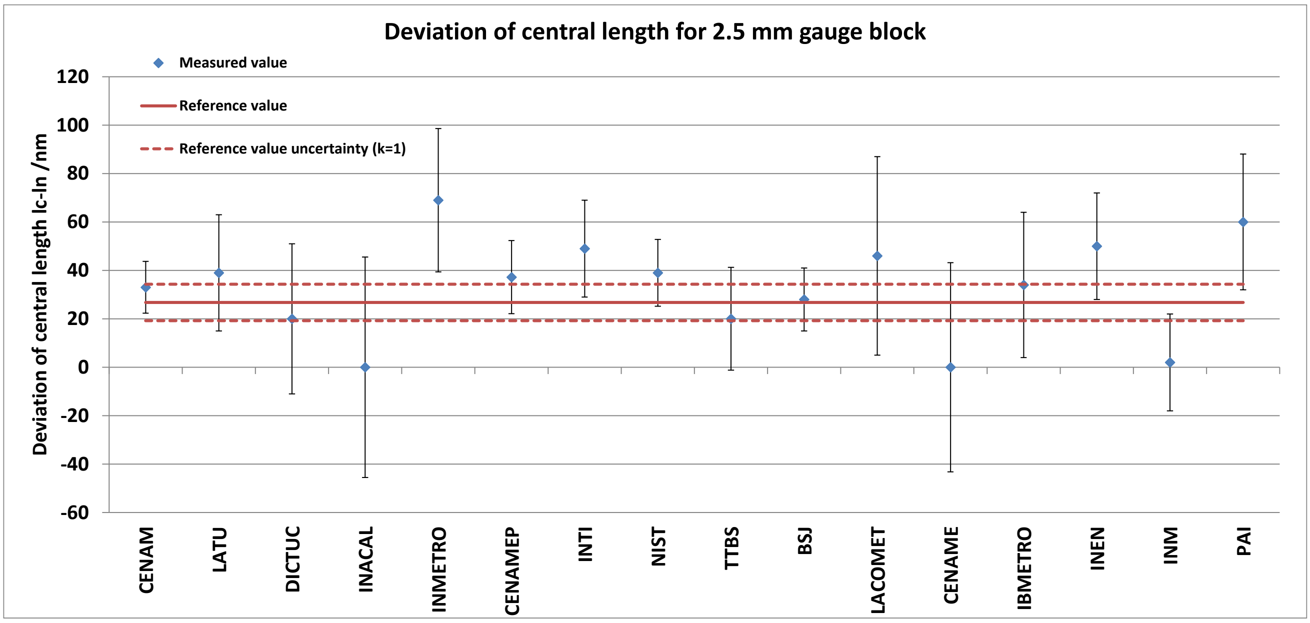

Figure 25 – Deviation from central length submitted results and ($X_W \pm u_{int}$), 2.5 mm gauge block

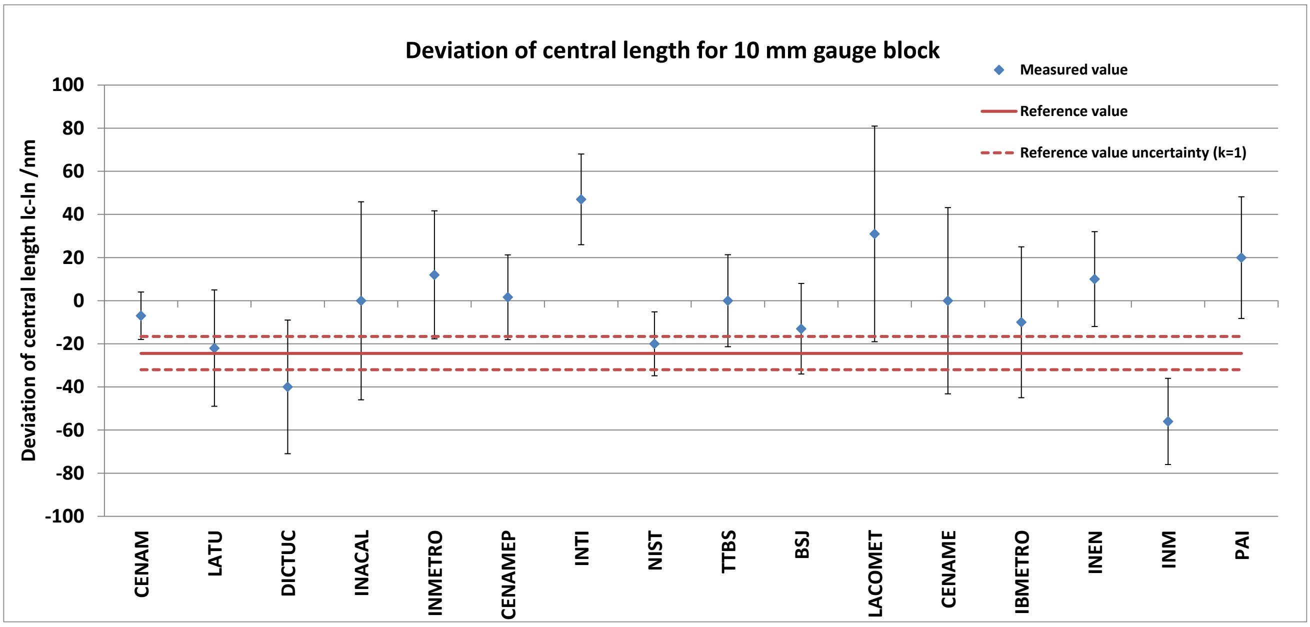

Figure 26 – Deviation from central length submitted results and ($X_W \pm u_{int}$), 10 mm gauge block

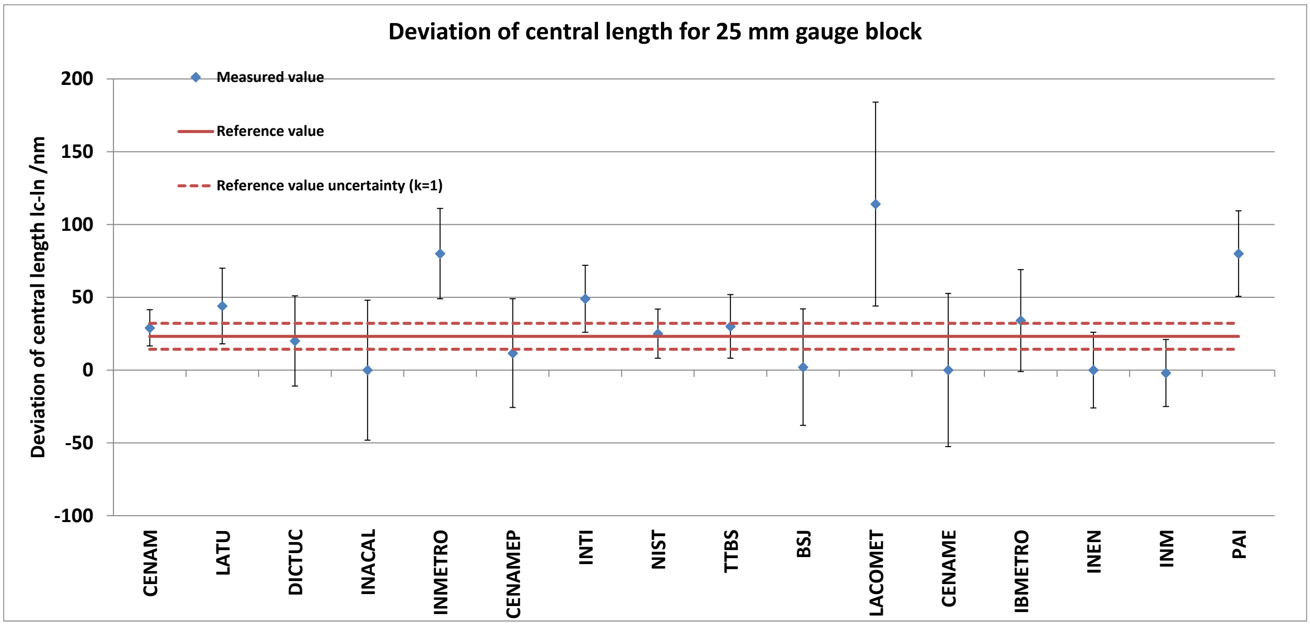

Figure 27 – Deviation from central length submitted results and ($X_W \pm u_{int}$), 25 mm gauge block

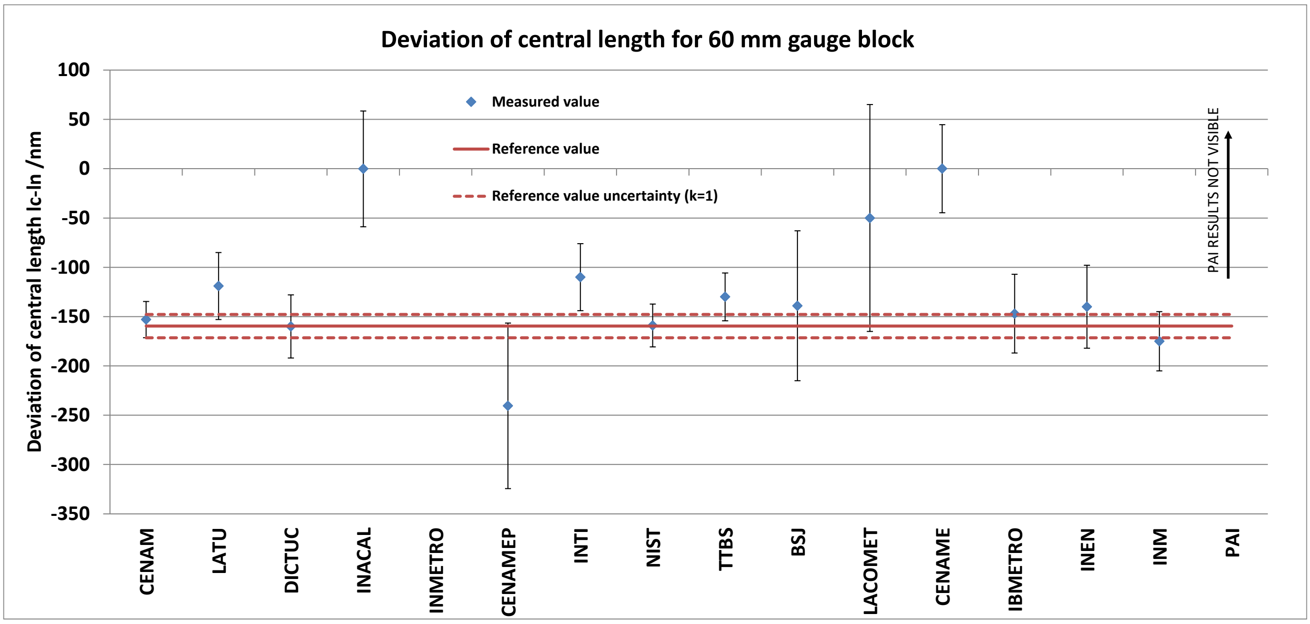

Figure 28 – Deviation from central length submitted results and ($X_W \pm u_{int}$), 60 mm gauge block

To improve visualization, PAI results are not visible.

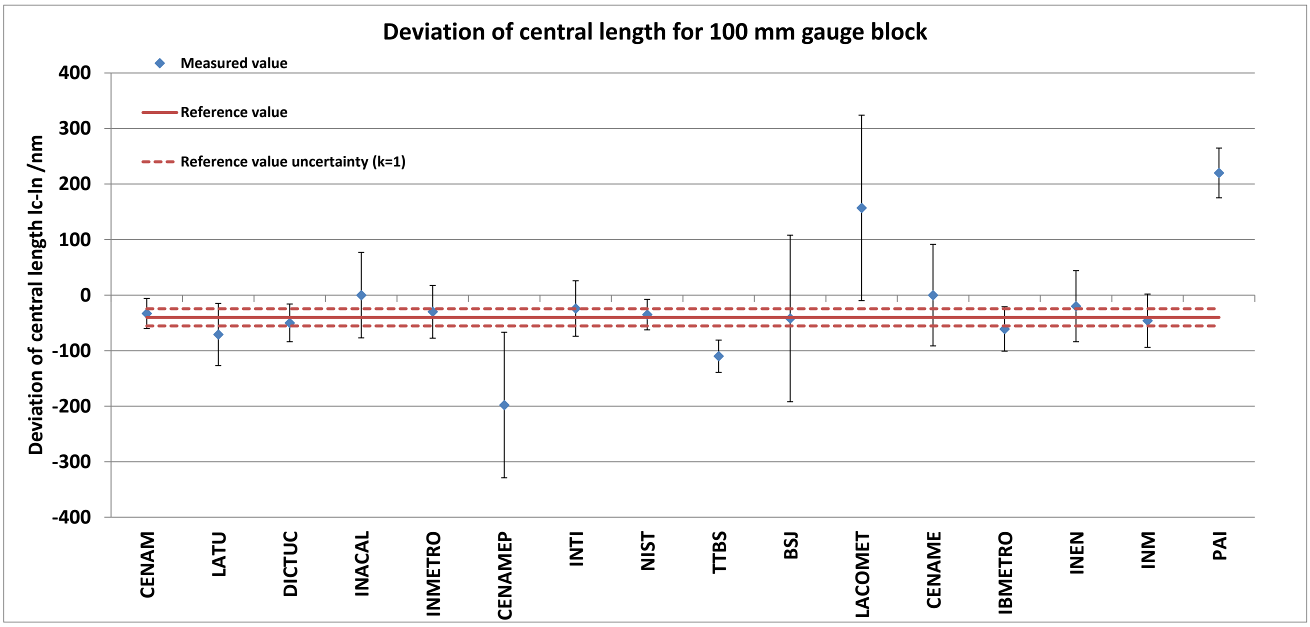

Figure 29 – Deviation from central length submitted results and ($X_W \pm u_{int}$), 100 mm gauge block

10.2 f_o results

Table 21 shows the weighted mean X_W, and the standard uncertainty (k=1) for the reference values of f_o.

Table 22 shows the differences of the submitted results from the calculated CRV (the weighted mean X_W) and the E_n values for k = 1.

The arithmetic mean of three mechanical measurements of CENAM were used as reference values for f_o.

Figures 30 to 35 show the submitted results with the standard uncertainties and the X_W ± uncertainty $u(X_W)$.

REFERENCE VALUE		
Nominal length /mm	X_w /nm	$u(X_w)$ (k=1) /nm
0.5	9.3	8.4
2.5	2.3	8.4
10	0.0	8.4
25	0.3	8.4
60	0.0	8.4
100	10.0	8.4

Table 21 – f_o reference value

DEGREE OF EQUIVALENCE FOR EACH LABORATORY								
Nominal length /mm	**LATU**		**DICTUC**		**INACAL**		**INMETRO**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	21.7	0.7	0.7	0.0	-9.6	-0.4	0.7	0.0
2.5	-2.3	-0.1	-2.3	-0.1	-2.4	-0.1	0.7	0.0
10	0.0	0.0	20.0	0.8	0.1	0.0	0.0	0.0
25	-0.3	0.0	19.7	0.7	-0.3	0.0	-0.3	0.0
60	0.0	0.0	40.0	1.5	-0.1	0.0	--	--
100	13.0	0.3	50.0	1.9	-10.3	-0.2	14.0	0.2
Nominal length /mm	**CENAMEP**		**INTI**		**NIST**		**TTBS**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	35.7	1.5	0.7	0.0	--	--	10.7	0.3
2.5	-2.3	-0.2	0.7	0.0	--	--	-2.3	-0.1
10	0.0	0.0	2.0	0.1	--	--	0.0	0.0
25	-0.3	0.0	2.7	0.1	--	--	19.7	0.6
60	0.0	0.0	3.0	0.1	--	--	40.0	1.1
100	-5.0	-0.2	2.0	0.1	--	--	10.0	0.2
Nominal length /mm	**BSJ**		**LACOMET**		**CENAME**		**IBMETRO**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	--	--	390.7	10.0	6.7	0.7	13.7	0.4
2.5	--	--	287.7	6.9	6.1	0.7	0.7	0.0
10	--	--	-28.0	-0.5	22.0	2.2	2.0	0.1
25	--	--	119.7	1.7	19.3	2.1	22.7	0.7
60	--	--	100.0	0.9	49.2	4.4	0.0	0.0
100	--	--	350.0	2.1	42.8	2.5	58.0	1.9
Nominal length /mm	**INEN**		**INM**		**PAI**			
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n		
0.5	0.7	0.0	0.7	0.0	0.7	0.0		
2.5	17.7	0.9	-2.3	-0.1	-2.3	-0.1		
10	0.0	0.0	0.0	0.0	0.0	0.0		
25	-0.3	0.0	-0.3	0.0	-0.3	0.0		
60	0.0	0.0	0.0	0.0	0.0	0.0		
100	-10.0	-0.5	20.0	1.1	0.0	0.0		

Table 22 – f_o degree of equivalence

E_n values that are higher than 2.0 (superior $E_{n\ limit\ (k=1)}$) and less than -2.0 (inferior $E_{n\ limit\ (k=1)}$) are colored in red

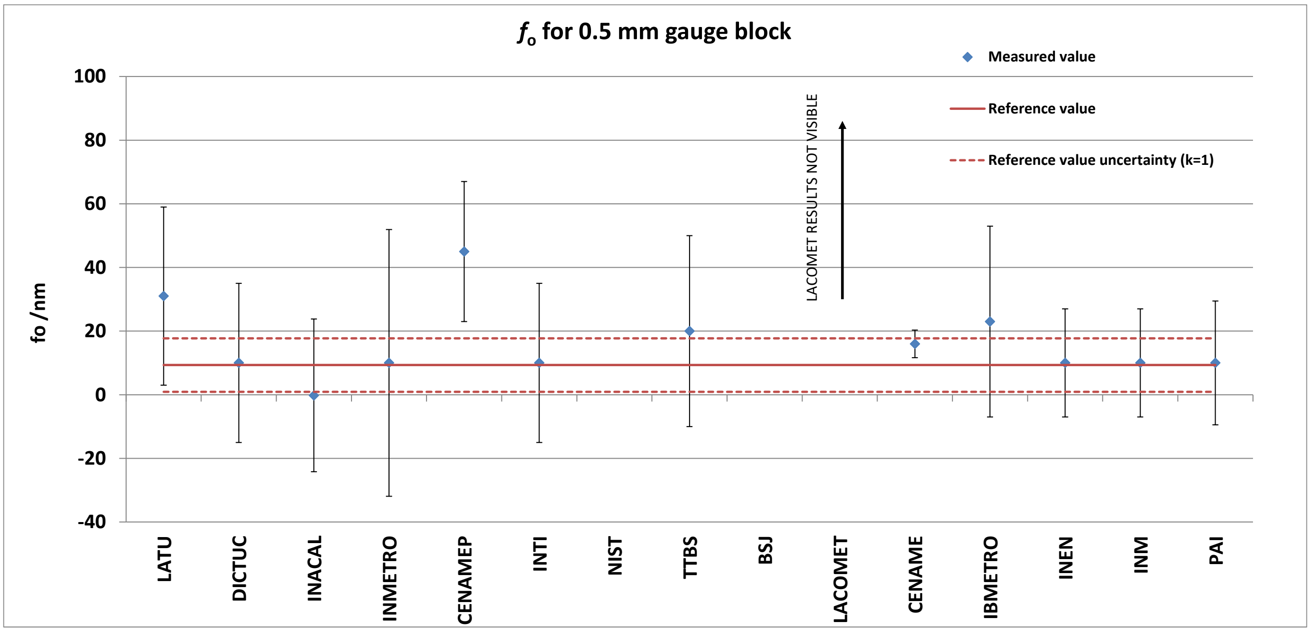

Figure 30 – Submitted results and ($X_W \pm u_{int}$), 0.5 mm gauge block

To improve visualization, LACOMET results are not visible.

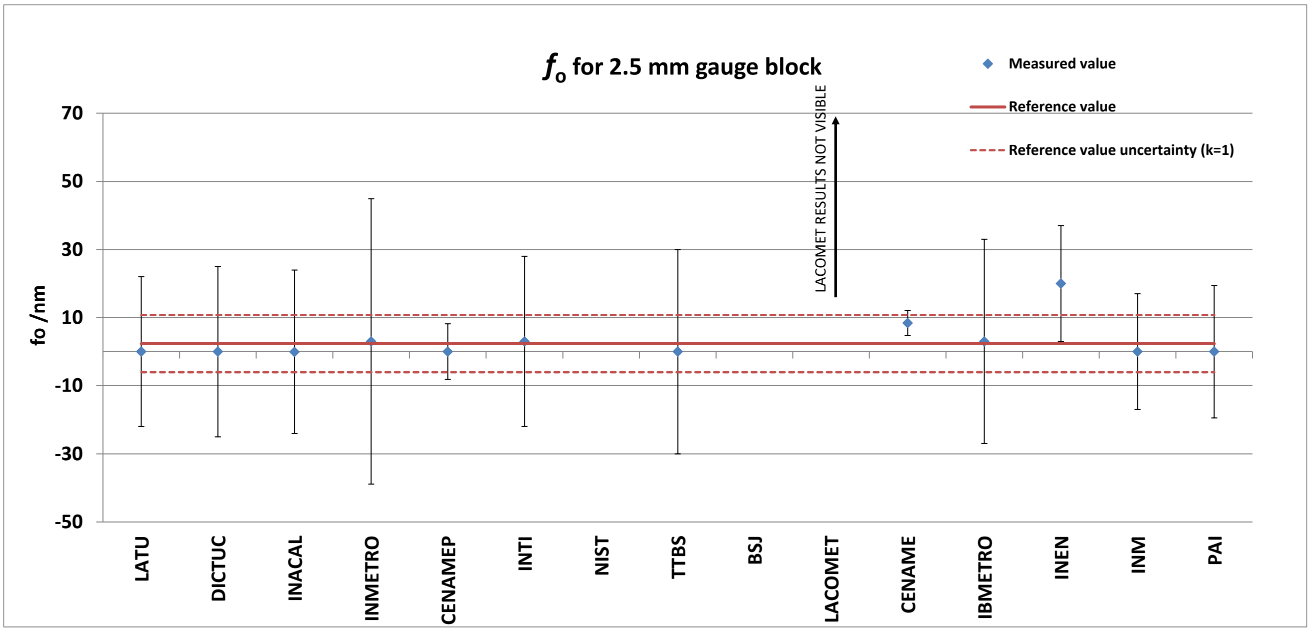

Figure 31 – Submitted results and ($X_W \pm u_{int}$), 2.5 mm gauge block

To improve visualization, LACOMET results are not visible.

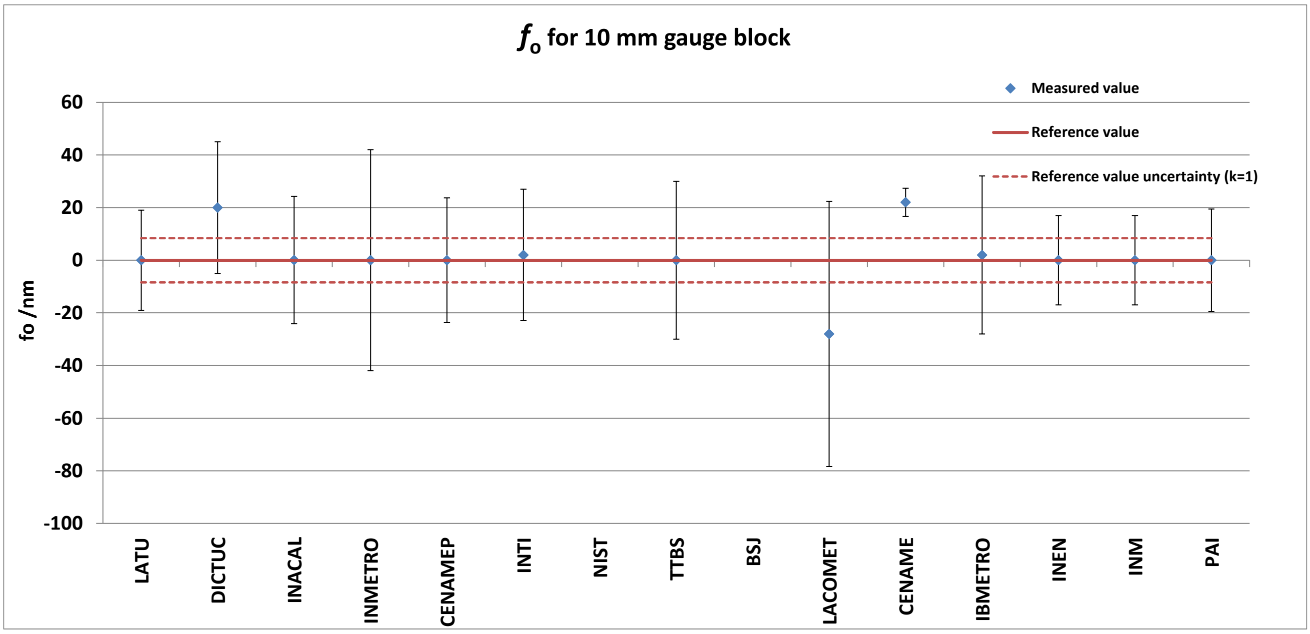

Figure 32 – Submitted results and ($X_W \pm u_{int}$), 10 mm gauge block

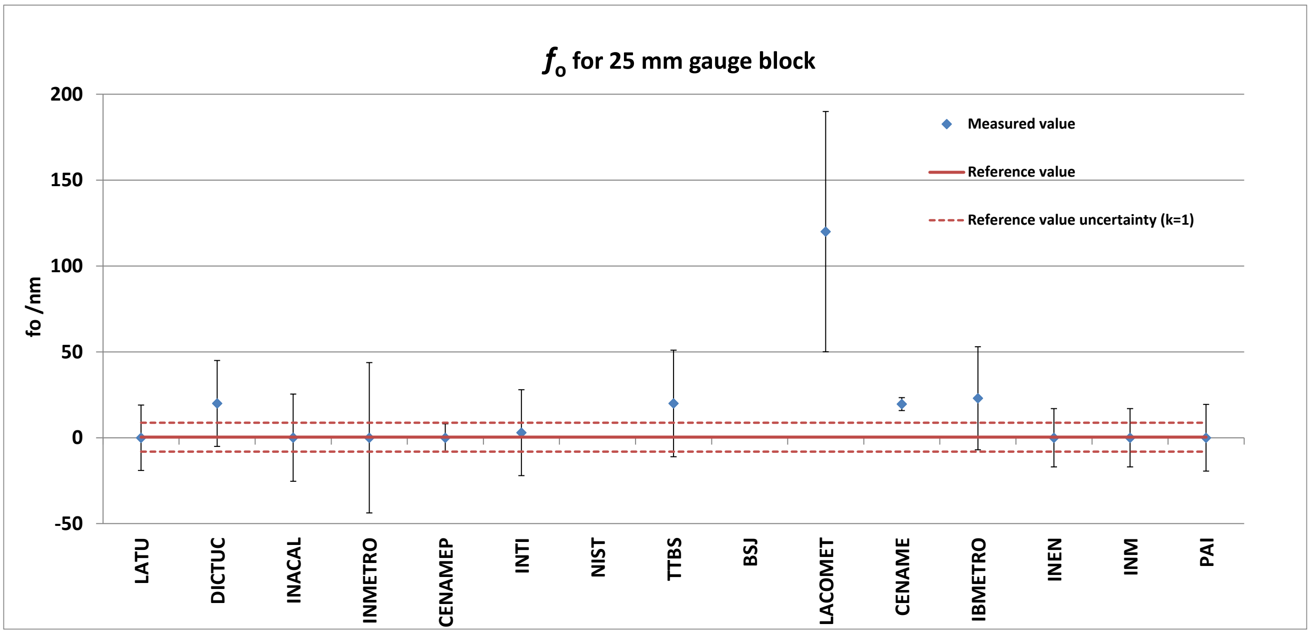

Figure 33 – Submitted results and ($X_W \pm u_{int}$), 25 mm gauge block

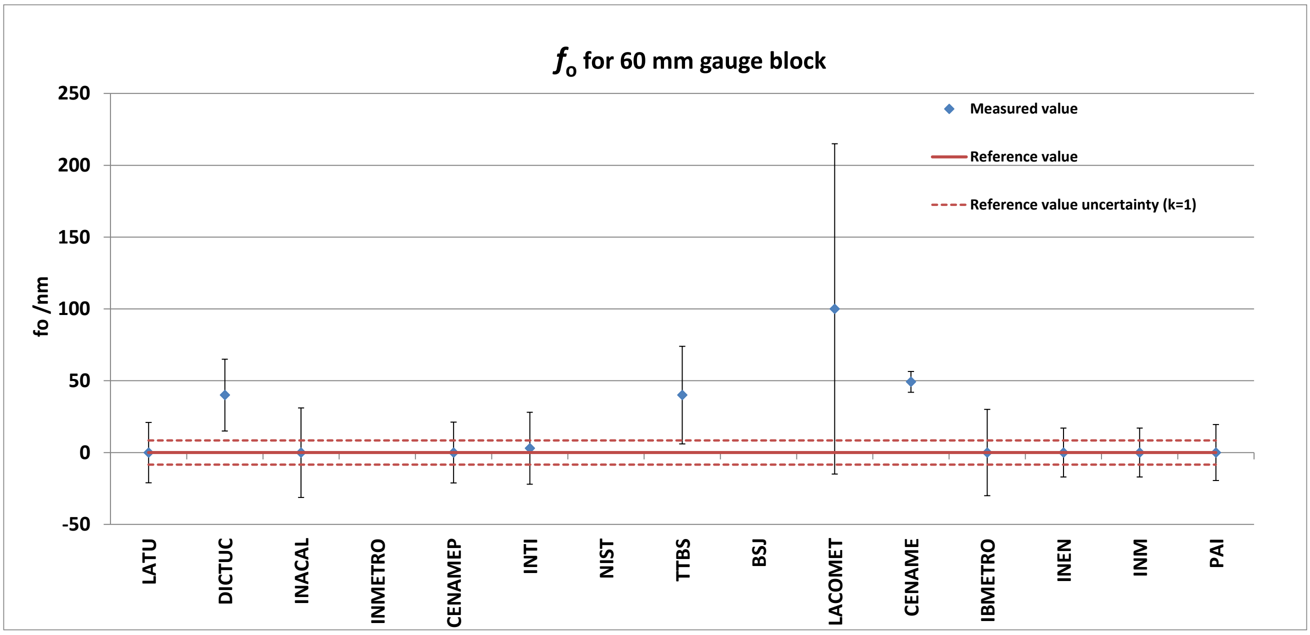

Figure 34 – Submitted results and ($X_W \pm u_{int}$), 60 mm gauge block

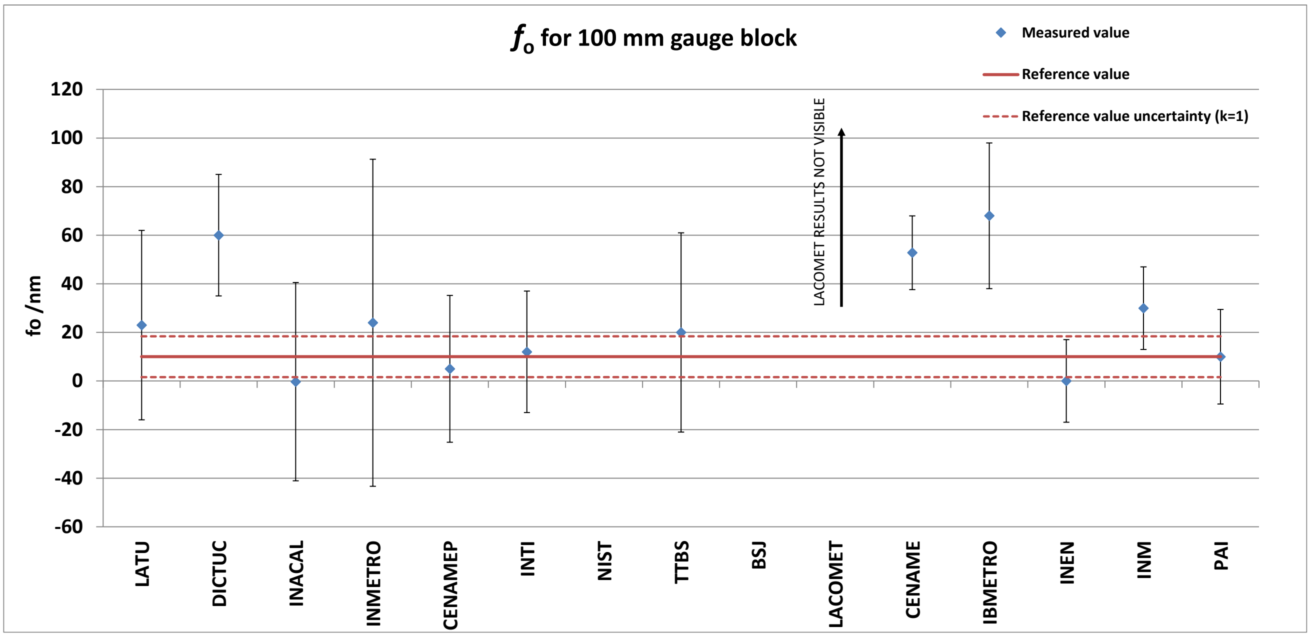

Figure 35 – Submitted results and ($X_W \pm u_{int}$), 100 mm gauge block

To improve visualization, LACOMET results are not visible.

10.3 f_u results

Table 23 shows the weighted mean X_W, and the standard uncertainty (*k*=1) for the reference values of f_u.

Table 24 shows the differences of the submitted results from the calculated CRV (the weighted mean X_W) and the E_n values for k = 1.

The mean of three mechanical measurements of CENAM were used as reference values for f_u.

Figures 36 to 41 show the submitted results with the standard uncertainties and the X_W ± uncertainty $u(X_W)$.

REFERENCE VALUE		
Nominal length /mm	**X_w /nm**	**$u(X_w)$ (k=1) /nm**
0.5	2.7	8.4
2.5	28.3	8.4
10	62.7	8.4
25	31.0	8.4
60	76.3	8.4
100	82.7	8.4

Table 23 – f_u reference value

DEGREE OF EQUIVALENCE FOR EACH LABORATORY								
Nominal length /mm	**LATU**		**DICTUC**		**INACAL**		**INMETRO**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	13.3	0.5	-2.7	-0.1	-2.4	-0.1	5.3	0.1
2.5	14.7	0.6	21.7	0.8	-28.3	-1.1	-25.3	-0.6
10	-0.7	0.0	-32.7	-1.2	-62.7	-2.4	-13.7	-0.3
25	18.0	0.9	9.0	0.3	-31.0	-1.2	-6.0	-0.1
60	10.7	0.5	-16.3	-0.6	-76.1	-2.4	--	--
100	-36.7	-0.9	-62.7	-2.4	-82.3	-2.0	-6.7	-0.1
Nominal length /mm	**CENAMEP**		**INTI**		**NIST**		**TTBS**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	28.0	1.2	1.3	0.1	--	--	-2.7	-0.1
2.5	-1.9	-0.2	-1.3	-0.1	--	--	11.7	0.4
10	18.7	0.7	-8.7	-0.3	--	--	-22.7	-0.7
25	-4.6	-0.4	-2.0	-0.1	--	--	-1.0	0.0
60	-3.4	-0.2	-2.3	-0.1	--	--	-26.3	-0.8
100	16.6	0.5	3.3	0.1	--	--	27.3	0.7
Nominal length /mm	**BSJ**		**LACOMET**		**CENAME**		**IBMETRO**	
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n
0.5	--	--	2987.3	76.6	9.3	1.0	0.3	0.0
2.5	--	--	-178.3	-4.3	-18.7	-2.0	-18.3	-0.6
10	--	--	-172.7	-3.4	-6.7	-0.7	-17.7	-0.6
25	--	--	-111.0	-1.6	11.4	1.2	-1.0	0.0
60	--	--	33.7	0.3	4.5	0.4	-13.3	-0.4
100	--	--	-362.7	-2.2	-41.5	-2.4	-47.7	-1.5
Nominal length /mm	**INEN**		**INM**		**PAI**			
	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n	X_i - X_W /nm	E_n		
0.5	77.3	4.1	17.3	0.9	7.3	0.3		
2.5	-8.3	-0.4	1.7	0.1	-8.3	-0.4		
10	37.3	2.0	-12.7	-0.7	-32.7	-1.5		
25	39.0	2.1	-1.0	-0.1	19.0	0.9		
60	33.7	1.8	3.7	0.2	-26.3	-1.2		
100	17.3	0.9	37.3	2.0	-52.7	-2.5		

Table 24 – f_u degree of equivalence

E_n values that are higher than 2.0 (superior $E_{n\ limit\ (k=1)}$) and less than -2.0 (inferior $E_{n\ limit\ (k=1)}$) are colored in red

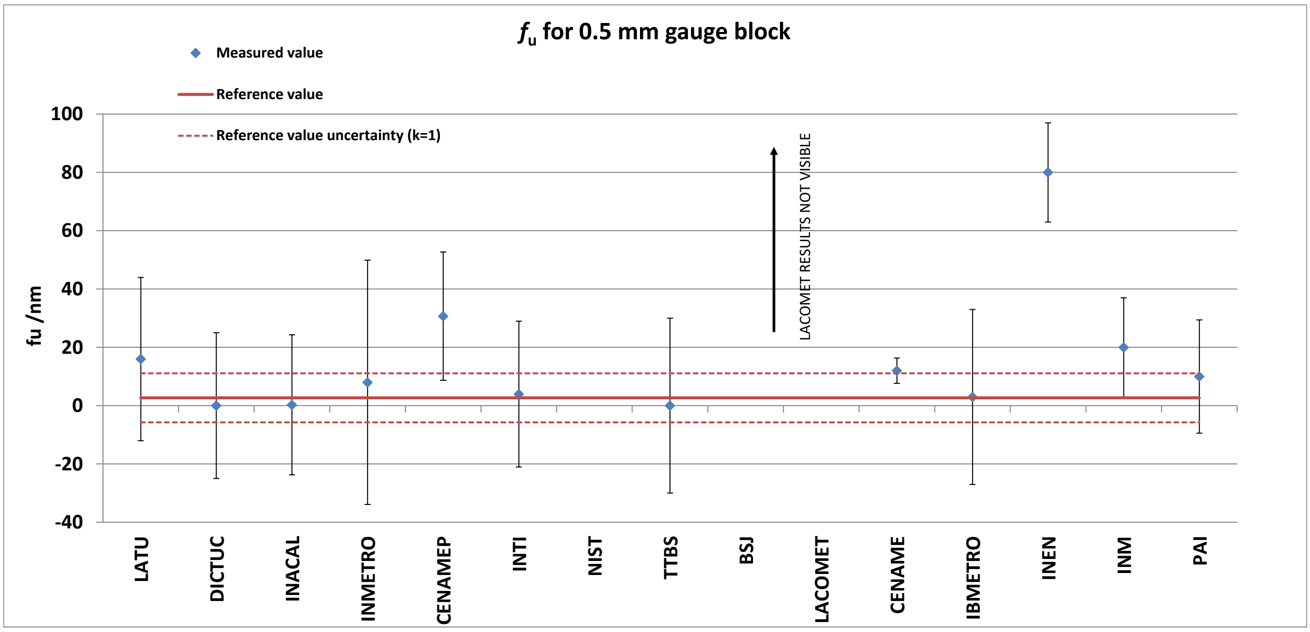

Figure 36 – Submitted results and ($X_W \pm u_{int}$), 0.5 mm gauge block

To improve visualization, LACOMET results are not visible.

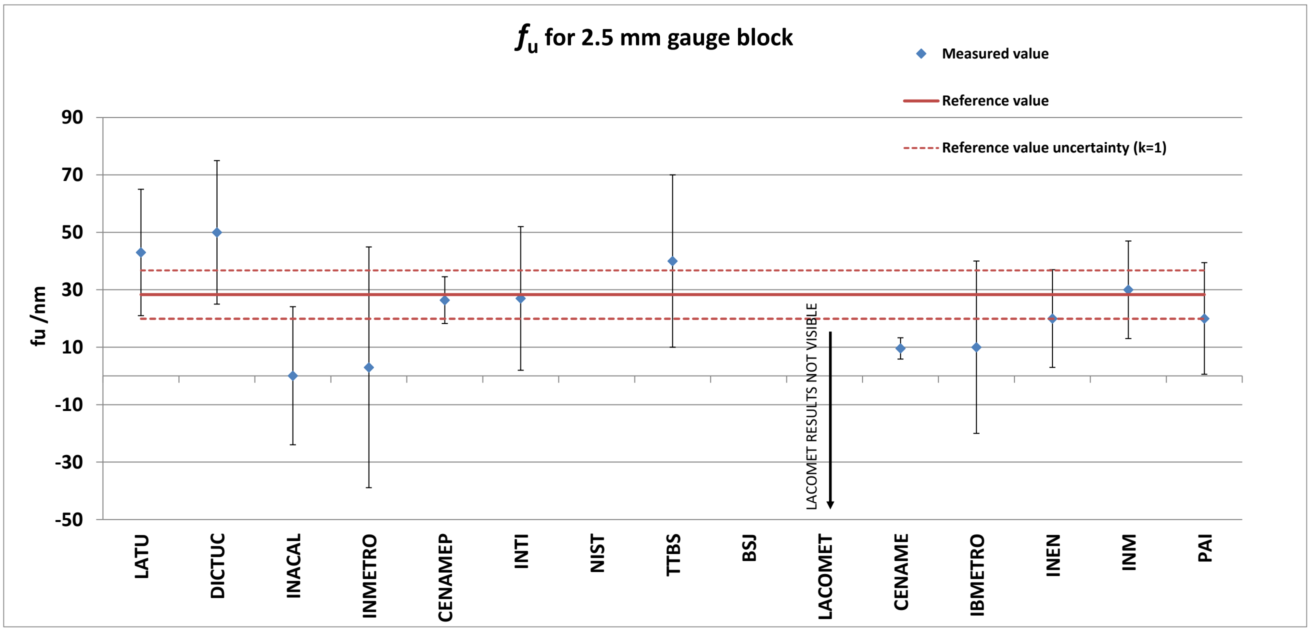

Figure 37 – Submitted results and ($X_W \pm u_{int}$), 2.5 mm gauge block

To improve visualization, LACOMET results are not visible.

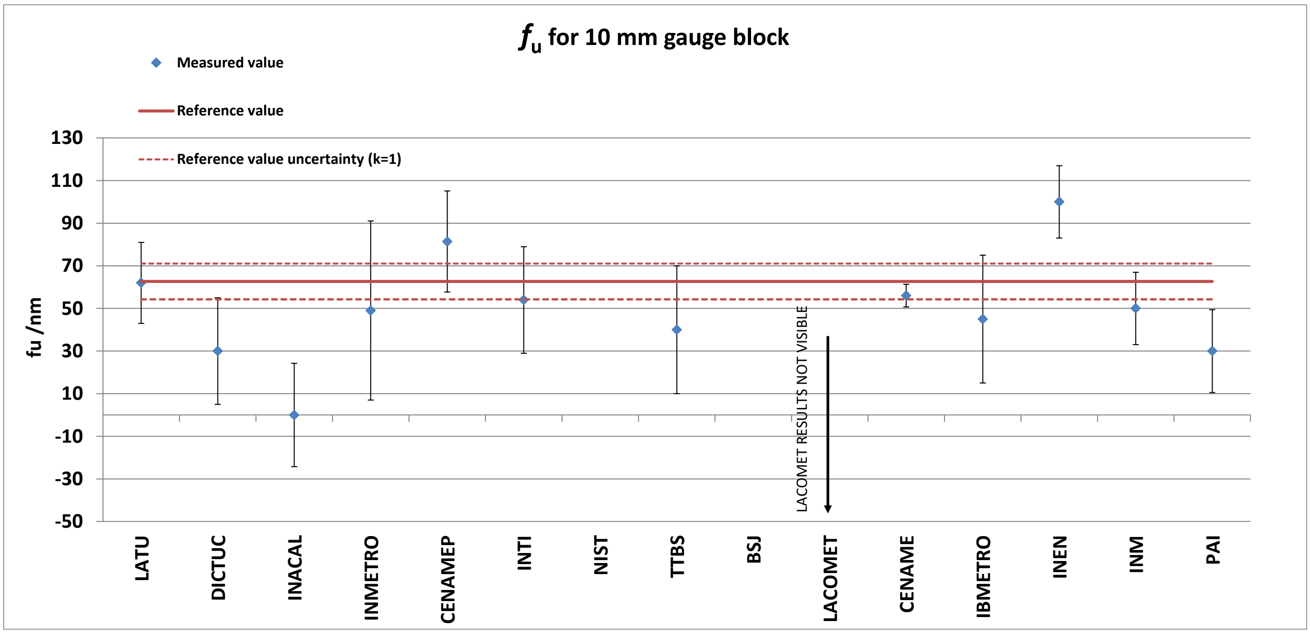

Figure 38 – Submitted results and ($X_W \pm u_{int}$), 10 mm gauge block

To improve visualization, LACOMET results are not visible.

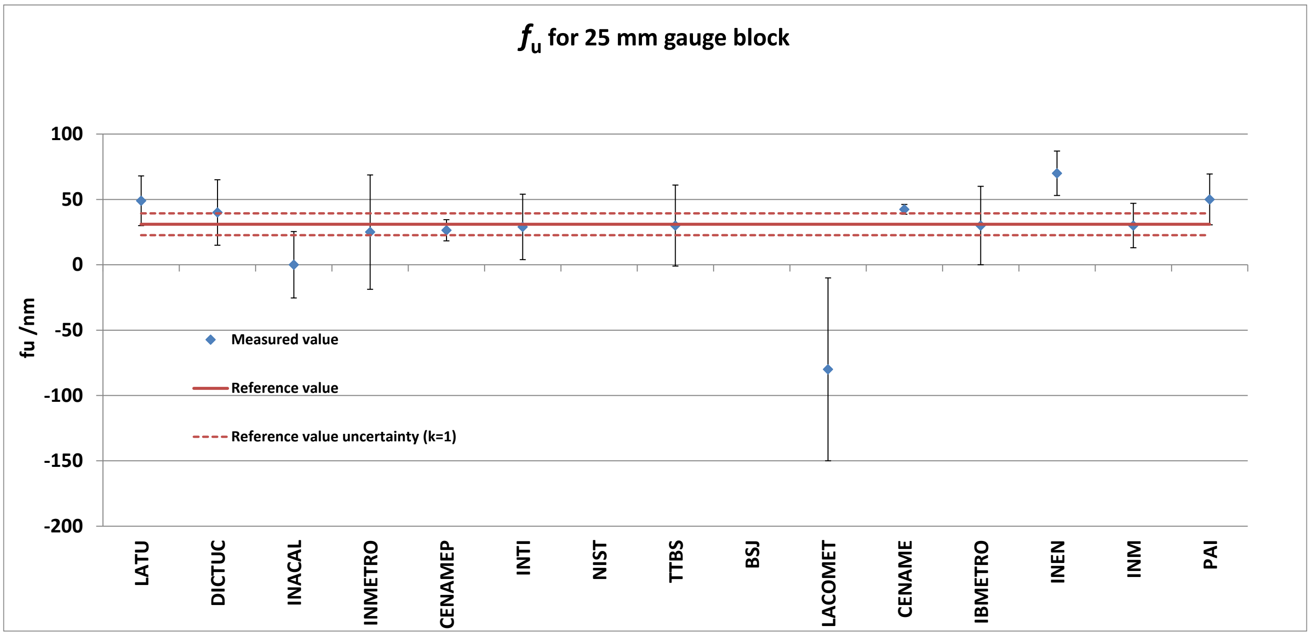

Figure 39 – Submitted results and ($X_W \pm u_{int}$), 25 mm gauge block

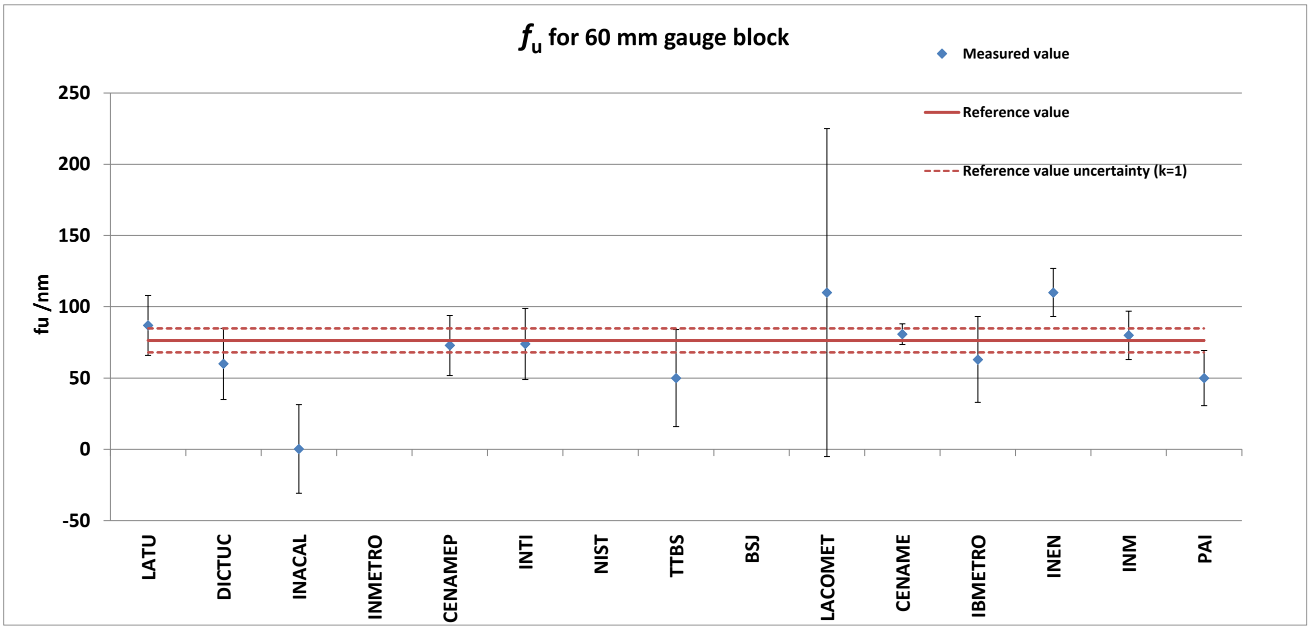

Figure 40 – Submitted results and ($X_W \pm u_{int}$), 60 mm gauge block

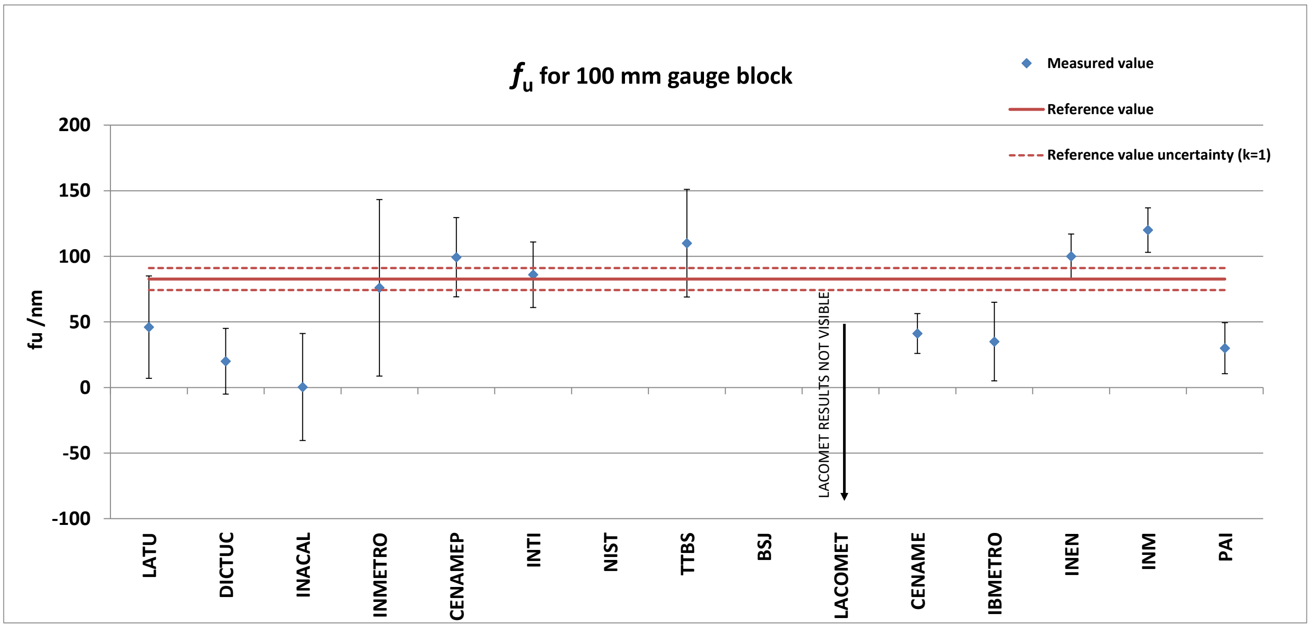

Figure 41 – Submitted results and ($X_W \pm u_{int}$), 100 mm gauge block

To improve visualization, LACOMET results are not visible.

11. Conclusions

Fifteen laboratories from SIM and one GULFMET laboratory participated in the SIM.L-S7.2019 calibration of GB comparison.

There were several important delays from the initial schedule established in the measurement protocol. The first delay occurred after the DICTUC measurements and was due to the Covid-19 Pandemic and the temporary closure some of the next participants. Schedule was changed to allow the laboratories which were not closed, to perform their measurements. The second delay occurred due to customs clearance when the GB came back to Argentina to perform intermediate interferometric measurements. More delays occurred in customs when the GB were going from INEN to INM, and another important delay occurred in Perú customs (when arriving and leaving Perú) when the GB were going from IBMETRO to INACAL and to INACAL to CENAM.

The apparent changes of the GB measured as the range of measured values of the deviation from central length, established between the opening, intermediate and closing interferometric measurements by INTI, and apparent change of f_o and f_u established as the range of measured values between the opening, intermediate and closing mechanical measurements by CENAM were not significant.

All the measurements of all the participants have been carried out with GB comparators and a set of calibrated GBs.

Some laboratories did not obtain good results of the measured parameters f_o and f_u, some laboratories do not have a good tolerance – uncertainty ratio (see Annex 1) that enables them to discriminate whether a GB is grade 0 or not, according to the Standard. Further investigation is recommended.

INACAL and LACOMET, had informed negative values for f_o and f_u which is not possible due to f_o and f_u definition (equations 2 and 3). Negative values of INCAL cannot be seen due to rounding of uncertainty decimals (tables 13 to 18). See INACAL Annex C page 85.

Two laboratories had made mistakes in the unit of informed values. Annex C asked for values in nm and INACAL gave them in µm. CENAME gave the results in mm.

After the first version of Draft A was published, INACAL sent the new values in nm and, CENAME was consulted by the pilot and copilot to check if there was a unit mistake, and CENAME changed for values in nm.

The results of these changes are informed in chapter 15 “Analysis of results after units change”

It is the opinion of this pilot laboratory that in the future, when this number of laboratories participate in a comparison, partial results (only En values) should be published. There has been four years since the first participant performed its measurement.

12. Acknowledgments

The pilot and co-pilot laboratories would like to thank all colleagues from SIM and GULFMET NMIs that participated in the comparison. Thanks for their work and support in measuring and circulating the gauges.

13. References

1. Guidelines for CIPM key comparisons, http://www.bipm.org/utils/en/pdf/guidelines.pdf
2. Bruno Remo Gastaldi, SIM.L-K3.2019, Calibration of Angle Standards. DOI 0.1088/0026-1394/60/1A/04002

14. Analysis of results after units change

In the following table it can be seen the degree of equivalence for INACAL and CENAME after the unit change for deviation from central length:

DEGREE OF EQUIVALENCE FOR DEVIATION OF CENTRAL LENGTH				
Nominal length /mm	**INACAL**		**CENAME**	
	$X_i - X_W$ /nm	E_n	$X_i - X_W$ /nm	E_n
0.5	2.1	0,0	-5,9	-0,1
2.5	-16.8	-0.4	12,8	0,3
10	4.5	0.1	-111,5	-2,5
25	-73.2	-1.5	39,2	0,7
60	-10.4	-0.2	477,6	10,3
100	30.0	0.4	320,0	3,4

Table 27 – Degree of equivalence after units change

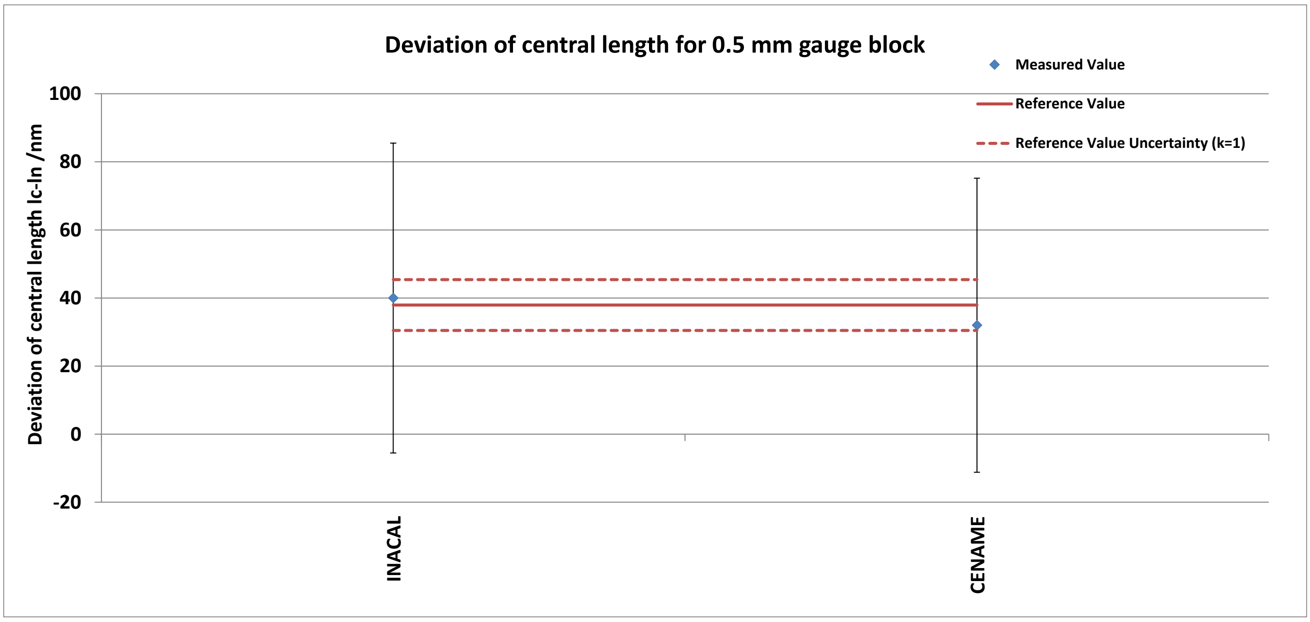

Figure 42 – Results after units change and ($X_W \pm u_{int}$), 0.5 mm gauge block

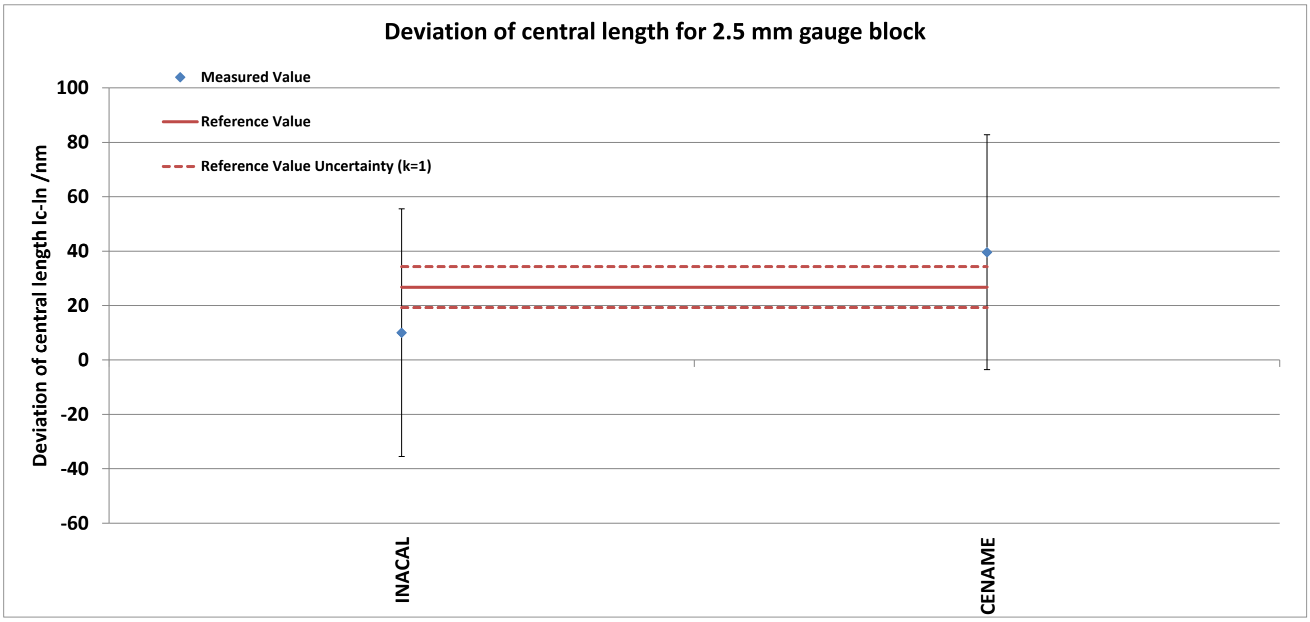

Figure 43 – Results after units change and ($X_W \pm u_{int}$), 2.5 mm gauge block

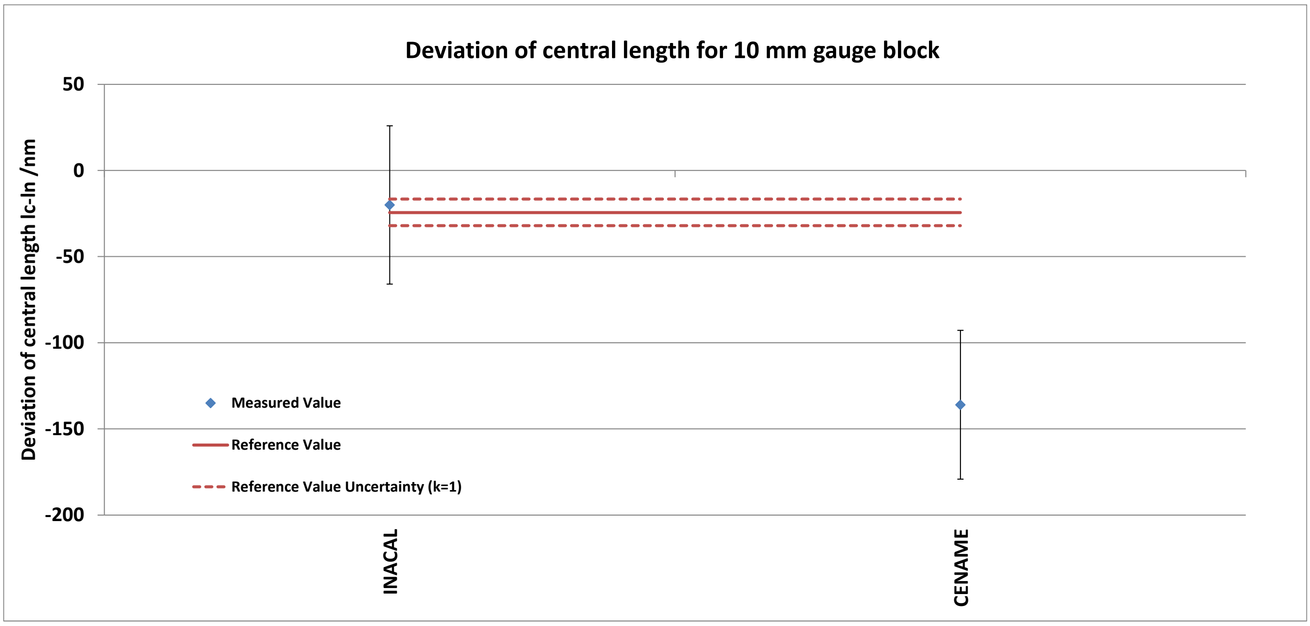

Figure 44 – Results after units change and ($X_W \pm u_{int}$), 10 mm gauge block

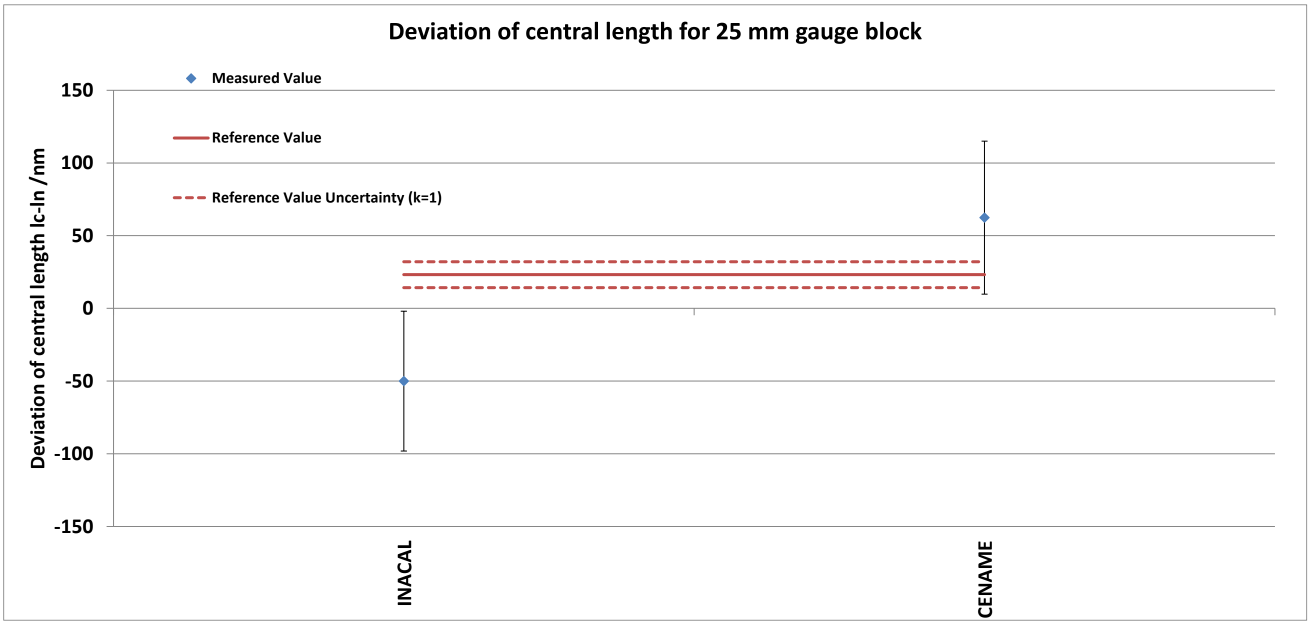

Figure 45 – Results after units change and ($X_W \pm u_{int}$), 25 mm gauge block

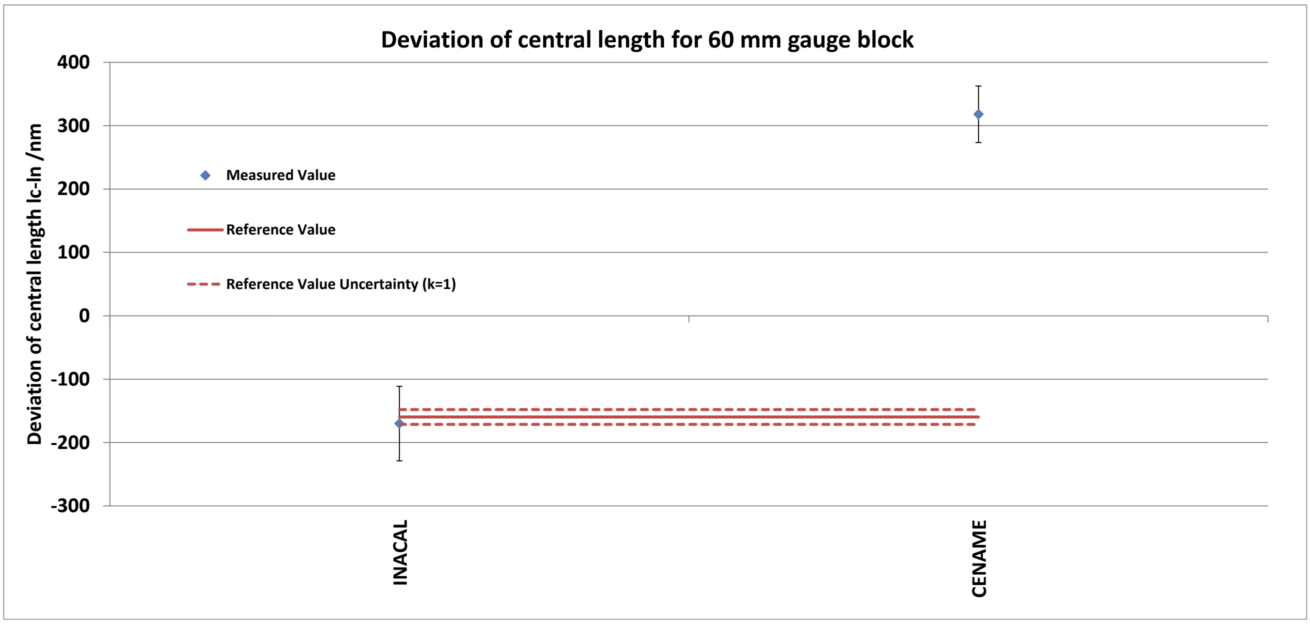

Figure 46 – Results after units change and ($X_W \pm u_{int}$), 60 mm gauge block

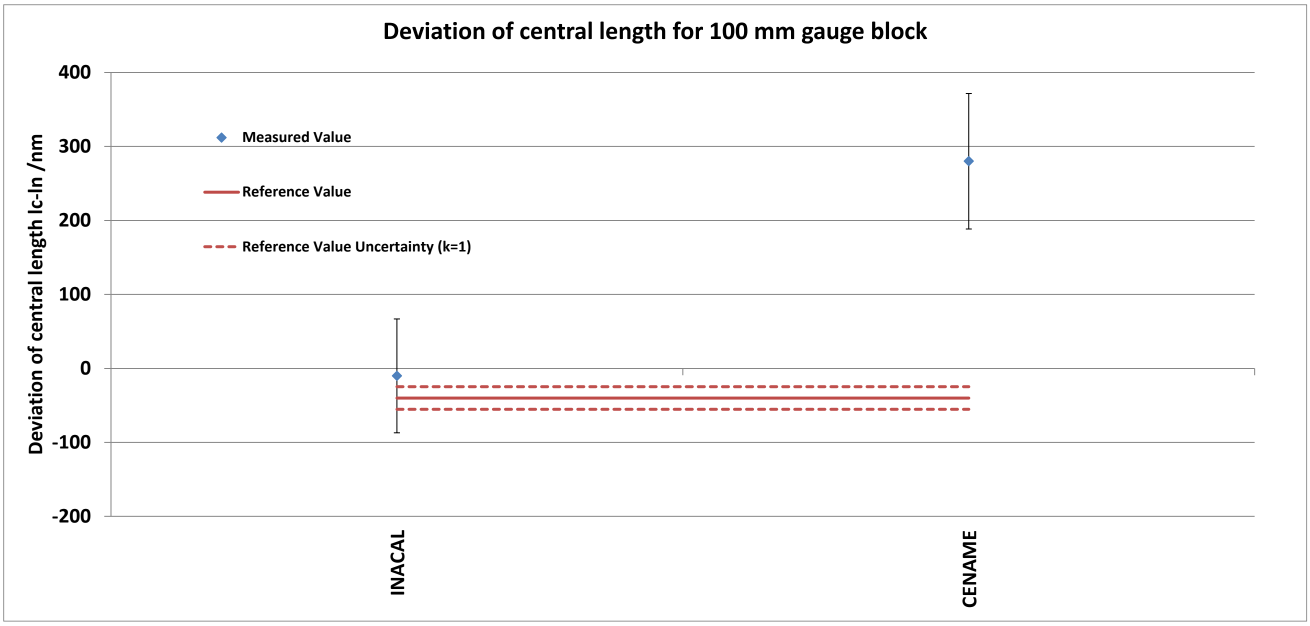

Figure 47 – Results after units change and ($X_W \pm u_{int}$), 100 mm gauge block

15. Annex C / Annex D / Annex E forms

Measurements results, uncertainty of measurement informed by the participants and description of the measuring system/set-up

INTI

Annex C

Por favor llenar las celdas azules / Please fill in the blue cells						
Laboratory:	INTI - Mechanical comparison					
Nominal length	Deviation of the central length from the nominal length (*lc*-*ln*)	Uncertainty of central length (*k*=1)	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	46	20	10	4	25	725292
2.5	49	20	3	27	25	525083
10	47	21	2	54	25	180342
25	49	23	3	29	25	3225200
50	-110	34	3	74	25	1425127
100	-24	50	12	86	25	1425351
Date:	12/8/2021		Name:	Diego Bellelli		

Annex D

	Reference gauge block nominal length	l_s	100 mm				
GAUGE BLOCKS UNCERTAINTY - CENTRAL LENGTH DEVIATION							
SYMBOL	NAME	VALUE	SENSITIVITY COEFFICIENT	u_i (nm)	u_i independant (nm)	u_i length dependant (nm)	υeff
First order							
$u_{cal}(l_s)$	Reference gauge block uncertainty (nm)		1		10.49	0.2540	100
$u(l_s)$	Drift (nm)		1		2.52	0.0776	100
$u_c(d)$	Comparator uncertainty (nm)	32	1		16.00		100
$u(\theta_r)$	Thermometer resolution (ºC)	0.005	1	0.003			
$u(\theta)$	Cyclic variation (ºC)	0.300	1	0.173			
$u(\theta_{cal})$	Thermometer calibration uncertainty (ºC)	0.040	1	0.020			
$u_c(\theta_s)$	Temperature measurement uncertainty (ºC)	0.174	-0.7			-0.1221	50
$u(\delta\theta)$	Temperature difference between gauge blocks (ºC)	0.0300	-11.5			-0.1992	25
$u(\alpha_s)$	α (CTE) uncertainty of reference gauge block (10%α)	0.0000011	250000			0.1559	25
$u(\alpha)$	α (CTE) uncertainty of gauge block under measurement (10%α)	0.0000012	280000.00			0.1859	25
u_{cero}	Back to zero uncertainty (nm)	8	1		4.33		2
Second order							
$u(\theta s)u(\alpha s)$	Temperature effects on the reference gauge block	1.09E-07	1000000			0.1087	25
$u(\alpha)u(\theta s)$	Temperatur effects on the gauge block under measurement	1.16E-07	1000000			0.1158	25
$u(\delta\theta)u(\alpha)$	Temparature difference between gauge blocks	1.15E-08	1000000			0.0115	25
u_c	Combined uncertainty				**19.77694**	**0.4575**	207
	Expanded uncertainty				**40**	**0.92**	
$U_{95\%}$						**100**	

Caculation based on "Uncertainty of gauge block calibration by mechanical comparison: A worked example. Case 1: Gauges of like materials" de Jennifer Decker y James Pekelsky - 16 de mayo de 1996. NRC Document Nº 39998

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Double probing system	UPC	16.10401041.901 906K	0,01	03/10/2020

Instrument description.

Type of instrument:
Double inductive TESA probing system, with vacuum pump for probe lifting, mounted in a anti vibrating table. Al the measuring system is inside a plastic thermal box.
1 thermistor temperature sensor for GB under 20 mm (measures the table temperature) and 2 thermistor temperature sensor for GB from 20 mm up to 100 mm

Traceability:
Argentinian realization of the metre.

Calibration method of your reference:

Reference GB calibrated by interferometry

Interval of temperature during measurements:
20 ºC ± 0,25 ºC

Laboratory: INTI
Date: 17/08/2021 Name and Signature: Diego Bellelli

TTBS

Annex C form

SIM.L-S7.2019 Supplementary Comparison
Calibration of Gauge Blocks by Mechanical Comparison Technical protocol

Annex C: Result Report Forms.
Laboratory: Trinidad and Tobago Bureau of Standards

Nominal length	Deviation of the central length from the nominal length (*lc-ln*)	Uncertainty of central length	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	10	21	20	0	30	725292
2.5	20	21	0	40	30	525083
10	0	21	0	40	30	180342
25	30	22	20	30	31	3225200
~~50~~ 60	-130	24	40	50	34	1425127
100	-110	29	20	110	41	1425351

Date: 2022-09-16 **Name:** Kevin Lemessy **Signature:**

Activ

Annex D form

Annex D. Form of uncertainty estimation

Source of Uncertainty x_i	Standard Uncertainty $u(x_i)$	Sensitivity Coefficient $\lvert c_i\rvert = \delta\lvert/\delta x_i$	Combined Standard Uncertainty $u_i = \lvert c_i\rvert u(x_i)$
Gauge Block Uncertainty (nm)	$\sqrt{[(15)^2 + 0.2^2L^2]}$	1	$\sqrt{[225 + 0.04000L^2]}$
Gauge Block Comparator Uncertainty (nm)	$1000(0.03 + 0.002D) \div 2$	1	$15 + D$
Temperature measurement uncertainty (°C)	$\sqrt{[(0.1 \div \sqrt{12})^2 + (0.5 \div \sqrt{3})^2 + (0.37 \div 2)^2]}$	$L(\alpha_s - \alpha)$	$(-2.40857 \times 10^{-7})L$
Temperature difference between standard and measurand (°C)	$(11.5L \times 10^{-6}) \times (0.0001 \div \sqrt{3})$	1	$(6.64010 \times 10^{-10})L$
Thermal Expansion for test blocks uncertainty (nm)	$L(0.6 + 0.0001)(6.6395281 \times 10^{-7})$	1	$(3.98438 \times 10^{-7})L$
Thermal Expansion for reference blocks uncertainty (nm)	$L(0.6)(6.2353829 \times 10^{-7})$	1	$(3.74123 \times 10^{-7})L$
Temperature effects on reference standard blocks	$L \times \sqrt{[(0.1 \div \sqrt{12})^2 + (0.5 \div \sqrt{3})^2 + (0.37 \div 2)^2]} \times (10\% \times 10.8 \times 10^{-6} \div \sqrt{3})$	1	$(2.14548 \times 10^{-8})L$
Temperature effects on the measurand block	$L \times \sqrt{[(0.1 \div \sqrt{12})^2 + (0.5 \div \sqrt{3})^2 + (0.37 \div 2)^2]} \times (10\% \times 11.5 \times 10^{-6} \div \sqrt{3})$	1	$(2.28453 \times 10^{-8})L$
Temperature difference between gauge blocks	$L \times (0.0001 \div \sqrt{3}) \times (10\% \times 11.5 \times 10^{-6} \div \sqrt{3})$	1	$(3.83366 \times 10^{-11})L$
COMBINED STANDARD UNCERTAINTY (k=1)			$\sqrt{(D^2 + 30D + 0.04L^2 + 450)}$
Effective Degrees of Freedom			$(D^2 + 30D + 0.04L^2 + 450)^2 \div [((15 + D)^4 \div 9]$

Laboratory: Trinidad and Tobago Bureau of Standards
Date: 2022-09-16 **Name and Signature:** Kevin Lemessy

Annex E form

SIM.L-S7.2019 Supplementary Comparison
Calibration of Gauge Blocks by Mechanical Comparison Technical protocol

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Gauge Block Comparator	None Indicated	6EO4	0 mm to 100 mm	2022-06-06

Instrument description.

Type of instrument: Mechanical Comparator

Traceability: The traceability for the comparator comes from gauge blocks calibrated by PTB via the light interference measurement principle, using frequency stabilized lasers (633 nm, 532 nm / 612 nm and 780 nm).

Calibration method of your reference: EURAMET cg-2 Version 2.0 (03/2011)

Interval of temperature during measurements: 19.7 degrees Celcius to 20.3 degrees Celcius

Laboratory: Trinidad and Tobago Bureau of Standards
Date: 2022-09-16 **Name and Signature** Kevin Lemessy

CENAM

Annex C form

Annex C: Result Report Forms.

Laboratory: CENAM, México

Nominal length	Deviation of the central length from the nominal length (*lc-ln*)	Uncertainty of central length (k=1)	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	+44	10.7	10	10	9.8	725292
2.5	+33	10.7	10	30	9.8	525083
10	−7	11.0	0	70	9.8	180342
25	+29	12.4	0	40	9.8	3225200
60	−153	18.4	0	80	9.8	1425127
100	−33	27.2	0	90	9.8	1425351

Date: 2021-06-01

Name: José Armando López Célis

Signature:

Annex D form

Annex D. Form of uncertainty estimation.

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\|c_i\|=\partial l/\partial x_i$	VARIANCE $u^2 = c_i^2 * u^2(x_i)$
COMPARATOR	6.51	1	42.4
REFERENCE GB	2.8 + 0.39 L	1	64 + 0.023 L^2
TEMP. MEASUREM.	0.031	L δα	0.0014 L^2
DIFF. TEMP. GB	0.279	L θs	0.020 L^2
CET REF. GB	0.5	L δθ	0.0001 L^2
DIFF. TEM GB	0.01	L α	0.0175 L^2
SECOND ORDER TER	0.014	L	0.000862 L^2
SECOND ORDER TER	0.79 + 0.11 L	L θs	0.078 + 0.0005 L^2
COMBINED STANDARD UNCERTAINTY (*k* = 1)			$\sqrt{106.478 + 0.063 L^2}$
Effective degrees of freedom			350

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
TESA	upd	7Q 01	0 -525	JANUARY 2020

Instrument description.

Type of instrument:

GAUGE BLOCKS COMPARATOR WITH TWO PROBES RESOLUTION 2 nm AND MEASUREMENT SPAN 25 mm

Traceability:

CENAM, México

Calibration method of your reference:

STEEL GAUGE BLOCKS CALIBRATED BY INTERFEROMETRY

Interval of temperature during measurements:

20 °C ± 0.2 °C

Laboratory: CENAM, México

Date: 2021-06-01 **Name and Signature:** José Armando López Celis

INEN

Annex C form

Annex C: Result Report Forms.
Laboratory: Servicio Ecuatoriano de Normalización (INEN-Ecuador).

Nominal lenght	Deviation of the central length from the nominal lenght *(lc - ln)*	Uncertainty of central lenght ***(k=1)***	Deviation from central length *fo (l$_{max}$ -lc)*	Deviation from central lenght *fu* (*lc* -l$_{min}$)	Uncertainty (***k*** =**1**) for *fo* and *fu*	Identification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0,5	70	22	10	80	17	725292
2,5	50	22	20	20	17	525083
10	10	22	0	100	17	180342
25	0	26	0	70	17	3225200
60	-140	42	0	110	17	1425127
100	-20	64	0	100	17	1425351

Date: 2022-03-24

Annex D form

Annex D: Form of uncertainty estimation.

Estimation of the uncertainty of the central lenght			
Source of uncertainty X_i	Standard uncertainty $u(X_i)$	Sensitivity Coefficient $\|C_i\| = \partial l / \partial X_i$	Combined Standard Uncertainty. $u_i = \|C_i\|\ u(X_i)$ [nm]
First order terms			
1. Reference gauge blocks (u_{lbp})			
1.1. Certificate blocks	Q[10, 0.223 L]	1	Q[10, 0.223 L]
1.2. Drift	Q[5.193, 0.287 L]	1	Q[5.193, 0.287 L]
2. Differential comparator (u_d)			
2.1. Comparator Certificate in center length	Q[16, 0 L]	1	Q[16, 0 L]
3. Temperature ($u_{\theta bp}$)			
3.1. Thermometer resolution	2.8E-05	1	2.8E-05
3.2 Cyclical variation	0.288 67	1	0.288 67
3.3. Thermometer certificate	0.009	1	0.009
Total temperature contribution	0.288 82	-0.7	Q[0, -0.202 L]
4. Temperature difference between gauge blocks ($u_{\delta\theta}$)			
4.1. Temperature difference	0.017 320	-11.5	Q[0, -0.199 L]
5. Thermal expansion coefficient of reference gauge block ($u_{\alpha bp}$)			
5.1. Thermal expansion coefficient of the reference gauge block BP	6.24E-07	300 000	Q[0, 0.187 L]
6. Thermal expansion coefficient block to be calibrated ($u_{\alpha bc}$)			
6.1. Thermal expansion coefficient of the BP to be calibrated	6.64E-07	-330 000	Q[0, -0.219 L]
7. Probe return to zero hysteresis (u_{cero})			
7.1. Back to zero	8.660	1	Q[8.660, 0 L]
Second order Terms			
8. Temperature effect on the reference gauge block ($u_{\alpha bp} \cdot u_{\theta bp}$)			
8.1. Effects of temperature on the reference gauge block	1.80E-07	1 000 000	Q[0, 0.18 L]
9. Temperature difference between gauge blocks ($u_{\alpha bc} \cdot u_{\delta\theta}$)			
9.1. Temperature difference between gauge blocks	1.15E-08	1 000 000	Q[0, 0.01 L]
10. Temperature effect on the gauge block to be calibrated ($u_{\alpha bc} \cdot u_{\theta bp}$)			
10.1. Temperature effect on the gauge block to be calibrated	1.92E-07	1 000 000	Q[0, 0.19 L]
COMBINED STANDARD UNCERTAINTY (*k* =1)			**Q[21.4, 0.6 L]**
Effective degrees of freedom			***V* [58.97, 3.48 L]**

To Standard Uncertainty

$$Q_{[a,bL]} = Q[a, bL]$$

$$u_L = Q_{[a,bL]} = \sqrt{a^2 + b^2 * L^2}$$

To Effective degrees of freedom

$$V_{[a,bL]} = V[58.97, 3.48\ L]$$

$$V_L = \sqrt{a^2 + b^2 * L^2}$$

Where: - L: central length of the gauge block in mm.
- Q: combined standard uncertainty expressed in nm for *k* =1
- V: effective degrees of freedom

Annex D: Form of uncertainty estimation.

Estimation of the uncertainty for *fo* and *fu*			
Source of uncertainty X_i	Standard uncertainty $u(X_i)$ [um]	Sensitivity Coefficient $\|C_i\|=\partial l / \partial X_i$	Combined Standard Uncertainty. $u_i=\|C_i\|\ u(X_i)$ [nm]
1. Differential comparator			
1.1. Certificate of comparator in variation to	0.016	1	16
1.2 Resolution of the comparator bank	0.003	1	3
1.3. Repeatability	0.004	1	4
COMBINED STANDARD UNCERTAINTY (*k* =1)			**17**
Effective degrees of freedom			***201***

Date: 2022-03-24

Annex E form

Annex E: Form of technical characteristics of the used instrument.
Laboratory: Servicio Ecuatoriano de Normalización (INEN-Ecuador).

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Differential comparator, Brand Mahr.	826	1455/07	(0 a 175) mm	2021-10-26
Steel block, Brand Mitutoyo	5184	1406332	(0 a 100) mm	2019-03-15

Instrument description:

Type of instrument:

- The Mahr brand differential comparator has a range of (0 to 175) mm, it has two 1340/826 inductive probes, an 826 Ev lifting device coupled to a pedal and a Millimar 1240 data display.
- The set of gauge blocks used is 122 Mitutoyo brand elements, steel material, grade K, series 1406332, with certificate number CNM-CC-740-126/2019.

Traceability:

- The block comparator is traceable to the SI, through a set of 11 standard blocks, Mahr brand, tungsten carbide material, series 07013, the same ones that are calibrated at CENAM-Mexico in the D17-A laboratory, the standard blocks are calibrated under absolute interferometry, using an automatic interferometer, brand NPL-TESA, model AGI-1-300 and serial number 014. The reference standards are two stabilized lasers at 633 and 543 nm, with traceability to the national length standard CNM-PNM- 2 and to the length standard of the NPL of England, with calibration certificates CNM-CC-740-179/2017 and 2017100320-LL03, respectively.
- The reference standard blocks of 122 elements have traceability to the SI, their brand is Mitutoyo and they are calibrated in the same way at CENAM-Mexico and describe the same traceability indicated for the set of 11 tungsten carbide blocks indicated

Calibration method of your reference:

- Calibrated differential comparator with blocks of 11 tungsten carbide elements under the absolute interferometry method.
- Set of standard blocks of 122 steel elements calibrated under the absolute interferometry method.

Interval of temperature during measurements:

- Temperature measurement interval between (20 ± 0.3) °C

Date: 2022-03-24

CENAME

Annex C form

Por favor llenar las celdas azules / Please fill in the blue cells

Laboratory:

Nominal length	Deviation of the central length from the nominal length (*lc-ln*)	Uncertainty of central length	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	3.2 E-05	43.21	16	12	4.34	725292
2.5	3.96E-05	43.2	8.4	9.6	3.7	525083
10	-1.36E-04	43.21	22	56	5.33	180342
25	6.24E-05	52.6	19.6	42.4	3.74	3225200
50	-3.18E-04	44.62	49.2	80.8	7.2	1425127
100	2.80E-04	91.48	52.8	41.2	15.19	145351
Date:	8/3/2023		Name:	Carola Berioska García García		

Annex D form

CENAME presented one Annex D form for each gauge block. To minimize this draft A length only Annex D for 0.5 mm gauge block is presented here.

CENAME

CC-GD-FO-003
Versión 4
2021-03-11
Página 5/12

Annex D. Form of uncertainty estimation.

***Uncertainty Budget* 0.5 mm**

Source of uncertainty x_i	**Standard uncertainty $u(x_i)$ µm**	**Sensitivity Coefficient. $\|c_i\| = \partial l / \partial x_i$ µm**	**Combined Standard Uncertainty $\mu_i = \|c_i\|\mu(x_i)$ µm**
Calibration of standard gauge	4.00E-02	1E+00	2E-03
Measured lent difference repeatability Calibration of gage block comparator resolution of gage block comparator	2.96E-02	1E+00	8.78E-04
Average coefficient of thermal expansion of the reference standard block and the IBC.	1.99E-05	3E-01	2.53E-11
Temperature difference between gauges	-3.57E-01	6E-06	4.22E-12
Thermal dilatation difference between gauges.	0.00E+00	-1E-01	0.00E+00
Deviation of the standard block temperature (IBC) from the reference temperature 20°C.	-2.15E-01	0E+00	0.00E+00
Asymmetry	5.77E-03	1E+00	3.33E-05
Second order	5.15E-05	1E+00	2.65E-09
COMBINED STANDARD UNCERTAINTY (*k* = 1)			**0.0025**
Effective degrees of freedom			**1118**

Annex E form

CC-GD-FO-003
Versión 4
2021-03-11
Página 11/12

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Gage block comparator	826 PC	2214-08-20	0.5 mm a 170 mm	2019-08-22
Gauge block	Grade 0	120338	0.5 mm	2016-04-22
Gauge block	Grade 0	195725	2.5 mm	2021-02-20
Gauge block	Grade 0	142148	10 mm	2016-04-22
Gauge block	Grade 0	190273	25 mm	2021-02-20
Gauge block	Grade 0	200593	60 mm	2022-11-04
Gauge block	Grade 0	111015	100 mm	2016-04-22
Thermometer	Liquid-in-glass	934309	-2.5 °C to 38 °C	2021-08-18

Instrument description.

Type of instrument:

Measuring system

Gage block comparator	Mechanical , model: 826 PC, Make: Marh;
Display Unit	Model: Millimar C 1240; Make: Marh; Resolution: 10 nm

Standards

Gauge block 0.5 mm, 10 mm, 100 mm	Material: steel; Opus; Grade 0;
Gauge block 2.5 mm; 25 mm, 60 mm	Material: steel; Mitutoyo; Grade 0
Thermometer	Liquid-in-glass

Traceability:

Gage block comparator	Marh	Calibration certification: MOL_1149_201-08-22
Display Unit	Marh	Calibration certification: MOL_1149_201-08-22
Gauge block 0.5 mm, 10 mm, 100 mm	OPUS Metrology	Certification number: 127429
Gauge block 2.5 mm; 25 mm	assicontrol	Certification number: 2057/20
Gauge block 60 mm	Mitutoyo Mexico	Certification number: 182845
Thermometer	CENAME - Guatemala	Certification number: TE - 042

Calibration method of your reference:

DI-P-004 - Calibración de Bloques Patrón - Guide to the expression of uncertainty in measurement and Combined standard uncertainty presented AT WG4-Length meeting

Interval of temperature during measurements:

Gauge block	T_0	T_f
0.5 mm	19.9	20.0
2.5 mm	19.7	19.7
10 mm	19.6	19.7
25 mm	19.7	19.7
60 mm	20.0	20.0
100 mm	20.1	20.1

Laboratory: **Metrología dimensional, Laboratorio Nacional de Metrología, - CENAME, MINECO-Guatemala**

Date: **2023-03-08** **Name and Signature:** CAROLA BERIOSKA GARCÍA GARCÍA

Digitally signed by CAROLA BERIOSKA GARCÍA GARCÍA
Date: 2023.03.08 16:13:45 -06'00'

DICTUC

Annex C form

Annex C: Result Report Forms.
Laboratory: DICTUC, Laboratorio Nacional de Longitud de Chile

Nominal length	Deviation of the central length from the nominal length (*lc*-*ln*)	Uncertainty (*k*=1) of central length	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	30	31	10	0	25	725292
2.5	20	31	0	50	25	525083
10	-40	31	20	30	25	180342
25	20	31	20	40	25	3225200
60	-160	32	40	60	25	1425127
100	-50	34	60	20	25	1425351

Date of measurement: March 19 to April 02 / 2020

Date: **Name:** **Signature:**

August 14, 2020

Roberto Morales
Jefe Laboratorio Nacional de Longitud
DICTUC – CHILE

Annex D form

DICTUC presented one Annex D form for each gauge block. To minimize this draft A length only Annex D for 0.5 mm gauge block is presented here.

Annex D. Form of uncertainty estimation.

Nominal length **: 0,5 mm**
Material : Steel
Thermal exp. standard gauge block : $10{,}7 \cdot 10^{-6}$ 1/°C
Thermal exp. gauge block : $11{,}5 \cdot 10^{-6}$ 1/°C
Temperature during all calibration : 20,04°C
Date of measurement : March 14 to April 02 /2020

Source of uncertainty x_i	Standard uncertainty $u(x_i)$		Sensitivity Coefficient. $\lvert c_i \rvert \equiv \partial l / \partial x_i$	Combined Standard Uncertainty. $u_i \equiv \lvert c_i \rvert\, u(x_i)$
u (*l*s) Calibration of standard gauge block	10,00	nm	1	10,00
u (*l* cer) standard gauge block certificate	10,00	nm		
u (*l* der) standard gauge block drift	0,00	nm		
u (d) Measured difference between gauge blocks	29,14		1	29,14
u (*d* com) gauge blocks comparator	14,95	nm		
u (*d* rep) repeated observations	11,55	nm		
u (*d* res) comparator indication	5,77	nm		
u (*d* al) sensor alignment	5,77	nm		
u (*d* des) probing deviation	5,77	nm		
u (*d* pl) gauge blocks flatness	17,32	nm		
u (*d* defe) elastic deformation	9,62	nm		
u (αr) Thermal expansion standard gauge block	6,18E-07	1/°C	0	0
u (αc) Thermal expansion gauge block	6,64E-07	1/°C		
u (θ) Temperature	0,050	°c	0	0
u (cal) termistor certificate	0,050	°c		
u (res) indication termistor	0,003	°c		
u (Δ) thermal gradient	0,006	°c		
u (*δθ*) Temperature difference between gauge blocks	0,009	°c	-lsαs	0,05
u (*δα*) Thermal exp. difference between gauge blocks	4,6E-07	1/°C	-lsθ	0,00
Second order terms:				
Effects of temperature on standard gauge block $\theta_s \alpha_s$	3,11E-08	1/°C	ls	0,02
Effects of temperature on gauge block $\theta_s \alpha$	3,35E-08	1/°C	ls	0,02
Temperature difference between gauge blocks $\delta\theta\, \alpha$	5,75E-09		ls	0,00
COMBINED STANDARD UNCERTAINTY (*k* = 1)				31 nm
Effective degrees of freedom				

Laboratory: DICTUC, Laboratorio Nacional de Longitud de Chile

Date: August 14, 2020

Name and Signature: Roberto Morales
Jefe Laboratorio Nacional de Longitud
DICTUC – CHILE

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Gauge blocks Mechanical comparator	TESA UPC	=====	100 mm	March 16 / 2020
Steel gauge blocks Set.	ISO 3650 (grade 00)	954623	0,5 - 100	October 29 / 2018

Instrument description.

Type of instrument:

Gauge Block Comparator for Comparative Measurement.
Steel gauge blocks set. Mitutoyo BM1-112-00, ISO 3650, grade 00

Traceability:

Gauge Block Comparator: internal traceability with gauge blocks calibrated in PTB.
Steel gauge blocks set: direct traceability to PTB.

Calibration method of your reference:

Gauge Block Comparator: by mechanical comparisons according to EURAMET cg-2
Steel gauge blocks set: calibration by interferometry.

Interval of temperature during measurements:

20,00 – 20,04°C

Laboratory: DICTUC, Laboratorio Nacional de Longitud de Chile

Date:_ August 14, 2020

Name and Signature Roberto Morales
Jefe Laboratorio Nacional de Longitud
DICTUC – CHILE

IBMETRO

Annex C form

SIM.L-S7.2019 Supplementary Comparison
Calibration of Gauge Blocks by Mechanical Comparison Technical protocol

Annex C: Result Report Forms.
Laboratory: LENGTH - IBMETRO

Nominal length	Deviation of the central length from the nominal length (*lc*-*ln*)	Uncertainty (*k*=1) of central length	Deviation from central length *fo* $(l_{max}-lc)$	Deviation from central length *fu* $(lc-l_{min})$	Uncertainty (*k*=1) for *fo* and *fu*	Identification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	47	30	23	3	30	725292
2.5	34	30	3	10	30	525083
10	-10	35	2	45	30	180342
25	34	35	23	30	30	3225200
60	-147	40	0	63	30	1425127
100	-61	40	68	35	30	1425351

Date: **2023-03-10**

Name: **Romer Didier Larico Laura**

Signature:

Annex D form

IBMETRO presented one Annex D form for each gauge block. To minimize this draft A length only Annex D for 0.5 mm gauge block is presented here.

SIM.L-S7.2019 Supplementary Comparison
Calibration of Gauge Blocks by Mechanical Comparison Technical protocol

Annex D. Form of uncertainty estimation.

Nominal length block 0,5 mm			
Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\lvert C_i \rvert$	Combined Standard Uncertainty $u_i = \lvert C_i \rvert \cdot u(x_i)$
ln (µm)	0,015	1,000000004	0,015
d (µm)			
Cal. C.B. - random error (µm)	0,0144338	1	0,014433757
Cal. C.B. - systematic error (µm)	0,0150468	1	0,015046774
Resolution (µm)	0,0028868	1	0,002886751
Repeatability(µm)	0,0018333	1	0,001833333
$\delta\alpha$ (°C^{-1})	6,45497E-07	3	1,93649E-06
θ_P (°C)			
Calibration (°C)	0,0075	0,00035	0,000002625
Resolution (°C)	0,000288675	0,00035	1,01036E-07
Gradient (°C)	0,002309401	0,00035	8,0829E-07
α_N (°C^{-1})	2,88675E-07	0	0
$\delta\theta$ (°C)	-0,005773503	0,0054	-3,11769E-05
COMBINED STANDARD UNCERTAINTY (*k* = 1)			**30 nm**
Effective degrees of freedom			**187**

Laboratory: LENGTH - IBMETRO

Date: 2023-03-20

Name and Signature: Romer Didier Larico Laura 

Annex E form

SIM.L-S7.2019 Supplementary Comparison
Calibration of Gauge Blocks by Mechanical Comparison Technical protocol

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Block Comparator STEINMEYER	EMP II	1105/00	100 mm	2023-01-10

Instrument description: Equipment for calibration of blocks by mechanical comparison
Type of instrument: Measurement equipment
Traceability: Grade k gauge block set with traceability to INTI Argentina
Calibration method of your reference: Direct reading method by comparison
Interval of temperature during measurements: 19,3 °C to 20,2 °C

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Gauge Block MITUTOYO	Bm1-122-k/YJ	2204362	0,5 mm to 100 mm	2022-07-28

Instrument description: Grade k gauge block set
Type of instrument: Grade k gauge block set
Traceability: to MITUTOYO JCSS ILAC - MRA
Calibration method of your reference: Interferometry
Interval of temperature during measurements: 19,5 °C to 20,5 °C

Type.	Model.	Serial number.	Measurement range °C	Date of last calibration
Thermometer FLUKE	1529-R	B97136	-189 °C to 960 °C	2022-08-24

Instrument description: Thermometer for measuring the temperature of blocks
Type of instrument: Measurement equipment
Traceability: to LATU Uruguay
Calibration method of your reference: By comparison
Interval of temperature during measurements: 19 °C to 25 °C

Laboratory: LENGTH - IBMETRO

Date: 2023-03-20

Name and Signature: Romer Didier Larico Laura

LATU

Annex C form

Annex C: Result Report Forms.
Laboratory: Laboratorio Tecnológico del Uruguay, LATU.

Nominal length	Deviation of the central length from the nominal length (*lc*-*ln*)	Uncertainty of central length	Deviation from central length *fo*	Deviation from central length *fu*	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
			(l_{max}-*lc*)	(*lc*-l_{min})		
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0,5	35	24	31	16	28	725292
2,5	39	24	0	43	22	525083
10	-22	27	0	62	19	180342
25	44	26	0	49	19	3225200
60	-119	34	0	87	21	1425127
100	-71	56	23	46	39	1425351

Date: **Name:** **Signature:**

03/31/2020 **Alejandro Acquarone**

Annex D form

LATU presented one Annex D form for each gauge block for deviation of central length an fo & fu. To minimize this draft A length only Annex D for deviation of central length of 0.5 mm gauge block is presented here.

Annex D. Form of uncertainty estimation.

Gauge Block: 0,5 mm **Deviation from the nominal length (lc-ln)**

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\lvert c_i \rvert \equiv \partial l / \partial x_i$	Combined Standard Uncertainty. $u_i \equiv \lvert c_i \rvert \, u(x_i)$
Length correction of the reference gauge block	0,01	1	0,0100
Linear coefficient of thermal expansion (reference gauge block).	5,77E-07	8,373E+01	0,00005
Block temperature measurement (Cal. Cert. u)	0,0305	1,983E-04	0,00001
Maximum possible temperature deviation	0,0025	1,983E-04	0,000000
Temperature difference between reference and test gauge block.	0,0144	1,170E-02	0,0002
Length difference between reference and test gauge block.	0,0063	1	0,0063
Linear coefficient of thermal expansion (gauge block under test)	5,77E-07	8,376E+01	0,00005
Mechanical comparator uncertainty	0,017	1	0,0170
Correction due to drift of the reference gauge block	0,0115	1	0,0115
correction due to length variation of the reference gauge block	0,00385	1	0,00385
Thermometer resolution	0,00289	1,983E-04	0,000001
Difference of result between faces A and B	0,0012	1	0,0012
COMBINED STANDARD UNCERTAINTY (*k* = 1)			**0,024**
Effective degrees of freedom			**525**

Laboratory: Laboratorio Tecnológico del Uruguay, LATU

Date: 03/31/2020 **Name and Signature: Alejandro Acquarone**

Annex E form

INM

Annex C form

Por favor llenar las celdas azules / Please fill in the blue cells

Laboratory: INSTITUTO NACIONAL DE METROLOGÍA DE COLOMBIA

Nominal length	Deviation of the central length from the nominal length (*lc-ln*)	Uncertainty of central length (k=1)	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (k=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	22	20	10	20	17	725292
2.5	2	20	0	30	17	525083
10	-56	20	0	50	17	180342
25	-2	23	0	30	17	3225200
60	-175	30	0	80	17	1425127
100	-46	48	30	120	17	1425351

Date: 2022-06-21

Metrologist name: David Alonso Plazas Fernández

Reviewer name: Victor Hugo Gil Gil

Reviewer name (2): Jorge Galvis Arroyave (in training)

Annex D form

INM presented one Annex D form for each gauge block for deviation of central length an fo & fu. To minimize this draft A length only Annex D for deviation of central length of 0.5 mm gauge block is presented here.

Annex D. Form of uncertainty estimation.

Block 0.5 mm (725292)

Source of uncertainty *xi*		**Standard uncertainty *u(xi)***		**Sensitivity Coefficient |ci|≡∂l/∂xi**		**Combined Standard Uncertainty ui≡|ci|u(xi)**
Difference between blocks	*d*	*u(d)*	17,4	1		17,4
Comparator	*comp*	*u(comp)*	5,7			
Standard gauge block drift	*drift*	*u(drift)*	11,5			
Comparator Resolution	*res*	*u(res)*	1,4			
Damaged measuring faces	*δv*	*u(δv)*	11,5			
CTE standard gauge block	*αs*	*u(αs)*	5,8E-07	*ls θs*	-229999,54	-0,1
CTE test gauge block	*α*	*u(α)*	5,8E-07	*-L(δθ+θs)*	115505,313	0,1
Temperature difference between gauge blocks	*δθ*	*u(δθ)*	2,2E-02	*-L α*	5,75E+00	0,1
Temperature Measurement	*θs*	*u(θs)*	2,2E-02	*(ls αs-L α)*	6,15E+00	0,1
Standard gauge block calibration	*ls*	*u(ls)*	10,0		1	10,0
		u(d)u(α)	1,0E-05	*-(δθ+θs)*	0,231	2,3E-06
		u(ls)u(α)	5,8E-06	*(δθ+θs)*	-0,231	-1,3E-06
		u(α)u(δθ)	1,3E-08	*-L*	-500023	-6,4E-03
		u(α)u(θs)	1,3E-08	*-L*	-500023	-6,4E-03
		u(δθ)u(d)	0,38	*- α*	-1,15E-05	-4,4E-06
		u(δθ)u(ls)	0,22	*- α*	-1,15E-05	-2,5E-06
		u(θs)u(d)	0,38	*- α*	-1,15E-05	-4,4E-06
		u(θs)u(ls)	0,22	*αs- α*	4,00E-07	8,8E-08
		u(αs)u(ls)	5,8E-06	*θs*	-0,23	-1,3E-06
		u(αs)u(θs)	1,3E-08	*ls*	999998	1,3E-02
COMBINED STANDARD UNCERTAINTY CENTRAL LENGTH (*k*=1) (nm)						**20**
Effective degrees of freedom						**86,3**

Laboratory: Instituto Nacional de Metrología de Colombia (Length Laboratory)
Date: 2022-06-21
Metrologist Name: David Alonso Plazas Fernández

Responsible person for revision: Victor Hugo Gil Gil

Responsible person for revision (2): Jorge Luis Galvis Arroyave (in training)

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range	Date of last calibration
Gauge block KOBA	9 Telling	87564	1 mm	2021-10-19
			10 mm	
			25 mm	
			50 mm	
			100 mm	
Comparator TESA	UPD	3G-01	[0.5 to 500] mm	2018-11-22
Fluke Thermometer	Chub-E4	A65167	[-189 to 960] °C	2021-07-12

Instrument description.

KOBA steel 9 block set and Tesa UPD comparator

Type of instrument:

- Steel block, length nominal (1, 5, 10, 15, 20, 25, 50, 75, 100) mm
- Tesa UPD gauge block comparator
- Fluke Thermometer

Traceability:

The KOBA gauge blocks set used for the measurements are traceable to the International System of Units (SI) and were calibrated by the **Physikalisch Technische Bundesanstalt of Germany (PTB)** with calibration certificate **No. 51034 PTB 21 of 2021-10-19**. The gauge block comparator TESA UPD was calibrated by the **Instituto Nacional de Metrología de México (CENAM)** with calibration certificate No. CNMCC-740-602/2018 of 2018-11-22. The four sensors of the FLUKE digital thermometer were calibrated by the **Instituto Nacional de Metrología de Colombia** with calibration certificates No.. 5305, 5306, 5307 and 5308 of 2021-07-12, traceable to the 1990 International Temperature Scale, ITS-90.

Calibration method of your reference:

Traceability to the definition of the unit of length is provided by the measuring principle of light interference using frequency - Stabilized lasers (633 nm, 532 nm / 594 nm, 780 nm)

Interval of temperature during measurements:

19.767 °C to 20.459 °C

CENAMEP

Annex C form

Por favor llenar las celdas azules / Please fill in the blue cells						
Laboratory:	Centro Nacional de Metrología de Panamá (CENAMEP)					
Nominal length	Deviation of the central length from the nominal length (*lc-ln*)	Uncertainty of central length (*k*=2)	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	45.7	29.8	45	30.7	22	725292
2.5	37.2	30.2	0	26.4	8.15	525083
10	1.6	39.3	0	81.4	23.7	180342
25	11.6	74.7	0	26.4	8.15	3225200
50	-240.5	168	0	72.9	21.2	1425127
100	-198	262	5	99.3	30.2	1425351
Date:	2/2/2021		Name:	José Kuruc		

Annex D form

CENAMEP presented one Annex D form for each gauge block. To minimize this draft A length only Annex D for 0.5 mm gauge block is presented here.

SIM.L-S7.2019 Supplementary Comparison
Calibration of Gauge Blocks by Mechanical Comparison Technical protocol

Annex D. Form of uncertainty estimation.

0.5 mm

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\lvert c_i \rvert \equiv \partial l / \partial x_i$	Combined Standard Uncertainty. $u_i \equiv \lvert c_i \rvert\, u(x_i)$
a. u_L (mm)	1.15×10^{-5}	1.00	1.15×10^{-5} mm
b. u_{dL} (mm)	3.46×10^{-6}	1.00	3.46×10^{-6} mm
c. $u_{\Delta Tr}$ (°C)	7.64×10^{-2}	9.30×10^{-6}	7.10×10^{-7} mm
d. $u_{\Delta Tx}$ (°C)	7.64×10^{-2}	1.15×10^{-5}	8.78×10^{-7} mm
e. $u_{\alpha r}$ (1/°C)	5.37×10^{-7}	9.45×10^{-1}	5.07×10^{-7} mm
f. $u_{\alpha x}$ (1/°C)	6.64×10^{-7}	9.45×10^{-1}	6.28×10^{-7} mm
g. $u_{\Delta Lx}$ (mm)	5.54×10^{-6}	1.00	5.54×10^{-6} mm
h. $u_{\Delta Lr}$ (mm)	5.65×10^{-6}	1.00	5.65×10^{-6} mm
i. u_{rep} (mm)	2.13×10^{-6}	1.00	2.13×10^{-6} mm
j. u_{res} (mm)	2.89×10^{-6}	1.00	2.89×10^{-6} mm
COMBINED STANDARD UNCERTAINTY (k = 1)			1.49×10^{-5} mm = 14.9 nm
Effective degrees of freedom			580

a. Block Reference.
b. Block Reference drift.
c. Block Reference Temperature.
d. Unknown Block Temperature.
e. Thermal Expanssion Reference
f. Thermal Expanssion Unknown block.
g. Unkown Block Deformation
h. Reference Block Deformation
i. Repetibility
j. Resolution.

Laboratory: Centro Nacional de Metrología de Panamá

Date: 2021-03-01 **Name and Signature** José Kuruc

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Gauge Block Set.	BM3-112-K/YJ	0110477	0.5mm to 100mm	2020-01-23

Instrument description.

Type of instrument:
Material: Ceramics
Grade: K

Traceability:
This blocks are trazable at CENAM by interferometric.

Calibration method of your reference:
Our Method is based in the document ISO-365 Geometrical Product Specifications (GPS)-Length Standards-Gauge Blocks

Interval of temperature during measurements:
20 °C to 21 °C

Laboratory: Centro Nacional de Metrología de Panamá
Date: 2021-03-01 **Name and Signature** José Kuruc

INMETRO

Annex C form

Annex C: Result Report Forms.

Laboratory: Laboratório de Metrologia Dimensional (LAMED)-INMETRO

Nominal length	Deviation of the central length from the nominal length (*lc-ln*)	Uncertainty of central length (*k*=1)	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Identification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	31	29,6	10	8	41,9	25292
2.5	69	29,6	3	5	41,9	25083
10	12	29,7	0	49	42,0	0342
25	80	31,0	0	25	43,8	25200
*60	--	--	--	--	--	--
100	-30	47,6	24	76	67,3	25351

*Obs: Este bloco-padrão não foi medido, pois não temos um padrão de referência neste comprimento. (This gauge block has not been measured as we do not have a reference in this length).

Date:31/10/2022 **Name: Wellington S. Barros** **Signature:**

Annex D form

INMETRO presented one Annex D form for each gauge block. To minimize this draft A length only Annex D for 0.5 mm gauge block is presented here.

Annex D. Form of uncertainty estimation.

0,5 mm

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\|c_i\| \equiv \partial l / \partial x_i$	Combined Standard Uncertainty. $u_i \equiv \|c_i\|\ u(x_i)$
δl Repetitividade (Type A evaluation of standard uncertainty)	nm 2,00	1,0	nm 2,00
l_s Padrão de Referência (reference standard)	nm 14,00	1,0	nm 14,00
δl_C Comparador Bloco Padrão (Comparator)	nm 25,00	1,0	nm 25,00
δt Temperatura do Bloco (Temperature corrections)	°C 0,01155	nm°C^{-1} 5,7502415	nm 6,64E-02
δl_V Variação no Comprimento (Variation in length)	nm 5,774	1,0	nm 5,774
δl_D Deriva bloco Padrão (Drift of the standard)_	nm 4,082	1,0	nm 4,082
Coeficiente de dilatação (linear thermal expansion coefficient)	2,35702E-07	nm 5,00E+05	nm 1,179E-01
COMBINED STANDARD UNCERTAINTY (*k* = 1)			29,6
Effective degrees of freedom			4,30682E+05

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range	Date of last calibration
Electromechanical Comparator	Tesa Modul	005959	10 µm	10/08/2022
Thermometer	Onset	UX100-003	18 °C – 22 °C	11/02/2020
Gauge Blocks Steel	Mitutoyo	960614 960082 968284 963992 965237	0,5 à 100 mm	06/11/2018

Instrument description.

Type of instrument:

Electromechanical Comparator.
Gauge Blocks Steel. Set 112 pcs Grade 00.

Traceability:
Gauge Blocks - Laboratório de Interferometria - LAINT (INMETRO),
Thermometer - Laboratório de Termometria - LATER (INMETRO)
Electromechanical Comparator - Laboratório de Metrologia Dimensional – LAMED (INMETRO)

Calibration method of your reference: Interferometry

Interval of temperature during measurements: 19,7 °C – 19,9 °C

Laboratory: Laboratório de Metrologia Dimensional (LAMED)-INMETRO

Date: 31/10/2022 Name and Signature_ Wellington S. Barros

LACOMET

Annex C form

Annex C: Result Report Forms.
Laboratory: <u>LCM (Costarrican Laboratory of Metrology)</u>

Nominal length	Deviation of the central length from the nominal length (*lc*-*ln*)	Uncertainty of central length	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	79	38	400	2990	38.1	725292
2.5	46	41	290	-150	40.7	525083
10	31	50	-28	-110	50.4	180342
25	114	70	120	-80	69.9	3225200
50	-50	115	100	110	115	1425127
100	157	167	360	-280	167	1425351

Note: The 0.5 mm gauge block has a scratch in one of the corners of the Face B, it was considerate in the initial inspection, and we consider altered the results of the deviation from central length of this gauge block.

Date:	**Name:**	**Signature:**
September 2020	**Leonardo Rojas Rapso (LCM)**	LEONARDO ENRIQUE ROJAS RAPSO (FIRMA) Firmado digitalmente por LEONARDO ENRIQUE ROJAS RAPSO (FIRMA) Fecha: 2021.09.02 10:04:45 -06'00'

Annex D form

Annex D. Form of uncertainty estimation.

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\lvert c_i \rvert \equiv \partial l / \partial x_i$	Combined Standard Uncertainty. $u_i \equiv \lvert c_i \rvert\ u(x_i)$
Measurement Repeatability	0.002	1	0.002
Gauge Block comparator	16	1	16
Standard Gauge blocks	$0.0007 * (L_n)^2 + 0.0589 * L_n + 11.229$	1	$0.0007 * (L_n)^2 + 0.0589 * L_n + 11.229$
Drift of the Standard Gauge blocks	2.523	1	5.6847
elastic deformation differences of the gauge blocks materials	3 E-7	1	3 E-7
Temperature measurement equipment	0.0656	$-1.8*L_n + 5E^{-5}$	$-0.118*L_n + 3.28E^{-6}$
Temperature difference between blocks	0.0652	$-0.664*L_n + 2E^{-5}$	$-0.0433*L_n + 1.3E^{-6}$
Coefficient of thermal expansion of the measuring	6.6E-7	$-974785*L_n + 1E^{+6}$	$-0.643*L_n + 0.66$
Coefficient of thermal expansion of the reference	5.6E-7	$945700*L_n - 1E^{+6}$	$0.53*L_n - 0.56$
-	-	-	-
-	-	-	-
-	-	-	-
COMBINED STANDARD UNCERTAINTY (*k* = 1)			**$0.0046*L_n^2 + 0.2656*L_n + 19.049$**
Effective degrees of freedom			**$0.0009*L_n^3 - 0.1516*L_n^2 + 11.462*L_n + 65.091$**

Note: L_n refers to the nominal length of the measurement performed

Laboratory: LCM (Costarrican Laboratory of Metrology)

Date: September 2020

Name and Signature: LEONARDO ENRIQUE ROJAS RAPSO (FIRMA) Firmado digitalmente por LEONARDO ENRIQUE ROJAS RAPSO (FIRMA) Fecha: 2021.09.02 10:05:12 -06'00'

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Ceramic Gauge Blocks, "K" grade	112 pieces TESA gauge block set	70057T / 707014	0,5 mm to 100 mm	December, 2015

Instrument description.

Type of instrument: Tesa Mechanical Gauge block comparator

Traceability: LACOMET, LACOMET 800116, Costa Rica

Calibration method of your reference: GS-DI-PR-04 "Calibración de Bloques Patrón V4".

Interval of temperature during measurements: 20.662°C – 20.992°C

Laboratory: LCM (Costarrican Laboratory of Metrology)

Date: September 2020

Name and Signature: LEONARDO ENRIQUE ROJAS RAPSO (FIRMA) Firmado digitalmente por LEONARDO ENRIQUE ROJAS RAPSO (FIRMA) Fecha: 2021.09.02 10:05:31 -06'00' ______________________

BSJ

Annex C form

Por favor llenar las celdas azules / Please fill in the blue cells						
Laboratory:						
Nominal length	Deviation of the central length from the nominal length (*lc-ln*)	Uncertainty of central length	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	43	40				
2.5	28	26				
10	-13	42				
25	2	80				
50	-139	152				
100	-42	301				
Date:	20/1/2023		Name:	Tomokie Burton		

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Mahr, Mechanical Gauge Block Comparator	2247386 (130B-24)	200104	100 mm	2017/09/27

Instrument description. Lever type system with dual probe for top and bottom.

Type of instrument: Gauge block comparator that measures the difference between reference and test gauges up to a maximum of 100 mm

Traceability: To the SI through Mahr calibration Certificate, Shop Order # 238729000

Calibration method of your reference:

Done by NIST using Electromechanical comparator: Test number 685-o-0000034739-21

Measurement Uncertainty was given for individual block and was not lenght dependent

Interval of temperature during measurements: Room temperature was stable to 20 degC +/- 0.3deg C

Laboratory: Bureau of Standards Jamaica

Date: 2024/08/07 **Name and Signature**

INACAL

Annex C form

ANNEX C:	RESULT REPORT FORMS					
LABORATORY:	LONGITUD Y ÁNGULO DEL INACAL-DM					
Nominal length (mm)	Deviation of the central length from the nominal length (lc - ln) (nm)	Uncertainty of central length (k = 1) (nm)	Deviation from central length fo (lmax-lc) (nm)	Deviation from central length fu (lc-lmin) (nm)	Uncertainty (k=1) for fo and fu (nm)	Identification number
0.5	0.04	46	-0.22	0.28	24	725292
2.5	0.01	46	-0.07	0.08	24	525083
10	-0.02	46	0.09	-0.02	24	180342
25	-0.05	48	0.04	-0.02	25	3225200
60	-0.17	59	-0.10	0.23	31	1425127
100	-0.01	77	-0.27	0.37	41	1425351
LABORATORY: LONGITUD Y ÁNGULO						
DATE: 2023-06-26						
Name and signature:	Daniel Cano Uribe					

Annex D form

UNCERTAINTY BUDGET OF GAUGE BLOCK CENTRAL LENGTH

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient $\lvert c_i \rvert = \partial l / \partial x_i$	Combined Standard Uncertainty $u_i = \lvert c_i \rvert u(x_i)$
$u(d)$	24	1	24
Repeatability	17.3		
Uncertainty	16		
Resolution	2.89		
Variation of length and central position	3.85		
$u(l_s)$	$\sqrt{(38\ \mathrm{nm})^2 + (0{,}35 \times 10^{-6} \times \mathrm{L})^2}$	1	$\sqrt{(38\ \mathrm{nm})^2 + (0{,}35 \times 10^{-6} \times \mathrm{L})^2}$
CEM Calibration	$\sqrt{(34\ \mathrm{nm})^2 + (0{,}7 \times 10^{-6} \times \mathrm{L})^2}$		
Drift standard gauge block	34.6		
$u(\theta_s)$	0.17	-0,7 x L	0,12 x L
Reading	0.00029		
Cyclic variation	0.17		
Calibration	0.0088		
$u(\delta\theta)$	0.029	11,5 x L	0,33 x L
Temperature difference between gauge	0.029		
$u(\alpha_s)$	0.29	0,5 x L	0,14 x L
Thermal dilatation of standard	0.29		
$u(\alpha)$	0.58	-0,55 x L	0,32 x L
Thermal dilatation of test	0.58		
$u(\alpha_s) * u(\theta_s)$	0.05	L	0,05 x L
Temperature effects on standard gauge	0.05		
$u(\alpha) * u(\theta_s)$	0.10	L	0,10 x L
Temperature effects on test gauge	0.10		
$u(\delta\theta) * u(\alpha)$	0.017	L	0,017 X L
Temperature difference between gauges	0.017		
Combined standard Uncertainty (k=1)			$\sqrt{(45\ \mathrm{nm})^2 + (0{,}6 \times 10^{-6} \times \mathrm{L})^2}$
Effective degrees of freedom			46
Laboratory:	Longitud y Ángulo		
Date:	26/6/2023		
Name and Signature:	Daniel Cano Uribe		

Annex E form

Type	Model	Serial number	Measurement range	Date of last calibration
Gauge Block grade K (steel)	BM1-122-K/YJ	0807874	0,5 mm a 100 mm	13/1/2022
Gauge block Comparator	826 PC	1478/09 and 4117/08	0 mm a 100 mm	8/6/2023
Digital thermometer	1586A	50735008	-200 °C a 1200 °C	8/11/2022

Instrument description:	Gauge Block of 0,5 mm to 100 mm
Type of instrument:	Grade K (Steel)
Traceability:	Centro Español de Metrología (CEM - SPAIN)
Calibration method of your reference:	Comparison Interferometer laser He-Ne (633 nm)

Instrument description:	Gauge block Comparator
Type of instrument:	0 mm a 100 mm
Traceability:	INSTITUTO NACIONAL DE CALIDAD (INACAL)
Calibration method of your reference:	EURAMET/cg-2/v.2.0 (03/2011) "Calibration of Gauge Block Comparators"

Instrument description:	Digital thermometer
Type of instrument:	Range: -200 °C a 1200 °C Resolution: 0,001 °C 02 Termorresistencias de platino de 100 ohm
Traceability:	INSTITUTO NACIONAL DE CALIDAD (INACAL)
Calibration method of your reference:	INDECOPI PC-017 "Calibration Procedure of Digital Thermometers" (2nd Edition December 2012)

Interval of temperature during measurements:	20 °C ± 0,5 °C

LABORATORY: LONGITUD Y ÁNGULO
DATE: 2023-06-26
Name and signature: Daniel Cano Uribe

NIST

Annex C form

Mechanical

Nominal length	Deviation of the central length from the nominal length (*lc*-*ln*)	Uncertainty of central length (k=1)	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	44	13.5				7-25292
2.5	39	13.8				5-25083
10	-20	14.8				18-0342
25	25	16.9				32-25200
60	-159	21.8				14-25127
100	-35	27.4				14-26361

Date:	17/10/2020		Name:	Eric Stanfield		

Annex D form

Annex D. Form of uncertainty estimation.

Mechanical Comparison

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\|c_i\| \equiv \partial l/\partial x_i$	Combined Standard Uncertainty. $u_i \equiv \|c_i\|\, u(x_i)$ (nm)
Master (l_S)	10.6 + 0.079L	1	(10.6 + 0.079L)
Reproducibility[1] (l_R)	4.0 + 0.11L	1	(4.1 + 0.12L)
Scale (S)	0.6 nm	1	0.6
CTE_{Test} (α_T)	0.66 °C^{-1}	0.1	0.066L
CTE_{Master} (α_S)	0.66 °C^{-1}	0.1	0.066L
Thermometer (T)	0.01 °C	$\alpha_T - \alpha_S$[2]	0
Thermal Gradient (δ)[3]	0.003 °C	α_{AVG}	0.033L
Elastic Deformation (Δ)	7 nm	1	7
COMBINED STANDARD UNCERTAINTY (*k* = 1)			**$u_{c\ LINEAR}$ = (13.4 + 0.14L) nm, where L is the nominal length in mm**
Effective degrees of freedom			**699**

NOTES:

[1]Reproducibility includes operator, instrument, typical block variability due to geometry evaluated from more than 10 years of process data.

[2]$(\alpha_T - \alpha_S)L = 0$, for like material comparison

[3]$\delta = T_T - T_S$

L = nominal length in mm

Laboratory: NIST
Date: 4/14/21 **Name and Signature** Eric S Stanfield

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
Two-Point Contact Comparator (Mahr/Federal)	130B-24		0.1 - 100	Every 3 months

Instrument description.

Type of instrument:

Two-Point Contact Gauge Block Comparator

Traceability:

Master blocks measured on a continuous cycle by interferometry here at NIST. Traceability to the SI unit of length, m, is through the vacuum wavelength of the 633 nm He-Ne laser calibrated periodically against the NIST Iodine stabilized laser.

Calibration method of your reference:

Interferometry

Interval of temperature during measurements:

At the beginning of every measurement sequence for each size.

Laboratory:__NIST______________________________________
Date:_______________**Name and Signature**_____________________

PAI

Annex C form

SIM.L-S7.2019 Supplementary Comparison
Calibration of Gauge Blocks by Mechanical Comparison Technical protocol

Annex C: Result Report Forms.
Laboratory:_ PAI, Calibration and Measurement Laboratory, Kuwait

Nominal length	Deviation of the central length from the nominal length (*lc-ln*)	Uncertainty of central length (*k*=1)	Deviation from central length *fo* (l_{max}-*lc*)	Deviation from central length *fu* (*lc*-l_{min})	Uncertainty (*k*=1) for *fo* and *fu*	Indentification number
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	
0.5	180	30.00	10.00	10.00	19.44	7' 25292
2.5	60	28.01	0.00	20.00	19.44	5' 25083
10	20	28.22	0.00	30.00	19.44	18' 0342
25	80	29.34	0.00	50.00	19.44	32' 25200
60	600	40.00	0.00	50.00	19.44	14' 25127
100	220	44.82	10.00	30.00	19.44	7' 25292

Date: 15/10/2023

Name: تهاني راشد الرباح
رئيس قسم مختبر القياس والمعايرة

Signature:

Annex D form

PAI presented one Annex D form for each gauge block. To minimize this draft A length only Annex D for 0.5 mm gauge block is presented here.

Annex D. Form of uncertainty estimation. (0.5 mm)

Source of uncertainty x_i	Standard uncertainty $u(x_i)$	Sensitivity Coefficient. $\|C_i\| \equiv \partial l / \partial x_i$	Combined Standard Uncertainty. $U_i \equiv \|C_i\| \, u(x_i)$
Value of reference gauge(l_S)	60 nm	1	٣٠
Value of reference gauge(l_S)	0.9 nm	1	4.5×10^{-1}
Drift of the reference gauge block (δl_D)	20 nm	1	$1.2 \times 10^{+1}$
Device Accuracy (δl_C)	17 nm	1	9.8
Device uncertainty (δl_C)	30 nm	1	$1.5 \times 10^{+1}$
Difference of Thermal expansion coefficients ($\delta \alpha$)	3×10^{-6} °C	0.5	8.7×10^{-7}
Difference of temperature (δt)	0.03 °C	$1.00 \cdot 10^{-5}$	1.7×10^{-7}
thermal expansion coefficient ($\bar{\alpha}$)	-3.45×10^{-7} nm	0.5	1.00×10^{-7}
Deviation of temperature ($\Delta \bar{t}$)	0.2 °C	1	0.116
Variation(δl_V)	0.67 nm	1	3.8×10^{-1}
Repeatability (δl)	15 nm	1	7.5
COMBINED STANDARD UNCERTAINTY (*k* = 1)			U= 38 nm
Effective degrees of freedom			232.1

Laboratory: PAI, Calibration and Measurement Laboratory, Kuwait
Date: 15/10/2023 **Name and Signature** تهاني راشد الرباح
رئيس قسم مختبر القياس والمعايرة

P.A.I.

Annex E form

Annex E. Form of technical characteristics of the used instrument.

Type.	Model.	Serial number.	Measurement range mm	Date of last calibration
1- Ceramic Grade (0)	1122M	10264	0.5	29/03/2023
2- Steel Grade (K)	BM1-112-K/YJ	191638	2.5	29/03/2023
3- Steel Grade (K)	BM1-112-K/YJ	205375	10	29/03/2023
4- Steel Grade (K)	BM1-112-K/YJ	202002	25	29/03/2023
5- Ceramic Grade (0)	1122M	10269	60	29/03/2023
6- Steel Grade (K)	BM1-112-K/YJ	200566	100	29/03/2023

Instrument description.

Instrument	Manufacturer	Serial number.	Uncertainty	Accuracy
Gauge Block Comparator	Ferinmess Suhl GmbH	345537	U=0.03μm+0.002*D	-
Gauge Block (Steel)	Mitutoyo	2005557	U=Q[56;0.7L]nm (L:mm)	Grade K
Gauge Block (Ceramic)	KOBA	AA22MM	U=Q[60;0.9L]nm (L:mm)	Grade 0

Type of instrument:

Accordance with ISO 3650:1998, Steel, Ceramic

Instrument	Model Type
Gauge Block Comparator	EMPII
Gauge Block (Steel)	BM1-112-K/YJ
Gauge Block (Ceramic)	1122M

Traceability:
TURKAK (UME)

Calibration method of your reference:
TLM-05-G2BM-04-02 which conforms with ISO 3650,1998

Annex 1 Tolerance – Uncertainty ratio

To be able to determine whether a GB´s central length falls within the tolerances of a certain grade according to the classification of the ISO 3650 Standard, the calibration uncertainty should be small enough with respect to the corresponding tolerance. It was observed that most of the laboratories announced uncertainties not small enough to be able to calibrate Grade 0 GBs.

A recommended ratio may be:

$$\frac{tolerance}{uncertainty\ (k=2)} \geq 3$$

Or

$$\frac{tolerance/2}{uncertainty\ (k=1)} \geq 3$$

A1.1 Ratio for deviation of central length

Only CENAM, NIST and INM comply with the above ratio for all the measured GB. The rest of the laboratories have at least one GB where the ratio is not met. Further investigation is recommended to be able to calibrate Grade 0 GB for all lengths.

In the following table it can be seen the tolerance – uncertainty ratio for all the participants

Tolerance – uncertainty ratio								
Nominal length /mm	CENAM	LATU	DICTUC	INACAL	INMETRO(1)	CENAMEP	INTI	NIST
0.5	5.6	2.5	1.9	1.3	2.0	4.0	3.0	4.4
2.5	5.6	2.5	1.9	1.3	2.0	4.0	3.0	4.3
10	5.5	2.2	1.9	1.3	2.0	3.1	2.9	4.1
25	5.6	2.7	2.3	1.5	2.3	1.9	3.0	4.1
60	6.8	3.7	3.9	2.1	-----	1.5	3.7	5.7
100	5.5	2.7	4.4	2.0	3.2	1.1	3.0	5.5

Tolerance – uncertainty ratio								
Nominal length /mm	TTBS	BSJ	LACOMET	CENAME	IBMETRO	INEN	INM	PAI
0.5	2.8	3.0	1.6	1.4	2.0	2.7	3.0	2.0
2.5	2.8	4.6	1.5	1.4	2.0	2.7	3.0	2.1
10	2.8	2.9	1.2	1.4	1.7	2.7	3.0	2.1
25	3.2	1.8	1.0	1.3	2.0	2.7	3.0	2.4
60	5.1	1.6	1.1	2.8	3.1	3.0	4.2	3.1
100	5.2	1.0	0.9	1.6	3.8	2.3	3.1	3.3

Table 25 – Uncertainty – tolerance ratio for deviation of central length

A1.2 Ratio for f_o and f_u

Only CENAM and CENAME, have complying ratios for f_o and f_u for all the measured GB. The rest of the laboratories have at least four values that do not comply. Further investigation is recommended.

In the following table it can be seen the tolerance – uncertainty ratio for all the participants

Tolerance – uncertainty ratio								
Nominal length /mm	CENAM	LATU	DICTUC	INACAL	INMETRO(1)	CENAMEP	INTI	NIST(2)
0.5	5.1	1.8	2.0	2.1	1.2	2.3	2.0	-----
2.5	5.1	2.3	2.0	2.1	1.2	6.1	2.0	-----
10	5.1	2.6	2.0	2.1	1.2	2.1	2.0	-----
25	5.1	2.6	2.0	2.0	1.1	6.1	2.0	-----
60	6.1	2.9	2.4	1.9	-----	2.8	2.4	-----
100	6.1	1.5	2.4	1.5	0.9	2.0	2.4	-----

Tolerance – uncertainty ratio								
Nominal length /mm	TTBS	BSJ(2)	LACOMET	CENAME	IBMETRO	INEN	INM	PAI
0.5	1.7	-----	1.3	11.5	1.7	2.9	2.9	2.6
2.5	1.7	-----	1.2	13.5	1.7	2.9	2.9	2.6
10	1.7	-----	1.0	9.4	1.7	2.9	2.9	2.6
25	1.6	-----	0.7	13.4	1.7	2.9	2.9	2.6
60	1.8	-----	0.5	8.3	2.0	3.5	3.5	3.1
100	1.5	-----	0.4	3.9	2.0	3.5	3.5	3.1

Table 26 – Uncertainty – tolerance ratio for f_o and f_u

(1) INMETRO do not have a 60 mm reference gauge block
(2) These NMI´s did not informed f_u and f_u