SIM.L-K1.2007.1

Bilateral Comparison (Length) 2018-2019

Calibration of gauge blocks by Optical Interferometry

FINAL REPORT

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CONTENT

1. Introduction

The Mutual Recognition Arrangement (MRA) of the *Comité Internationale des Poids et Mesures* (*CIPM*) signed by the National Metrology Institutes (NMI) of different nations provides mutual recognition among the NMI of their national standards and their calibration services. A database has been set up by the *Bureau International des Poids et Mesures* (*BIPM*) at its website where the Calibration and Measurement Capabilities (CMC) of each NMI are posted. To support the CMC claims of the NMI, the MRA requires, among other things, that they participate, on a regular basis, in Key Comparisons (KC) that test key measuring techniques. This would prove their technical competence, that they can provide this calibration service with the claimed uncertainty of the corresponding CMC and that they have metrological equivalence with the other signatory NMI that provide the same calibration service.

KC should take place at the highest level amongst the members of the corresponding Consultative Committee (CC), in this case the Consultative Committee for Length (CCL). Similar regional KC should also be organized in every region with at least a few NMI from the region participating in the regional comparison as well as in the CCL KC.

The CIPM has also instructed the different CC to identify key techniques in order to define KC. The calibration of gauge blocks by optical interferometry has been identified as a key measuring technique by the Consultative Committee for Length (CCL). In one hand it requires good technical expertise and skills, the use of sophisticated equipment and stringent laboratory conditions; but in the other hand it is an unavoidable step in the dissemination of the length unit and therefore it is of paramount importance. These KCs have been designated as K1 comparisons.

Both levels of comparisons should be organized regularly in time at a frequency established by each CC. This bilateral comparison is needed because the last comparison INTI participated on is the SIM.L-K1:2007 performed 10 years ago. This comparison ranged from 1 mm to 100 mm. Since 2014 INTI expanded its CMC from 100 mm to 300 mm, so we need to participate in a new comparison for the range from 0,5 mm to 300 mm.The present bilateral comparison between CENAM and INTI is named SIM.L-K1:2007.1 and is intended to support and maintain the posted CMC of the NMI of the Americas that offer gauge block calibration by optical interferometry on the database, and, eventually, any other calibration services that stems out of this key technique.

The measurand is the central length of the gauge block as defined in [1]. The present comparison lasted less than one year from August 2018 to June 2019.

2. Participants

This bilateral comparison was planned by CENAM and INTI, who measured a total of eleven steel gauge blocks of different lengths in the range of short gauge blocks and long gauge blocks. NRC from Canada acted as independent laboratory to receive the results from the two participants. The Table 1 lists the information of the participating NMI.

Table 1. List of participants in comparison SIM.L-K1:2007.1.

Contact	NMI	Information
Carlos Colín Armando López Miguel Villesid	**CENAM,** Centro Nacional de Metrología km 4.5 Carretera a los Cués, El Marqués CP 76241, Querétaro, MEXICO	+52-442 2110574 / Fax +52-442 2110579 e-mail: ccolin@cenam.mx
Liliana Álvarez Ethel Beer Gastón Giarmana Karina Bastida	**INTI,** Instituto Nacional de Tecnología Industrial Metrología Física; Departamento de Óptica y Dimensional. Av. Gral. Paz 5445 B1650WAB – San Martín, Bs.As.; ARGENTINA**.**	(54) 11-4724-6264 Fax (54) 11-4713-4140 e-mail: ldalvarez@inti.gob.ar
Brian Eves	**NRC-INMS,** National Research Council Canada Institute for National Measurement Standards 1200 Montreal Road Building M-58 Ottawa, Ontario, K1A 0R6 CANADA	(613) 991-6853 Fax: (613) 952-1079 e-mail: brian.eves@nrc-cnrc.gc.ca

3. Circulation Schedule

The box containing the gauge blocks was transported personally by official personnel of INTI. The circulation of the artifacts had some delay mainly due to changes on the official mission schedule of the personnel who was in charge of the transportation. Each laboratory has approximately four weeks for measuring the gauge block set.

A circulation time of 6 months was initially scheduled and it took 9 months. Table 2 shows the actual dates of reception and shipment of the artifacts by the participants as well as the date of reception of the participant's results by the pilot laboratory.

Table 2. SIM.L-K1:2007.1 dates of reception and shipment of artifacts and reception of results by the pilot lab.

NMI	Dates		Reception of Results
	Reception	Shipment	
CENAM	06-08-2018	17-05-2019	03-07-2019
INTI (pilot)	22/05/2019		28-06-2019

4. Comparison Artefacts

The travelling standards were provided by INTI. A total of ten grade K (according to [1]) rectangular steel gauge blocks and one grade 0 gauge block were selected for the exercise. Eight grade K gauge blocks covering the range of short gauge blocks, from 0.5 mm to 100 mm were used. For covering the long gauge block range up to 300 mm, one grade 0 gauge block of 150 mm and two grade K gauge blocks of nominal length of 300 mm were considered.

The specifications of the gauge blocks are shown in tables 3 and 4. The associated Coefficients of Thermal Expansion (CTE) and their corresponding expanded uncertainties shown in the tables are those quoted by the manufacturers.

Table 3. Short Steel Gauge Blocks.

Nominal Length (mm)	Serial Number	Coefficient of Thermal Expansion (10^{-6} K^{-1})	Manufacturer
0,5	725292	11,5 ± 1	TESA
1,47	2425222	11,5 ± 1	TESA
2,5	525083	11,5 ± 1	TESA
6	290304	11,5 ± 1	TESA
10	180342	11,5 ± 1	TESA
25	3225200	11,5 ± 1	TESA
50	1825134	11,5 ± 1	TESA
100	1425351	11,5 ± 1	TESA

Table 4. Long Steel Gauge Blocks.

Nominal Length (mm)	Serial Number	Coefficient of Thermal Expansion (10^{-6} K^{-1})	Manufacturer
150*	87338	11,2 ± 1	KOBA
300	HW logo	11,5 ± 1	Hommel Werke
300	110115	10,8 ± 0,5	Mitutoyo

*grade 0

5. Measurement Protocol

Detailed measurement instructions were included in the comparison protocol. The gauge blocks were supposed to be measured wrung to the platens that the participant laboratories currently use to offer their gauge block calibration service.

Gauge block calibration by optical interferometry should be performed with the gauge blocks in vertical position wrung to a platen as indicated in [1]. The gauge block central length, l_c, is the perpendicular distance between the central point of the free measurement surface of the gauge block and the surface where it is wrung.

The values asked to be reported in the protocol were the deviations from nominal length, l_n, determined at the center for each measuring face "A" and "B", $e_{cX} = l_c - l_n$, (where X = "A" or "B"); the average of both values, e_{avg}; the so called phase change correction, Δl_ϕ; and the corrected average deviation after applying the phase change correction, e_c. For long gauges blocks an additional correction due to compression, Δl_C, is considered [2].

The method most commonly used to determine the phase change correction, Δl_ϕ is the stack method and it is described in **Annex A,** [3].

6. Measuring Instruments

Both participant laboratories measured the gauge blocks by optical absolute interferometry applying the method of exact fractions, [4]. Table 5 details the systems used, light sources, traceability and temperature conditions of the laboratories.

Table 5. Gauge block interferometers, laser sources, traceability and temperature variation of the participant laboratories.

NMI	Manufacturer and Type of Interferometer	Light sources and wavelengths used	Traceability	Temperature variation range during measurements (°C)
CENAM	NPL-TESA, Twyman-Green	He-Ne ~633 nm TESA laser, He-Ne ~543 nm TESA laser	To the Mexican realization of the metre: A ~633 nm Iodine-stabilized laser	19.85 – 20.13
INTI	NPL-TESA, Twyman-Green	He-Ne ~633 nm TESA laser, He-Ne ~543 nm TESA laser	To the realization of metre through 633 nm Iodine stabilized He-Ne laser (INTI 1)	According to PEO01

7. State and Behavior of Artifacts

7.1 State of the Artifacts upon Reception

The participants inspected the state of the artifacts upon reception. They were asked to document any scratches and other damage to the measurement surfaces with a drawing, which are included in **Annex B**, and inform to both the neutral and the pilot laboratories according to the protocol. Although the selected gauge blocks were not brand new, they were in good conditions. They do not seem to suffer any damage on the transportation. Small spots and some slight scratches could be observed on the surfaces but this degradation must be considered to be normal in the course of a comparison.

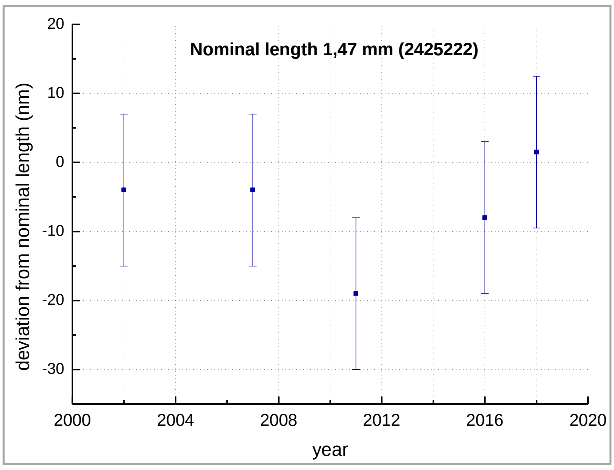
7.2 Stability of the Standards

The stability of the gauge blocks was monitored by different calibrations performed by the pilot laboratory (INTI) during several years before the current bilateral comparison. Most of the short gauge block interferometric measurements were carried out on 2002, 2007, 2011, 2016 and 2018. For 10 mm, 50 mm and 100 mm extra measurements on 2009 were performed. Table 6 shows the deviations from nominal length determined at these different occasions for the short steel gauge blocks.

Table 6. Short steel gauge block measurements before the current comparison

Nominal Length (mm)	Serial Number	Deviation from nominal value (nm)					
		2002	2007	2009	2011	2016	2018
0,5	725292	31	19		29	28	39
1,47	2425222	-4	-4		-19	-8	2
2,5	525083	27	17		16	21	32
6	290304	57	45		46	48	62
10	180342	-22	-14	-28	-31	-28	-21
25	3225200	52	40		20	22	31
50	1825134	63	69	30	38	29	36
100	1425351	41	18	-20	-12	-38	-6

Figure 1 a) through h) show the changes observed over these years for each gauge block. The uncertainty bars are standard uncertainties.



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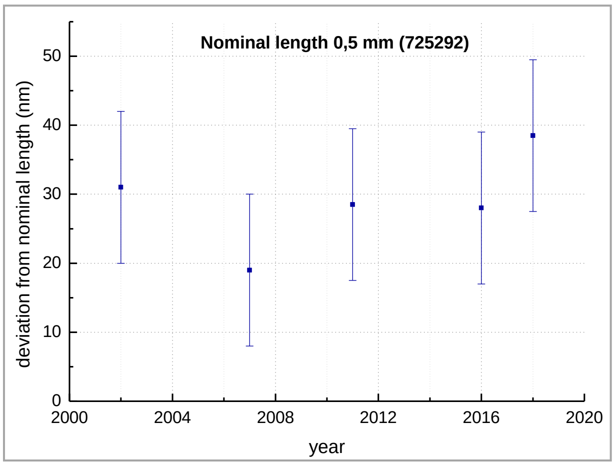

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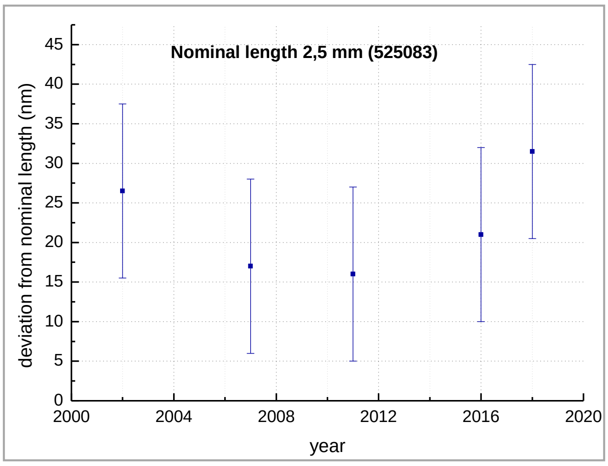

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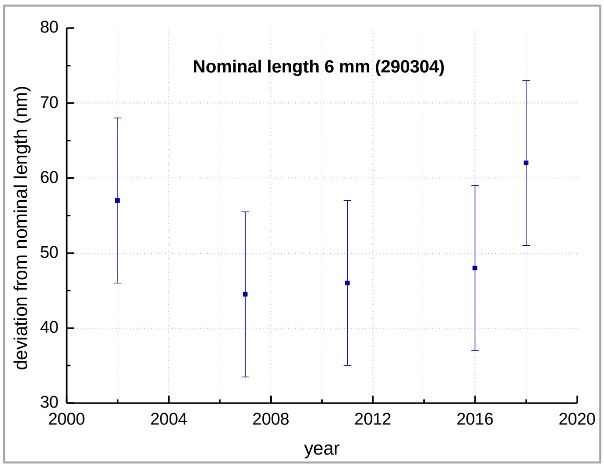

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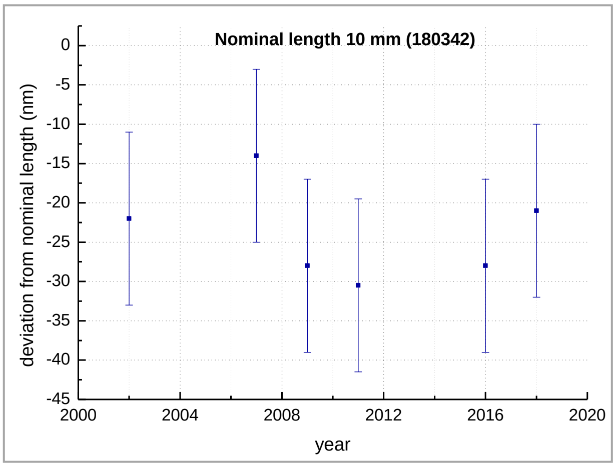

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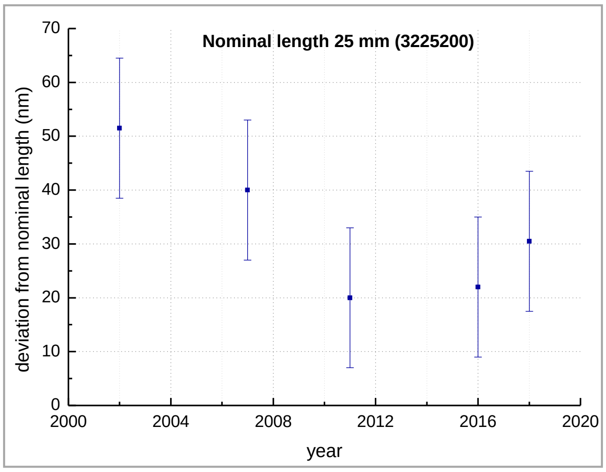

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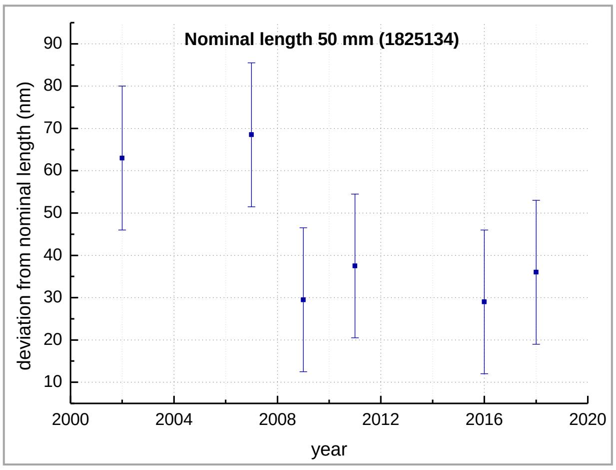

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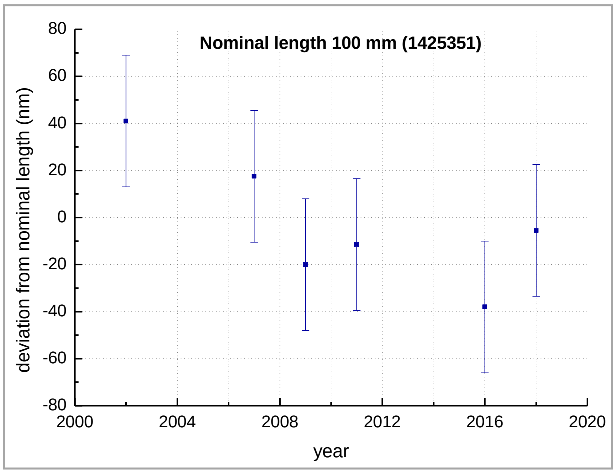


h)

Figure 1. a) to h) Short steel gauge block measurements before the current comparison for monitoring the stability.

In the case of long gauge blocks, there is an old 300 mm-length gauge block with measurement from 2008. This artifact was calibrated by mechanical comparison in 2008 and 2014 with higher standard uncertainty. Regular interferometric calibrations were performed by the pilot laboratory on 2009, 2011, 2012, 2014, 2016 2017 and 2018. A second newer 300 mm-length gauge block was measure since 2012, and in this case also the stated value on the manufacturer certificate was considered.

Table 7 shows the deviations from nominal length determined at these different occasions for this set of gauge blocks, including the stated values on the certificates of the manufacturer for the 150 mm and the second 300 mm gauge blocks.

Table 7. Long steel gauge block measurements before the current comparison

Nominal Length (mm)	**Serial Number**	**Deviation from nominal value** (nm)										
		2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
150	87338			-300*					-190†		-276	-275
300	HW	420†	349		439	384		459 440†		559	443	576
300	110115				157*	146	162	86	47	36	36	38

*manufacturer certificate †mechanical calibrations

Figure 2 a) through c) show the variations observed over these years for each gauge block. The uncertainty bars are standard uncertainties.

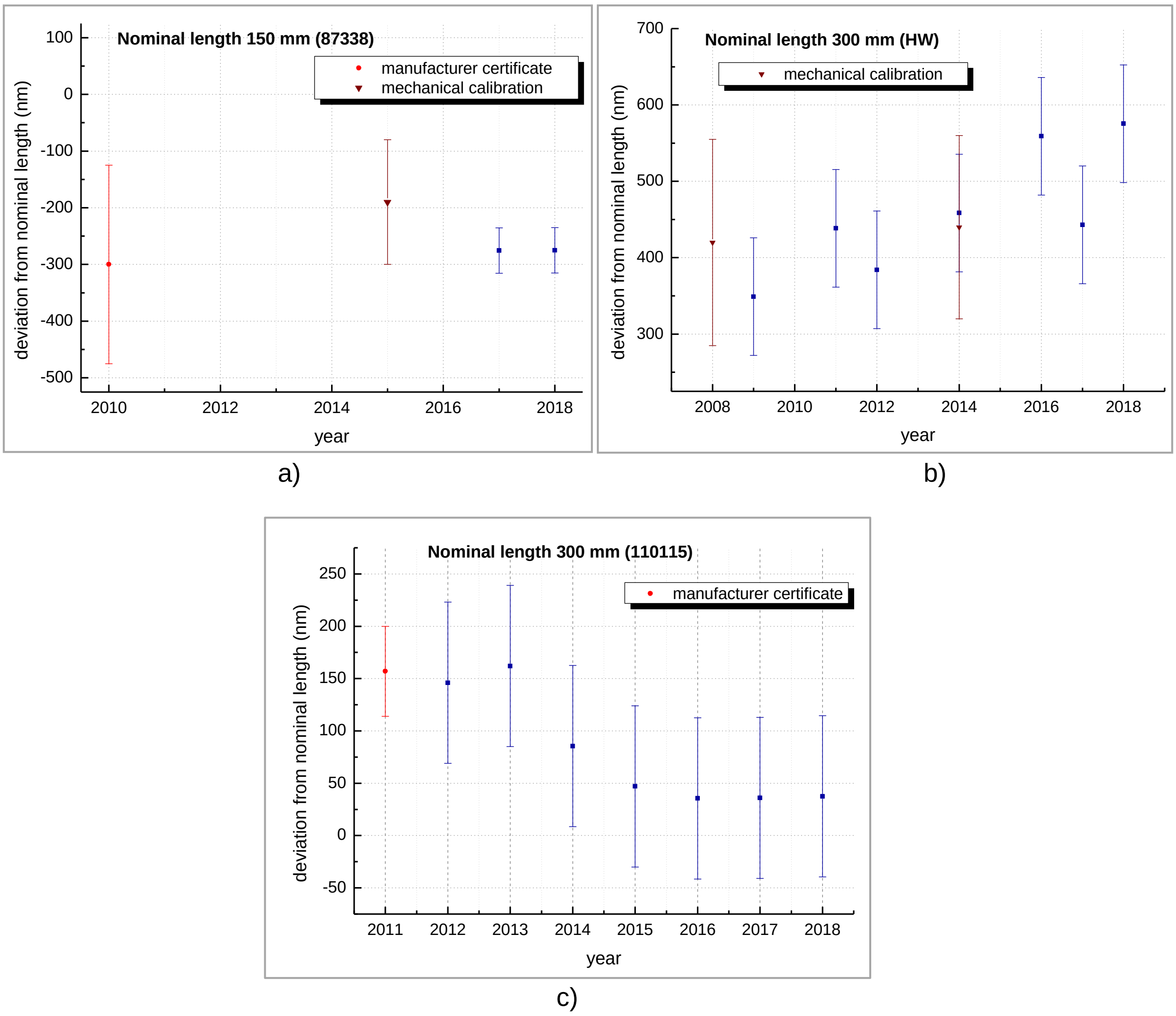


Figure 2. a) to c) Long steel gauge block measurements before the current comparison for monitoring the stability.

8. Measurement Results of Participants

The two laboratories sent their results by e-mail to the neutral and the pilot laboratory. All information was received on the specified formats from appendices A, B, C, D and E of the Technical Protocol.

8.1 Measurement of the Central Length

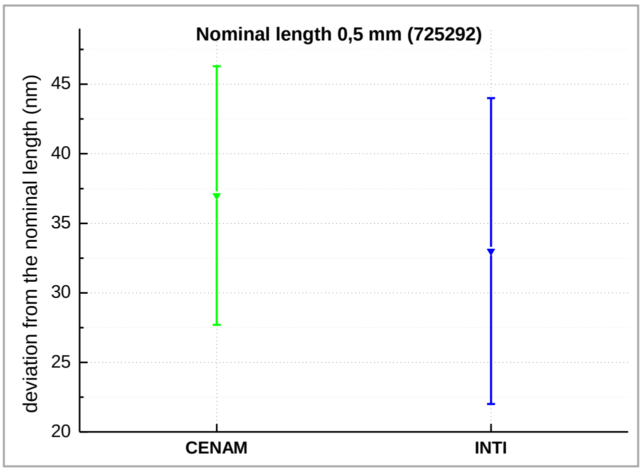
Table 8 shows the deviations of the central length with respect to nominal values of each participant for the short steel gauge blocks measured in this bilateral comparison.

Also all individual measurements carried out by the metrologists at each NMI participant were compared in Annex C. CENAM participates with two individual measurements; CENAM 1 and CENAM 2, while INTI contributes with three individual measurements, INTI 1, INTI 2 and INTI 3. These measurements were analyzed considering the criteria described in section 9, where *n* in this case is 5.

Table 8. Measurement results of the participants for the short steel gauge blocks.

Nominal Value (mm)	**Serial number**	**Deviation from nominal length for short steel gauge blocks** (nm)	
		CENAM	**INTI**
0,5	725292	37	33
1,47	2425222	1	-1
2,5	525083	33	28
6	290304	47	48
10	180342	-21	-28
25	3225200	30	24
50	1825134	27	27
100	1425351	-26	-31

Figure 3 a) through h) show the deviation from the nominal length measured and informed by the both laboratories for the short gauge blocks range. The uncertainty bars are standard uncertainties.



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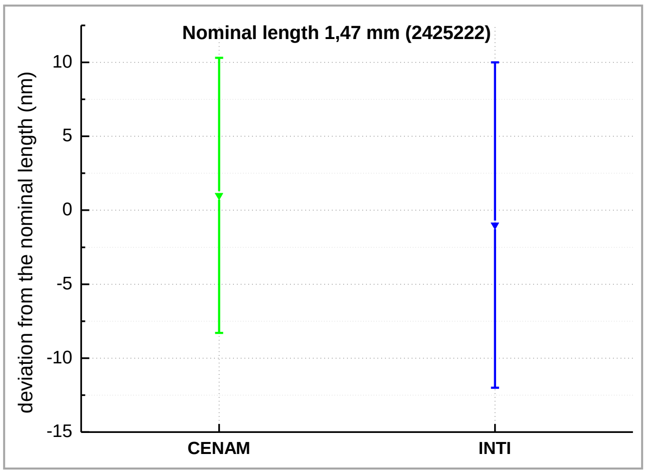

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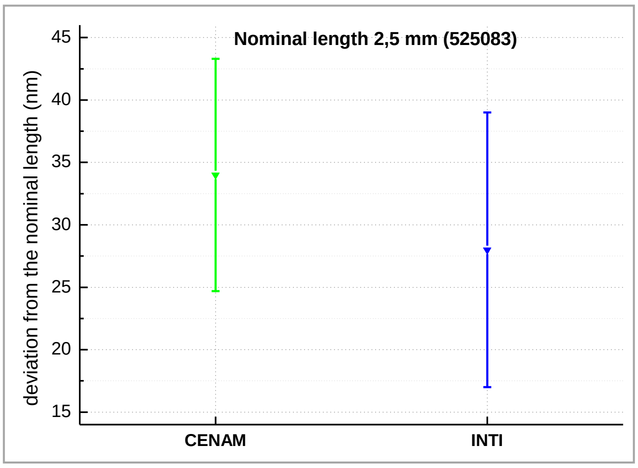
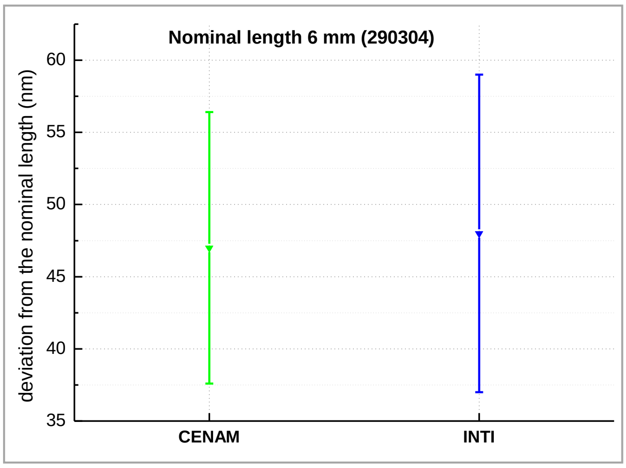


c)



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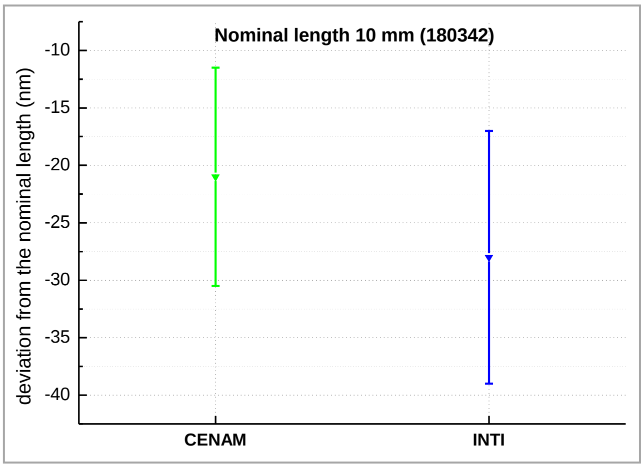

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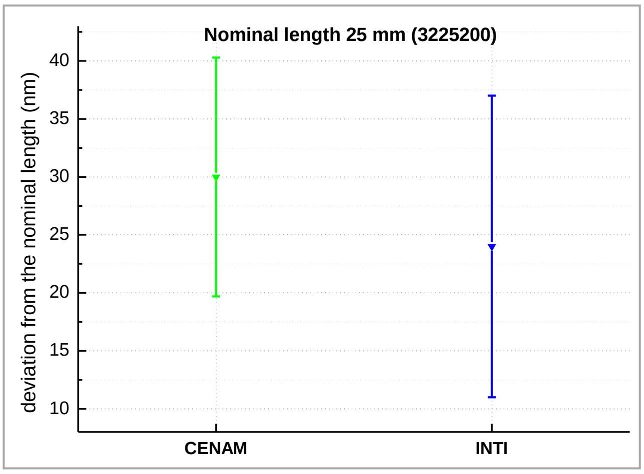

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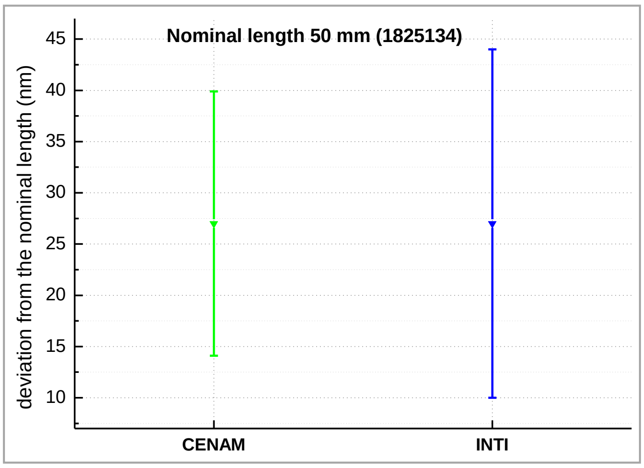

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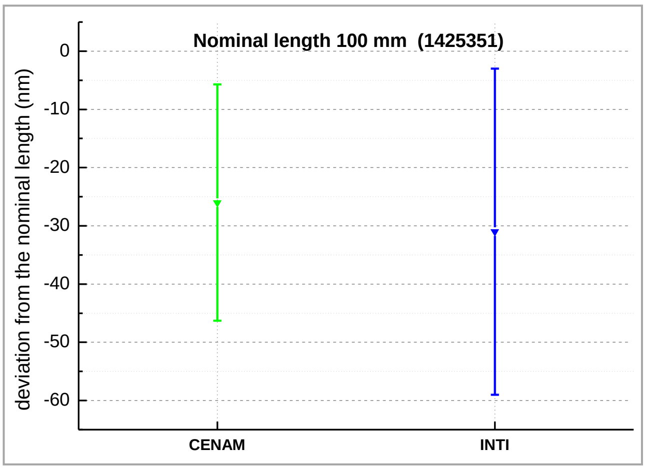


h)

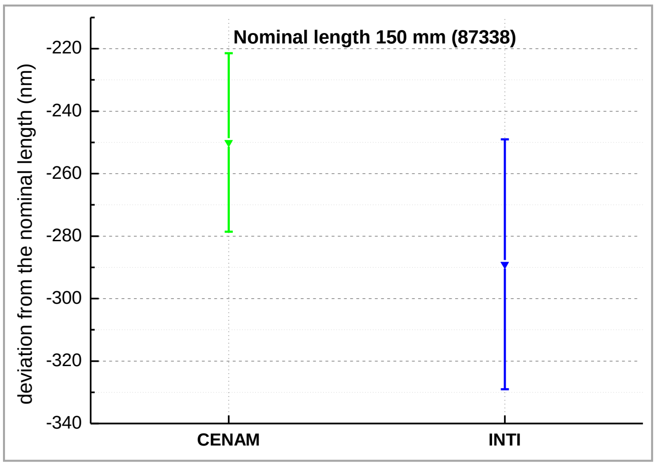
Figure 3. a) to h) deviation from the nominal length measured by the both laboratories for the short gauge blocks range.

Table 9 shows the deviations of the central length with respect to nominal values of each participant for the long steel gauge blocks measured in this bilateral comparison.

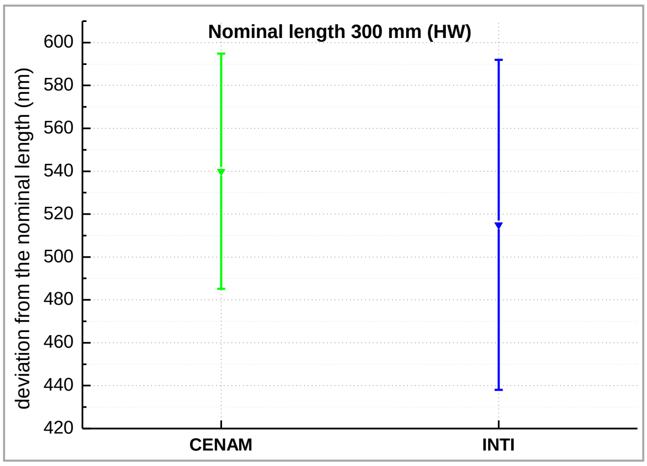
Table 9. Measurement results of the participants for the long steel gauge blocks.

Nominal Value (mm)	**Serial number**	**Deviation from nominal length for short steel gauge blocks** (nm)	
		CENAM	**INTI**
150	87338	-250	-289
300	HW	540	515
300	110115	-12	-11

Figure 4 a) through c) show the deviation from the nominal length measured by the both laboratories for the long gauge blocks range. The uncertainty bars are standard uncertainties.



a)



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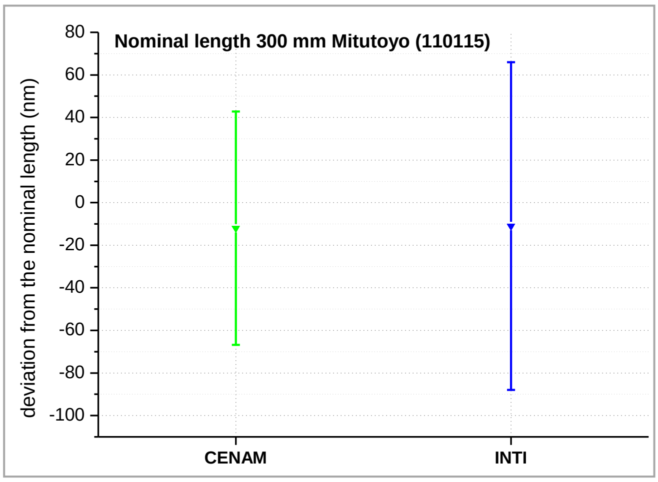


c)

Figure 4. a) to c) deviation from the nominal length measured by the both laboratories for the long gauge blocks range.

Table 10 shows the claimed standard measurement uncertainties by the two participants for the gauge block set used in this comparison. These standard uncertainties are shown in the Figure 5.

Table 10. Claimed standard uncertainties of the participants.

Nominal Value (mm)	**Claimed standard uncertainties** (nm)	
	CENAM	INTI
0,5	9,3	11
1,47	9,3	11
2,5	9,3	11
6	9,4	11
10	9,5	11
25	10,3	13
50	12,9	17
100	20,3	28
150	28,6	40
300	54,8	77

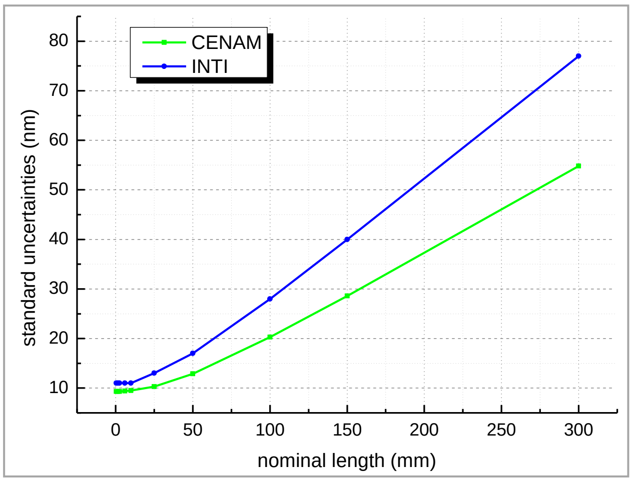


Figure 5. Claimed standard uncertainties by the two participants.

8.2 Measurement Difference of Length between the Two Measuring Faces

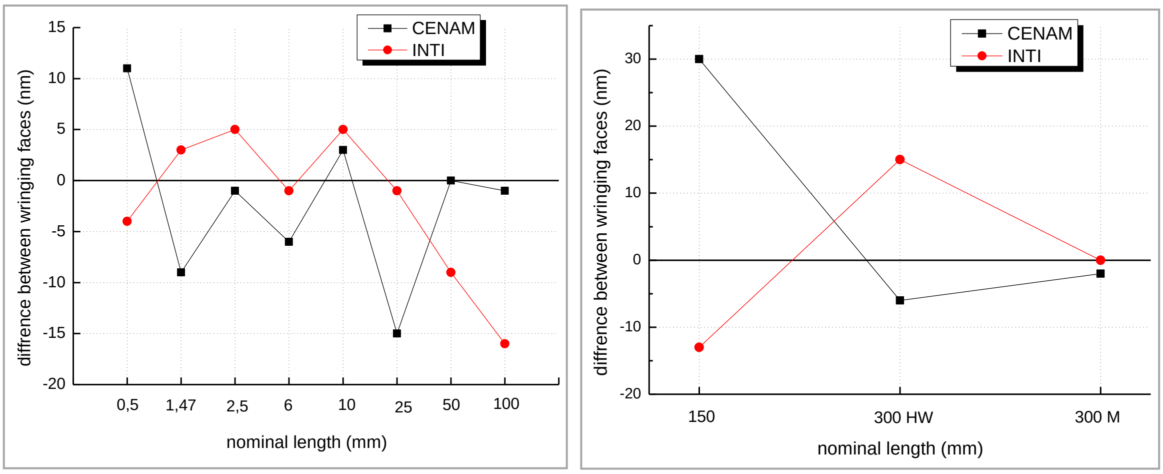
The protocol also asked to report the length measured on each of the measuring faces. Tables 11 and 12 show the differences between the two wringing faces for each laboratory on both gauge block ranges considered. Figures 6 (a) shows the differences between left and right wringing faces for all short gauge blocks, and b) shows this difference for long gauge blocks.

Table 11. Differences between measured faces for the short steel gauge blocks.

Nominal Value (mm)	**Serial number**	**Difference between the two wringing faces** (nm)	
		CENAM	**INTI**
0,5	725292	11	-4
1,47	2425222	-9	3
2,5	525083	-1	5
6	290304	-6	-1
10	180342	3	5
25	3225200	-15	-1
50	1825134	0	-9
100	1425351	-1	-16

Table 12. Differences between measured faces for the long steel gauge blocks.

Nominal Value (mm)	**Serial number**	**Difference between the two wringing faces** (nm)	
		CENAM	**INTI**
150	87338	30	-13
300	HW	-6	15
300	110115	-2	0



a) b)

Figure 6. Differences between wringing faces for
a) short and b) long gauge block range.

Table 13 shows the standard deviation and the absolute maximum value of the differences between the two wringing faces, for both laboratories for all the gauge blocks. Any difference might be interpreted as the quality of the wringing surfaces of the gauge blocks; the quality of the auxiliary wringing surface and the ability of the technician to repeatedly wring, [2,4]. Figure 7 shows the absolute values of these differences for the participants on every gauge block.

Table 13. Standard deviation and absolute maximum value
of the differences between left and right wringing faces.

Laboratory	**Short range**		**Long range**	
	Absolute maximum value (nm)	Stdev (nm)	Absolute maximum value (nm)	Stdev (nm)
CENAM	15	7,87	30	19,73
INTI	16	7,30	15	14,01

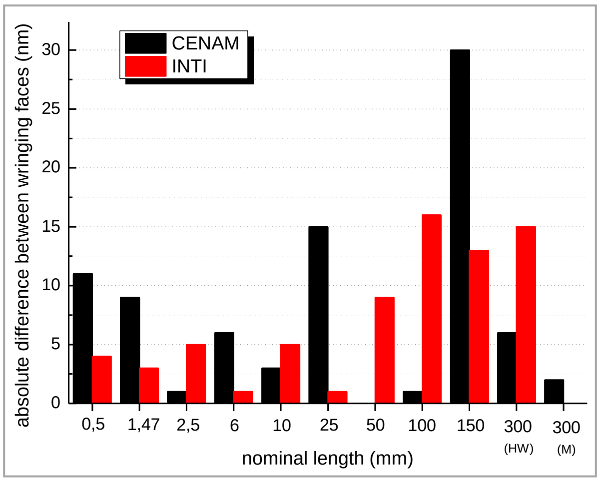


Figure 7. Absolute differences between
wringing faces for each gauge block.

8.3 Phase-change Correction

The two participating laboratories applied the stack method to determine the phase-change correction. Table 14 summarizes the kind of platens the participants used and the phase-change correction values they measured and submitted.

Table 14. Phase-change correction of participants.

Participant	Steel Gauge Blocks	
	Platen material	Phase-change correction (nm)
CENAM	Steel (PL-43)	2
INTI	Steel (106)	-22

For long gauge blocks CENAM used the value indicated in Table 14 for phase change correction, while INTI considered this value only for the 300 mm-HW-gauge block which has the same thermal expansion coefficient value as the sort gauge blocks. For the other two gauge blocks in the long range, INTI indicated that it used phase change corrections obtained from different sets with the same value of the thermal expansion coefficient. Thus for 150 mm length the phase change correction was -29 nm and for 300 mm-length (Mitutoyo) this correction was -18 nm, [3].

8.4 Other Correction

For the long gauge blocks also a deformation correction due to compression were considered by both participants. Table 15 summarizes the values for this correction they submitted.

Table 15. Deformation correction due to compression.

Nominal Value (mm)	Serial number	Deformation due compression (nm)	
		CENAM	INTI
150	87338	5	4
300	HW	17	16
300	110115	17	17

9. Analysis Method

9.1 Key Comparison Reference Value (KCRV) Determination

All usual parameter of the central tendency the simple mean was calculated. Thus, the KCRV is determined, for each gauge block j, as the simple mean $\bar{e}_j$ between both participants:

$$\overline{e_j} = \frac{\sum_{i=1}^{2} e_{ij}}{n} \quad (1)$$

where: e_{ij} is the deviation from nominal value of participant i, $i= 1,2$ on gauge block j

n is the number of participants, in this case 2

The aim of this analysis is to find the degree of equivalence between the measurement performed by CENAM and INTI. Based on that procedure, the degrees of equivalence is evaluated by calculating the following two parameters, [5,6,7]:

- $|d_{ij}|$ the absolute deviation from the mean of participant i on GB j;
- E_{Nij} the normalized error of participant i on GB j defined as

$$E_{Nij} = \frac{|d_{ij}|}{U_{d_{ij}}} \qquad (2)$$

where $U(d_{ij})$ is the expanded uncertainty of deviation d_{ij}, computed as:

$$U(d_{ij}) = 2 \cdot \sqrt{u^2(e_{ij}) + u^2(\overline{e_j}) - \frac{2}{n}\, u^2(e_{ij})} \qquad (3)$$

If $E_{Nij} > 1$ it is considered that the result is not consistent. For this bilateral comparison all the measurements resulted consistent.

9.2 KCRV uncertainty

The standard uncertainty corresponding to the reference value for each gauge block is given by the combined standard uncertainty of the simple mean, or internal uncertainty, of the both results:

$$u_{int}(\bar{e}_j) = \frac{1}{n}\sqrt{\sum_{i=1}^{n} u^2(e_{ij})} \qquad (4)$$

This value is used to calculate $u(\bar{e}_j)$ in equation (3) in the previous section, i.e. $u(\bar{e}_j) = u_{int}(\bar{e}_j)$.

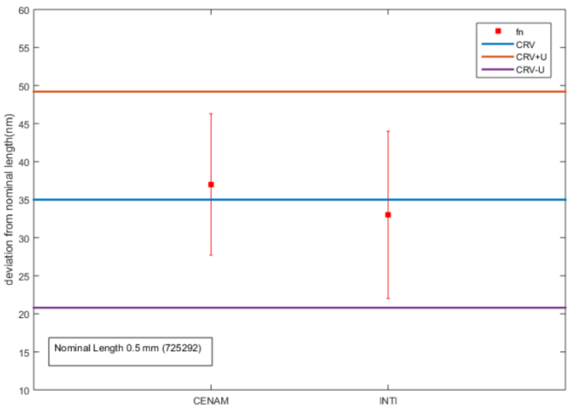
10. Results of the Comparison

10.1 KCRV Determination

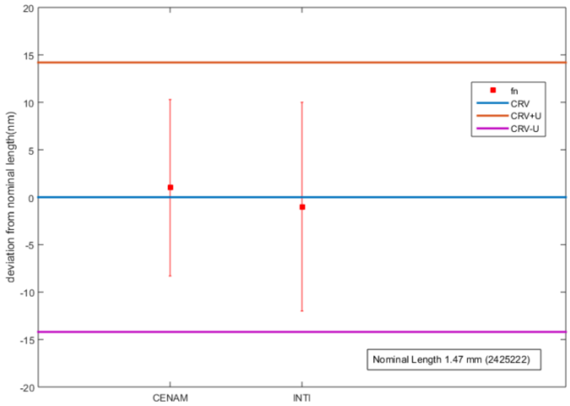
The reference values, $\bar{e}_j$, their expanded uncertainties, $U(\bar{e}_j)$, are shown in Table 16. Figure 8 a) to h) shows the deviations from the nominal lengths and their uncertainties in comparison with the reference comparison values and their expanded uncertainties for both participants in the short gauge block.

Table 16. Key Comparison Reference Values and corresponding standard and expanded uncertainties

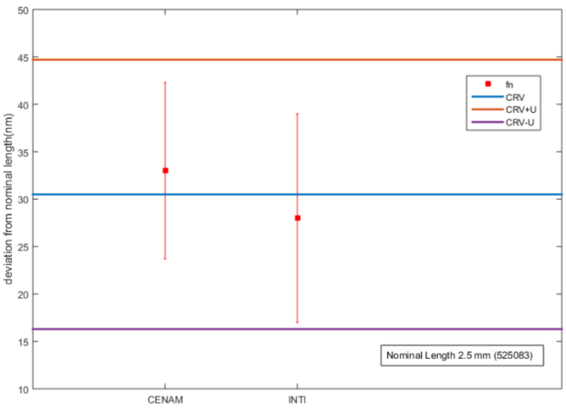
Key Comparison Reference Values				
Nominal Length	**Serial number**	***KCRV,*** $\bar{e}_j$ (nm)	$u(\bar{e}_j)$ (nm)	$U(\bar{e}_j)$ (nm)
0,5	725292	35,0	7,2	14,4
1,47	2425222	0,0	7,2	14,4
2,5	525083	30,5	7,2	14,4
6	290304	47,4	7,2	14,5
10	180342	-24,5	7,3	14,5
25	3225200	27,0	8,3	16,6
50	1825134	27,0	10,7	21,3
100	1425351	-28,5	17,3	34,6
150	87338	-269,5	24,6	49,2
300 (HW)	HW	527,5	47,3	94,5
300 (M)	110115	-11,5	47,3	94,5



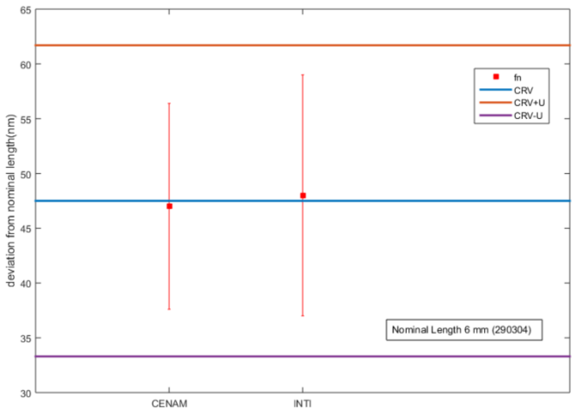
a)



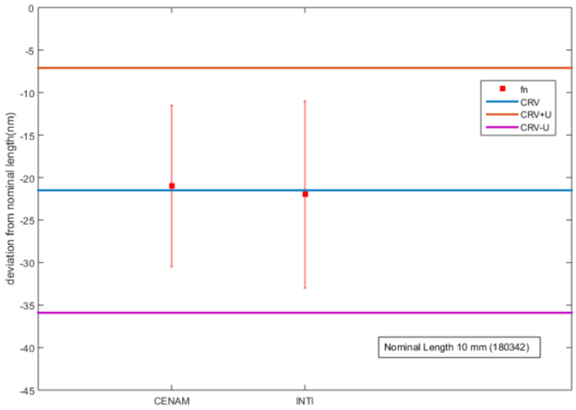
b)



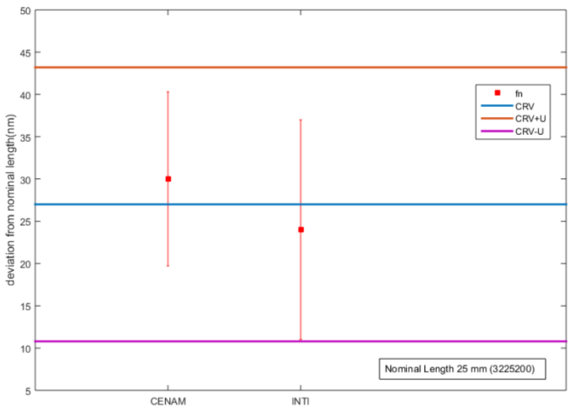
c)



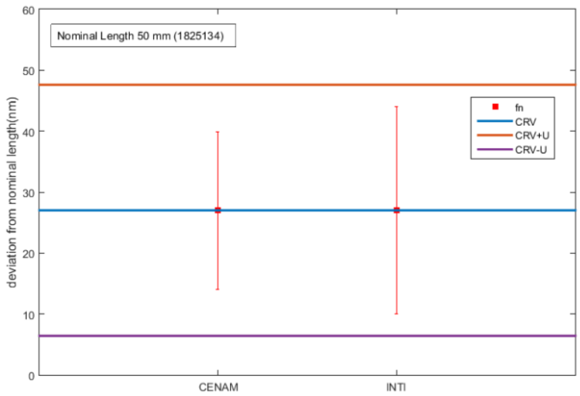
d)



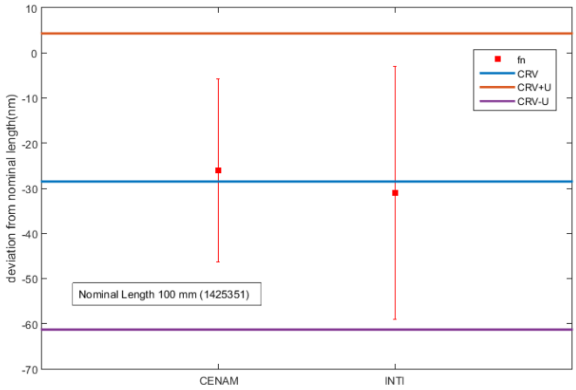
e)



f)



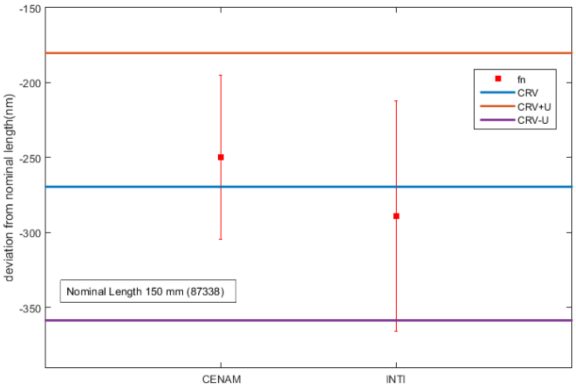
g)



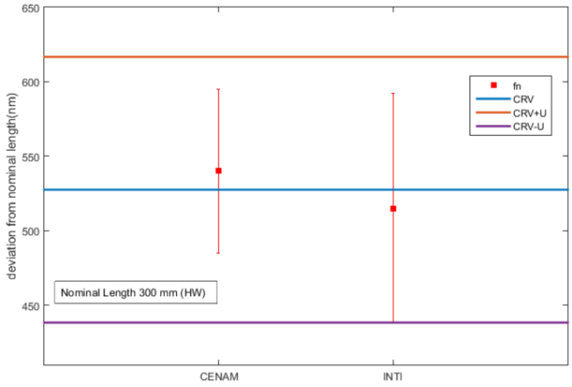
h)

Figure 8. a) to h) deviation from the nominal length measured by the both laboratories for the short gauge blocks range, reference comparison values and expanded uncertainties.

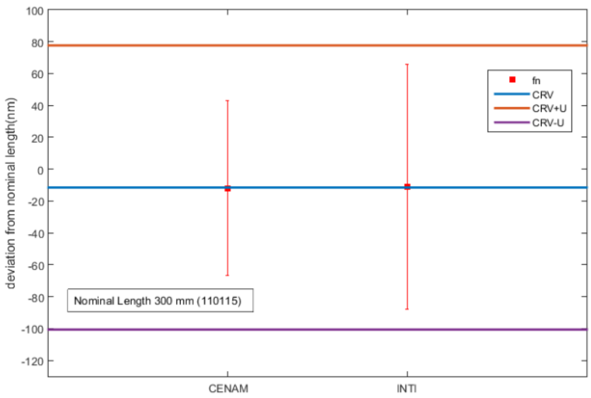
Figure 9 a) to c) shows the deviations from the nominal lengths and their uncertainties in comparison with the reference comparison values and their expanded uncertainties for both participants in the long gauge block.



a)



b)



c)

Figure 9. a) to c) deviation from the nominal length measured by the both laboratories for the long gauge blocks range, reference comparison values and expanded uncertainties.

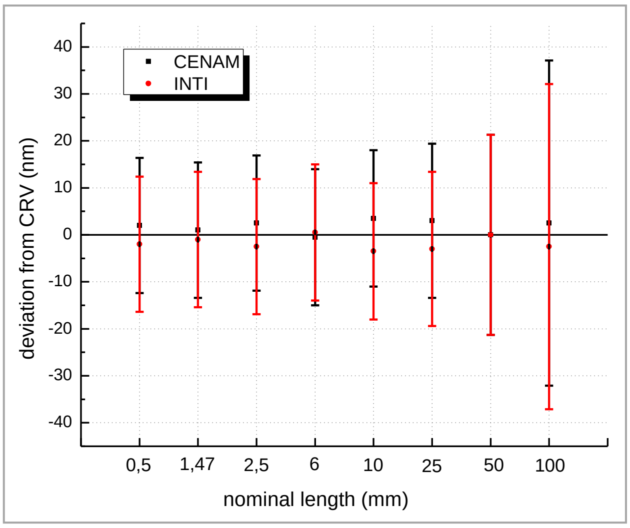
10.2 Participants Results

Table 17 shows the differences of the results of the participants with respect to the Comparison Reference Values of each gauge block j, d_{ij} ; along with the expanded uncertainty of these differences, $U(d_{ij})$; and the corresponding normalized error, E_{Nij}.

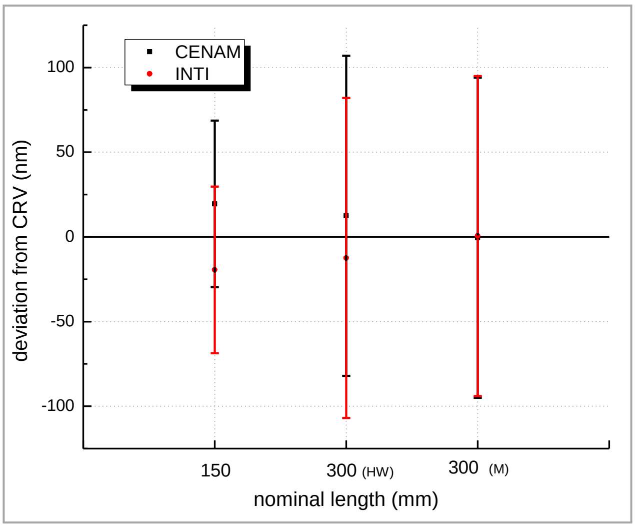
Table 17. Deviations from KCRV for each gauge block, d_{ij};
claimed expanded uncertainty $U_{ij;}$ and normalized error, E_{Nij}

NMI l ->		CENAM			INTI		
Nominal Length	**Serial number**	d_{ij} (nm)	$U_{ij}(d_{ij})$ (nm)	E_{Nij}	d_{ij} (nm)	$U_{ij}(d_{ij})$ (nm)	E_{Nij}
0,5	725292	2,0	14,4	0,14	-2,0	14,4	0,14
1,47	2425222	1,0	14,4	0,07	-1,0	14,4	0,07
2,5	525083	2,5	14,4	0,17	-2,5	14,4	0,17
6	290304	-0,5	14,5	0,03	0,5	14,5	0,03
10	180342	3,5	14,5	0,24	-3,5	14,5	0,24
25	3225200	3,0	16,6	0,18	-3,0	16,6	0,18
50	1825134	0,0	21,3	0,00	0,0	21,3	0,00
100	1425351	2,5	34,6	0,07	-2,5	34,6	0,07
150	87338	19,5	49,2	0,40	-19,5	49,2	0,40
300	HW	12,5	94,5	0,13	-12,5	94,5	0,13
300	110115	-0,5	94,5	0,01	0,5	94,5	0,01

Figure 10 shows the deviation from the reference value together with the expanded uncertainties for the gauge block set measured in this comparison, a) for short range and b) for long range.



a)



b)

Figure 10. Deviation from the KCRV and the expanded uncertainties,
a) Short gauge blocks, b) Long gauge blocks.

11. Conclusions

- The results of both laboratories were satisfactory for all artifacts, since all the results had E_{Nij} less than 1. This proves the technical competence of the participants and supports their claimed CMCs.

- No length-dependence on E_{Nij}, is observed so it is assumed that length dependence contribution as thermal measurement, thermal compensation and/or refraction index, does not affect the measurements.

- The worst value of E_{Nij} is 0,40. It corresponds to 150 mm-length gauge block. By considering the difference wringing faces, Section 8, the maximum difference was obtained for this gauge block, so it might be wringing effect associated. Despite this the measurement is accounted as satisfactory.

- No outlier was detected so no elimination process should have been applied. All the results reached adequate E_{Nij} therefore proving consistency of results.

- From Section 7 we observe that there were no appreciable changes on the measurements performed by the pilot laboratory of the ensemble of the GB over the last ten years, except for the 300 mm length gauge blocks, which will be analyzed separately. Even though some drift may be appreciated on the most of the gauge blocks during their first years of their history, the values shown prove they reached stability since 2008 approximately. Therefore, it can be assumed that the artifacts behaved adequately during the comparison exercise and that the exercise was valid.

- The 300 mm-HW gauge block presents a noticeable positive drift. This artifact is about eleven years old. Even though the observed drift both results are consistent, with absolute normalized error value of 0,13.

- The newest gauge block used in this comparison is the Mitutoyo 300 mm-length, which is seven years old. This gauge block shows a stepped drift. In base of the measurement of this comparison it is observed that the second stepped drift happened between the last measurement before the departure of the artifacts and the CENAM's measurement. The deviation from the nominal length dropped about 49 nm in the last year. This result is one of the most consistent since the low values of the normalized error.

- The two participants measured different change phase corrections. CENAM considered positive correction while INTI measured a negative correction. It must be outlined that the application of such corrections, prescribed in the international standards, is most important, not only to take into account any differences in the material, but also the different surface roughness of the gauge blocks and the platens. Therefore it assumed that the auxiliary platens used by the laboratories have very different characteristics.

- It is interesting to note, that of both laboratories uses the same make of interferometer (nearly duplicate systems). During this comparison two technician from CENAM and three from INTI performed the measurement. In view of the results of this comparison exercise all the technician measurements will be analyzed in order to investigate factors such as wringing skill, phase correction, quality of reference platen and calibration of the instruments used to measure the influence quantities.

12. References

1. **ISO 3650:1998(E)**, *Geometrical Product Specification (GPS) – Length Standards – Gauge Blocks*, International Organization for Standardization, Geneva, Switzerland.
2. **Decker J., Ulrich A., Lapointe A., Viliesid M., Pekelsky J. R.**, *Two-part Study towards Lowest Uncertainty Calibration O Ceramic Gauge Blocks: Interferometry And Mechanical Comparison Techniques*, en *Recent Developments in Traceable Dimensional Measurements*, Proceedings of *SPIE – The International Society for Optical Engineering*, **Vol. 4401** presented at Munich, Germany, June 2001.
3. **E Beer, L Álvarez, K Bastida, G Giarmana and L Di Lillo,** *Experimental study of phase correction determination in steel by stacking method experiment,* 2018 J. Phys.: Conf. Ser.975 012030 https://doi.org/10.1088/1742-6596/975/1/012030
4. **Decker, J.E. and Pekelsky, J.R., 1997**, *Uncertainty Evaluation for Mesurement of Gauge Blocks by Optical Interferometr*y, Metrologia, **34**, 479-493. [NRC Document No. 41374].
5. **Cox, M.G.**, 2002, *The evaluation of key comparison data*, *Metrologia*, 2003, **39**, pp 589-595.
6. **Beissner, K.**, 2002, *On a measure of consistency in comparison measurements*, *Metrologia*, 2003, **39**, pp 59-63.
7. **Kacker, R., Datla, R., Parr, A.**, 2002, *Combined result and associated uncertainty from interlaboratory evaluations based on the ISO Guide*, *Metrologia*, 2003, **39**, pp 279-293.

Annex A Phase Change Correction Determination by the Stack Method

A method usually applied to determine Δl_ϕ is the stack method where three or more GB are measured individually and then measured wrung together into a stack as shown in Figure 1. From these measurements the global phase change correction for this set of GB may be obtained as follows:

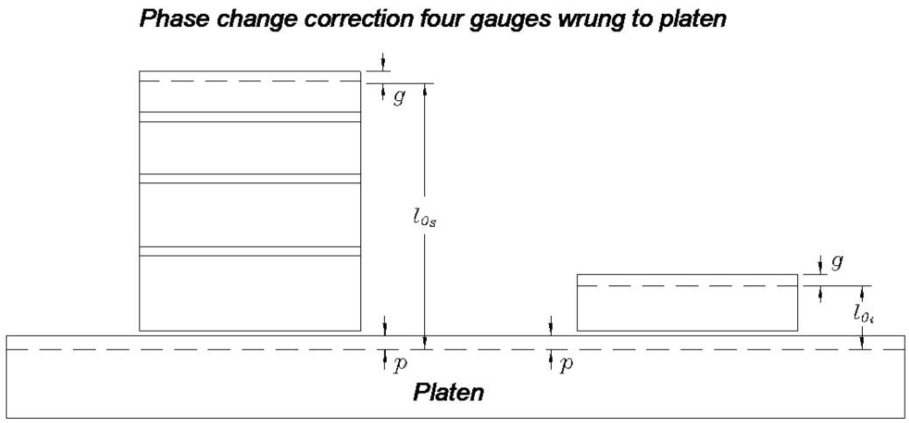


Figure 1. Stack method measurements to derive Δl_ϕ. g represents the difference between the optical plane and the mechanical plane of the GB free surface, and p represents this difference between planes for the platen.

$$\Delta l_\phi = \frac{l_{O_S} - \sum_{i=1}^{N} l_{O_i}}{N-1} \tag{A1}$$

Where***:***

l_{Os} – Optical central length of the stack.

l_{Oi} – Optical central length of the i^{th} individual GB, $i = 1,2,...,N,$ of the stack.

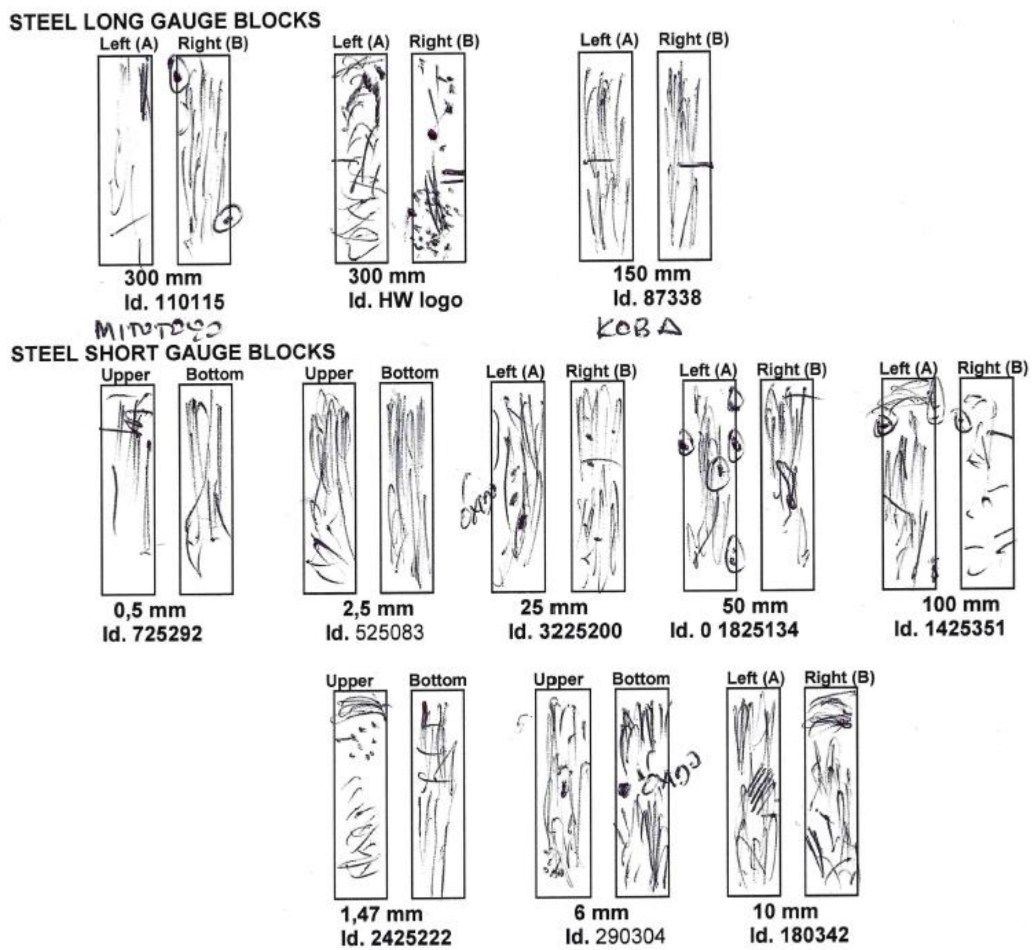
N – Number of gauge blocks in the stack.

Annex B Condition on Measuring Faces

This part includes the participant's (CENAM and INTI) reports "Annex B: Physical Conditions of the Gauge Blocks upon Reception"

Annex B: Physical Conditions of the Gauge Blocks upon Reception

After a detailed inspection of the measurement surfaces of the gauge blocks these are the results:



Observations:

Laboratory: CENAM

Date: 2018-08-27 **Name and Signature** CARLOS COLIN C.

Page 1/1

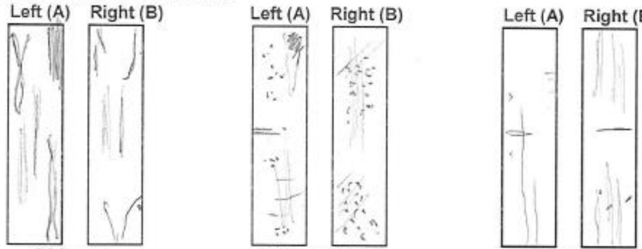
11

Annex B: Physical Conditions of the Gauge Blocks upon Reception

After a detailed inspection of the measurement surfaces of the gauge blocks these are the results:

STEEL LONG GAUGE BLOCKS

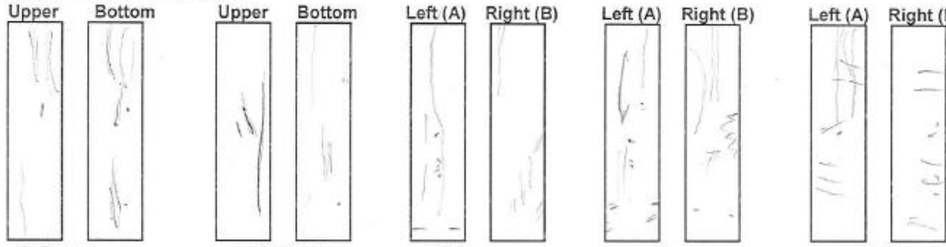
Left (A) Right (B) | Left (A) Right (B) | Left (A) Right (B)



300 mm Id. 110115 | 300 mm Id. HW logo | 150 mm Id. 87338

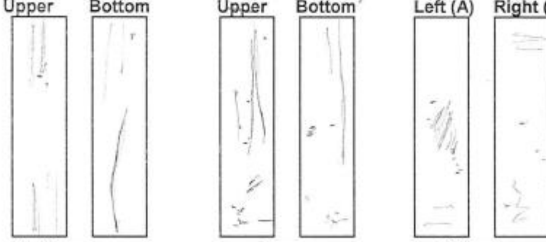
STEEL SHORT GAUGE BLOCKS

Upper Bottom | Upper Bottom | Left (A) Right (B) | Left (A) Right (B) | Left (A) Right (B)



0,5 mm Id. 725292 | 2,5 mm Id. 525083 | 25 mm Id. 3225200 | 50 mm Id. 0 1825134 | 100 mm Id. 1425351

Upper Bottom | L(A) Upper R(B) Bottom | Left (A) Right (B)



1,47 mm Id. 2425222 | 6 mm Id. 290304 | 10 mm Id. 180342

Observations:

Laboratory: Instituto Nacional de Tecnologia Industrial, INTI

Date: 28/06/2019 Name and Signature Liliana Alvarez [signature]

Page 1/1

11