Directorate of Measures and Precious Metals

EURAMET Project #1283

Calibration of Gauge Blocks by Mechanical Comparison

Final Report

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DMDM, Serbia
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Content

1 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.
In order to create network of metrology laboratories, to establish their technical performance and to stimulate knowledge transfer in the countries of Western Balkan and Turkey, at the meeting for pre-PT training in June 2012 of the Instrument for Pre-Accession Assistance (IPA), it was decided to conduct an intercomparison on short gauge blocks by mechanical comparison with the purpose of providing metrology laboratories in the countries of Western Balkan with exercise in participating in an intercomparisons.
This comparison was undertaken to verify the competence of participating laboratories in mechanical gauge block calibrations up to 100 mm length.
The initiative for this comparison was taken by the IPA.
DMDM (RS) acts as a pilot laboratory with substantial help of UM-FS/LTM (SI)
It is expected that this comparison will provide a basis for these countries for further participation in MRA gauge block comparisons and to identify the problems that may occur in their laboratories during gauge block calibrations.
The protocol used was adapted from EUROMET supplementary comparisons 601 (EUROMET.L-S12) and 797 (EUROMET.L-S16) with small changes.

2 Organization

The technical protocol was drafted by the pilot laboratory, DMDM Serbia with assistance from UM-FS/LTM, Slovenia. The technical protocol was issued to all participants prior to commencement of the comparison.
DMDM operateed as a pilot laboratory for the comparison.

2.1 Participants

The list of participants was prepared by the pilot laboratory after the IPA pre-PT meeting.
The participating laboratories with contact information are listed in Table 1.

Country (code)	Laboratory	Contact	Address	
Albania (AL)	DPMK	Vjolica Dedolli	General Directorate of Metrology Street Sami Frasheri 33 Tirana	Tel : +355692331580 e-mail: vjollca.dedolli@dpmk.gov.al
Croatia (HR)	HMI	Vedran Mudronja	National Laboratory for Length Ivana Lučića 5 10000 Zagreb	Tel : +385 1 616 8327 Fax : +385 1 616 8599 e-mail : vedran.mudronja@fsb.hr
Macedonia (MK)	BOM	Biljana Atanasov	Ministry of Economy Bureau of Metrology Bul. Jane Sandanski 109a 1000 Skopje	Tel : +389 2 24 03 676 Fax : +389 2 24 44 677 e-mail : biljana.atanasov@bom.gov.mk
Montenegro (ME)	MBM	Gordana Bajic	Bureau of Metrology Kralja Nikole 2 81000 Podgorice	Tel : +382 67226531 Fax : +385 1 616 8599 e-mail : gordana.bajic@metrologija.gov.me
Serbia (RS)	DMDM	Slobodan Zelenika	Directorate of Measures and Precious Metals Mike Alasa 14 11000 Belgrade	Tel : +381112024421 Fax : +381112181668 e-mail : zelenika@dmdm.rs

Table 1 Participants

2.2 Time schedule

Each laboratory had four weeks for measurement, including transportation.
All results was to be communicated directly to the pilot laboratory as soon as possible and certainly within two weeks of the completion of the measurements by a laboratory.
An ATA carnet was used to facilitate the transportation.
Each laboratory was responsible for organizing delivery to the next participant or pilot. Recommended ways for transportation were delivery by laboratory personnel, either by personal road transport or in an airplane cabin.
Nevertheless, due to many customs problems (troubles with issued ATA carnet) and cancellation of participation of some laboratories (DPMK and BOM had problems with their calibration facilities), the comparison needed more time than planned and proposed in the time schedule.
Final time schedule is given in Table 2.
The pilot laboratory, DMDM, made several measurements to check the stability of the artifacts, but only its first set of comparison measurements is reported in the main results.

Laboratory	Country	Final schedule
DMDM	Serbia	Oct. – Nov. 2012.
HMI	Croatia	Dec. 2012. – Jan. 2013.
MBM	Montenegro	Jul. – Avg. 2013.
DPMK	Albania	Cancelled
BOM	Macedonia	Cancelled
DMDM	Serbia	Sep. 2013.

Table 2 Final time schedule

3 Description of the standards

The package contains 5 gauge blocks made of steel. The gauge blocks are of grade 0 and of rectangular cross section, according to the international standard ISO 3650.
The participating laboratories were only informed of the nominal length of the gauge block, as marked on their faces, the gauge material and the predetermined expansion coefficients.
The standards were packed in a wooden box with with slots cut out to make a tight fit with the gauge blocks, to prevent any motion of the blocks during transport.
The nominal length of each gauge block was determined in advance of the comparison by interferometry at DMDM.
More detailed information about standards is given in Table 3.

Serial number	Nominal length (mm)	Thermal expansion coeff. (10^{-6} K^{-1})
783344	1,42	11,5 ± 1
783344	10	11,5 ± 1
783344	23	11,5 ± 1
783344	75	11,5 ± 1
783344	100	11,5 ± 1

Table 3 Steel gauge blocks

4 Measurement instructions

Before calibration, the gauge blocks had to be inspected for damage to the measurement surfaces.
On receipt of the gauge blocks and prior to calibration, each participating laboratory had to document measurement surfaces of each block by a drawing or sketching in the form in the Annex 2).
The gauge blocks were in the laboratory environment for an adequate period to allow temperature stabilization.
The gauge block temperature and/or surface plate temperature were recorded at the beginning and end of the calibration.
The measurement quantity (measurand) was the deviation of the central length of the gauge block from its nominal length, as defined in ISO 3650. The central length was determined by mechanical comparison against the laboratory reference gauge blocks using an appropriate comparator.
The central length of the gauge blocks had to be measured by mechanical comparison with the participant laboratory's reference gauge blocks and appropriate comparator, using the normal calibration procedure of the laboratory.
The measurement results had to be appropriately corrected to the reference temperature of 20 °C using the thermal expansion coefficients given in this document. Additional corrections had to be applied according to the usual procedure of the laboratory.
The gauges were positioned as follows (Figure 1):
• 1,42 mm – the measuring face with the nominal size marking should face upwards with the nominal size mark on the right side of the gauge facing the operator.

• 10 mm, 23 mm, 75 mm and 100 mm – the side of the gauge block with the nominal size marking should be standing vertically, facing the operator with the numerals running up the gauge side (on the right side).

After the measurements, the gauge blocks had to be cleaned and greased prior to dispatch to the next participating laboratory.

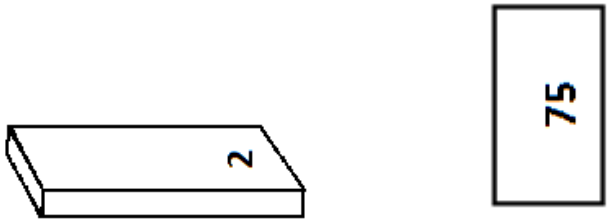

Figure 1 Orientation of faces

5 Measurement methods and instruments used by participants

Measurements were made by all participants by mechanical comparison with reference gauge blocks using a gauge block comparator. Comparators were used are Mahr 826 comparators. All comparators used has a resolution of 0.01µm.
All participants used Grade K gauge blocks as their reference.
Table 4 below is a summary of the equipment used by each participant.

Participant	Comparator	Ref. gauge blocks	Temperature range
DMDM - SR	Mahr 826	Steel, grade K	19,7 °C – 20,3 °C
HMI - CR	Mahr 826	Steel grade K	19,8 °C – 20,3 °C
MBM - ME	Mahr 826	Steel, grade K	19,5 °C – 20,5 °C

Table 4 Standards used by Participants

6 Stability and interferometric measurements and conditions of the gauge blocks

The Pilot Laboratory was monitored the central length stability of the blocks by undertaking interferometric measurements at the beginning and at the end of the comparison.
The pilot laboratory was made interferometric calibrations before the start of the comparison as well as measurements by mechanical comparison.
The participants could also made interferometric calibrations of gauge blocks, if they are able to perform them. The results of interferometric measurements were evaluated separately (an option).
Interferometric results were included in final analysis of comparison results solely for information (by graphical presentation).
The Pilot Laboratory used the same equipment, operator and calibration method for stability measurements. From the results obtained and taking into account the calibration uncertainty of the Pilot Laboratory there was no significant deviation in the central length of the blocks throughout the comparison.
The gauge blocks were essentially free from any damage at the beginning of the comparison**.**
The participating laboratories were asked to document any scratches or other damage which were observed on the measuring faces of the blocks by a drawing. This was reported by some participants. While some markings and scratches occurred, it was not considered to be excessive.

The DMDM mechanical comparison results agreed with the DMDM and HMI interferometric results for all gauges, at the start of the comparison and at the end of the comparison.
Figures 2(a), 2(b), 2(c), 2(d) and 2(e) below shows the deviation in central length for all five gauge blocks at the beginning and at the end of the comparison, measured by mechanical comparison (DMDM1 and DMDM2) and by interferometry made by DMDM (DMDM-int1 and DMDM-int2) and HMI (HMI-int) as well. The DMDM and HMI uncertainty bars are included at two sigma level (k= 2).

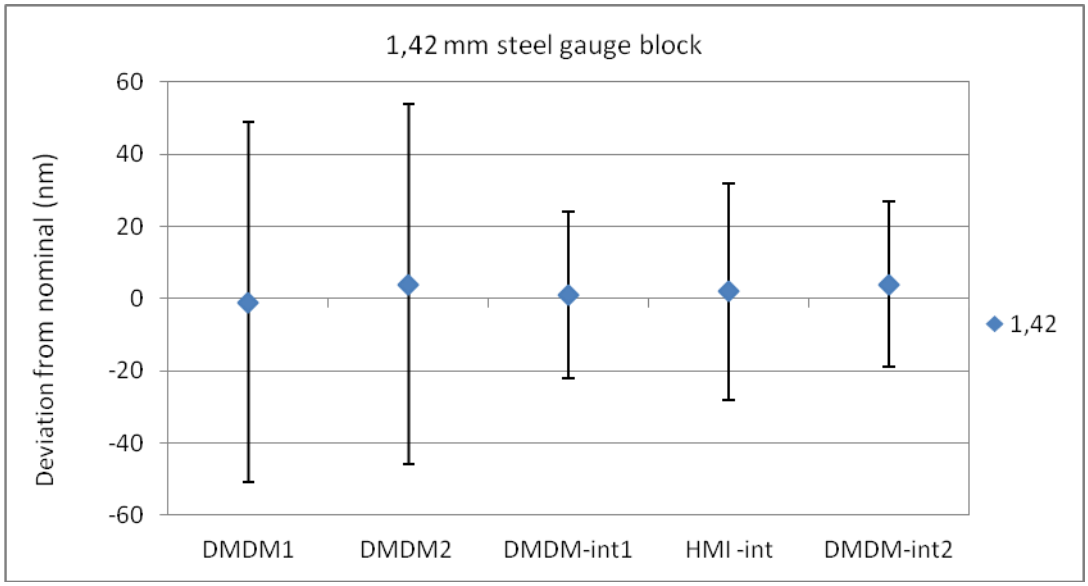

Figure 2(a). Deviation in Central Length of 1,42 mm gauge block

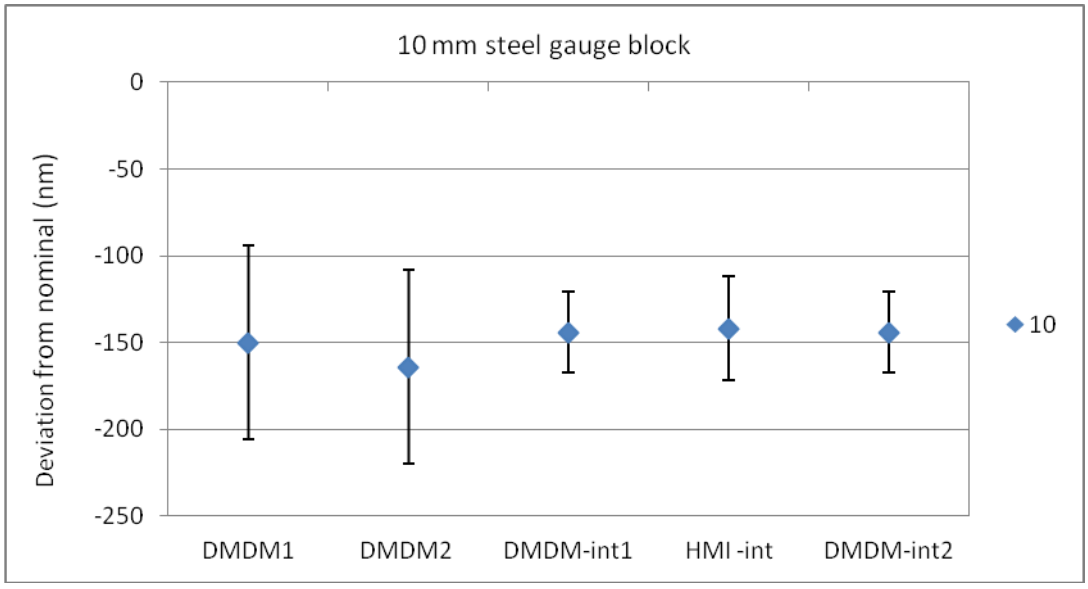

Figure 2(b) Deviation in Central Length of 10 mm gauge block

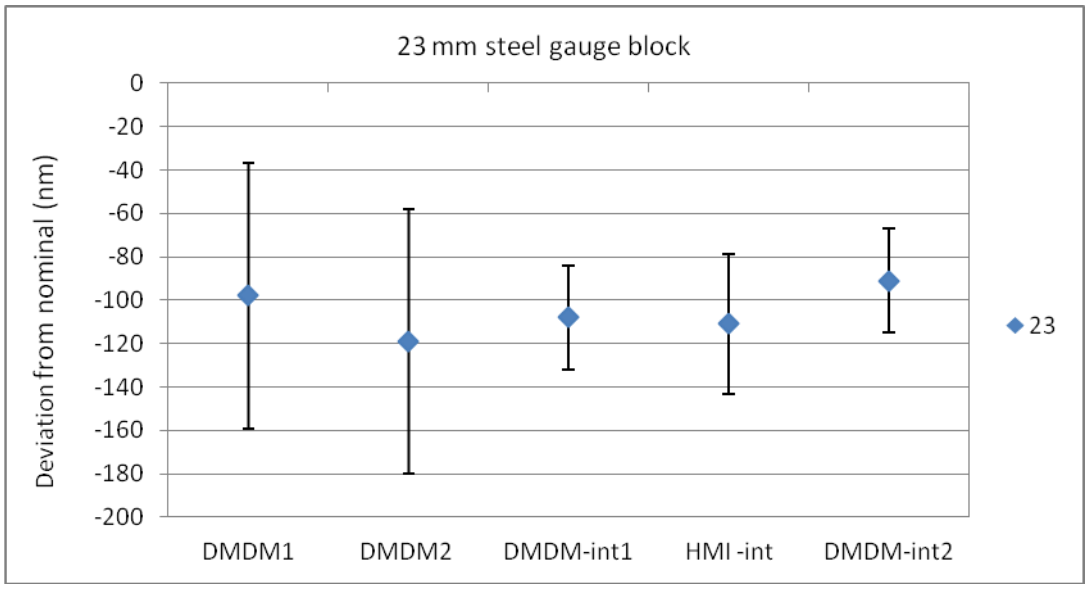

Figure 2(c) Deviation in Central Length of 23 mm gauge block

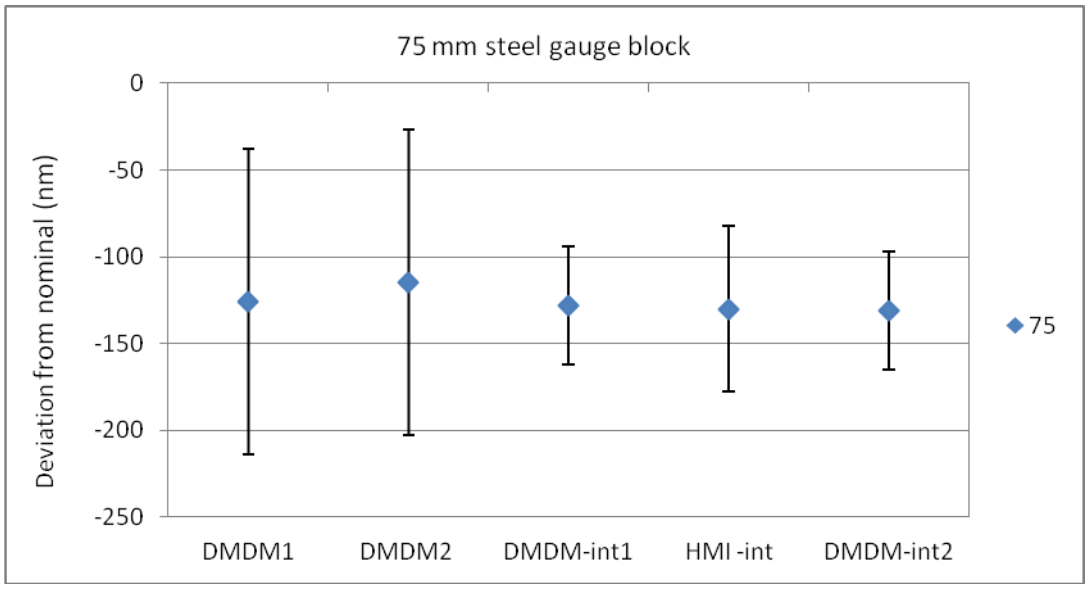

Figure 2(d) Deviation in Central Length of 75 mm gauge block

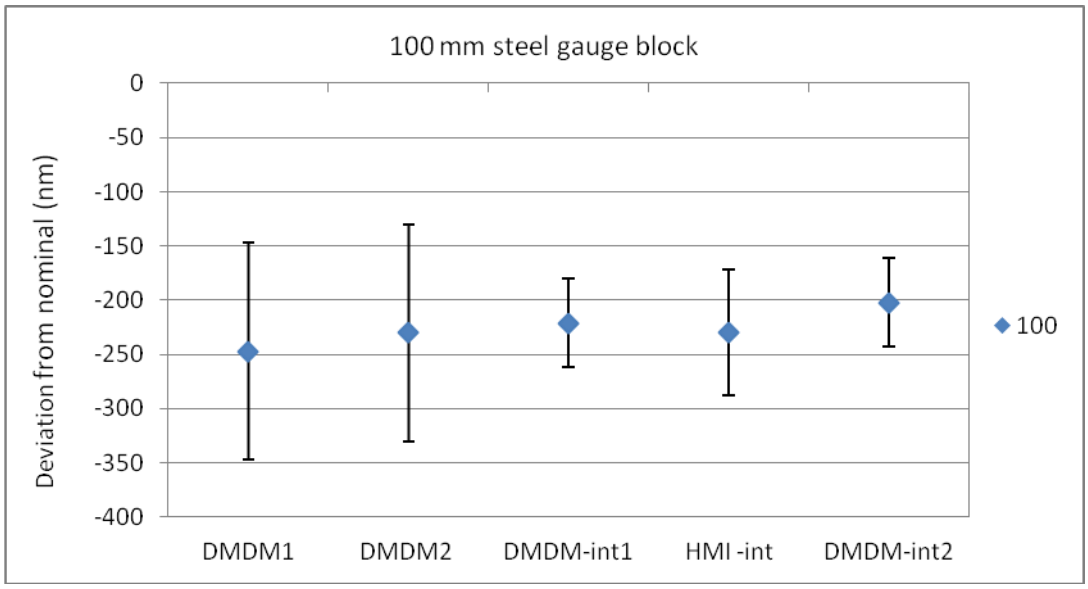

Figure 2(e) Deviation in Central Length of 100 mm gauge block

7 Measurement results

Each participating laboratory supplied measurement results on all gauges in the set. These results included:
- deviation in central length of each gauge block from its nominal value as a result of mechanical comparison with a reference gauge block
- measurement uncertainty associated with each measured value reported.
The results were analyzed and compiled by the Pilot Laboratory.

7.1 Analysis of the reported results

The reported measurement results are now analyzed by simple statistical means to allow identification of any significant bias or outliers, and to investigate the statistical distribution of the results.
For each gauge block the reported 'Central deviation from nominal length' and the associated measurement uncertainty (at k= 1) in µm was recorded for each participant.
The mean deviation was calculated by taking the mean of all the participants values.
The deviation from the calculated mean was then calculated for each participant.
Finally the uncertainty of this deviation from the calculated mean was calculated
This uncertainty was calculated using standard statistical guidelines *i.e.* taking into account the fact that the mean is correlated with each result so the square root of the difference of the two uncertainties (participant, mean) rather than the square root of the sum was taken.
The arithmetic mean value x_{ref} is calculated by the average of all measurement values x_i:

$$x_{ref} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

The standard uncertainty $u(x_{ref})$ of the arithmetic mean can either be determined by application of the error propagation law, i.e. by taking into account the uncertainties $u(x_i)$ of the individual results

or by the spread of the results, i.e. by the standard deviation divided by the square root of the number n of results contributing to the mean:

$$u(x_{ref}) = \frac{1}{n}\sqrt{\sum_{i=1}^{n} u^2(x_i)}$$

For calculating the uncertainty of the difference Δx between an individual result and the reference value (arithmetic mean), the corresponding uncertainties $u(x_i)$ and $u(x_{ref})$ cannot simply be geometrically added, because the values x_i and x_{ref} are correlated. It can be shown, that for the arithmetic mean approach, the uncertainty $U(\Delta x)$ is given by (k= 2):

$$U(\Delta x) = 2\sqrt{\left(1-\frac{2}{n}\right)u^2(x_i) + \frac{1}{n^2}\sum_{j=1}^{n} u^2(x_j)}$$

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

$$E_n = \frac{x_i - x_{ref}}{U(\Delta x)} \qquad (k= 2)$$

If $|En| > 1$ this means that result of the laboratory deviates more from the arithmetic mean than the combined expanded uncertainty of deviation.

7.1.1 Results of the 1,42 mm gauge block

Participant	Deviation from nominal length	Uncertainty (k=1)	Deviation from arithmetic mean	Uncertainty (k=2)	E_n
	Δl (µm)	$u(\Delta l)$ (µm)	$\Delta x = \Delta l - x_{mean}$ (µm)	$U(\Delta x)$ (µm)	
DMDM	-0,001	0,025	0,008	0,039	0,207
HMI	-0,006	0,013	0,003	0,030	0,101
MBM	-0,020	0,026	-0,011	0,039	-0,279
Mean deviation x_{mean} (µm)		-0,009			
Uncertainty $u(x_{mean})$ (k=1) (µm)		0,013			

Table 5 Reported results of participants and results calculated from participants values

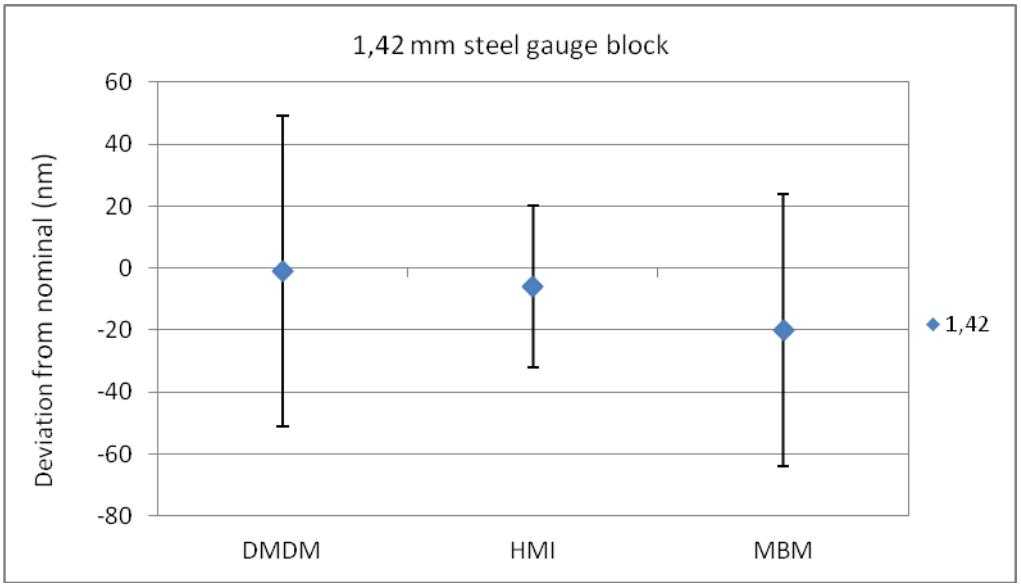

Figure 3 Deviation in central length of 1,42 mm gauge block (as reported by the participants, k= 2)

7.1.2 Results of the 10 mm gauge block

Participant	Deviation from nominal length	Uncertainty (k=1)	Deviation from arithmetic mean	Uncertainty (k=2)	E_n
	Δl (µm)	$u(\Delta l)$ (µm)	$\Delta x = \Delta l - x_{mean}$ (µm)	$U(\Delta x)$ (µm)	
DMDM	-0,150	0,028	0,014	0,043	0,326
HMI	-0,152	0,015	0,012	0,033	0,362
MBM	-0,190	0,028	-0,026	0,043	-0,606
Mean deviation x_{mean} (µm)		-0,164			
Uncertainty $u(x_{mean})$ (k=1) (µm)		0,014			

Table 6 Reported results of participants and results calculated from participants values

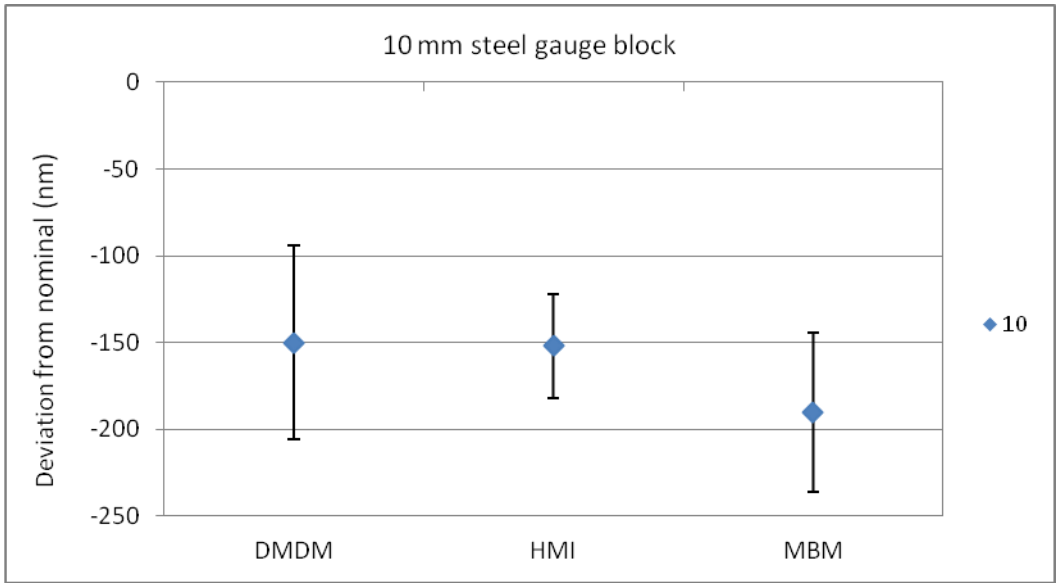

Figure 4 Deviation in central length of 10 mm gauge block (as reported by the participants, k= 2)

7.1.3 Results of the 23 mm gauge block

Participant	Deviation from nominal length	Uncertainty (k=1)	Deviation from arithmetic mean	Uncertainty (k=2)	E_n
	Δl (µm)	$u(\Delta l)$ (µm)	$\Delta x = \Delta l - x_{mean}$ (µm)	$U(\Delta x)$ (µm)	
DMDM	-0,098	0,031	0,009	0,049	0,184
HMI	-0,103	0,019	0,004	0,040	0,101
MBM	-0,120	0,034	-0,013	0,051	-0,253
Mean deviation x_{mean} (µm)		-0,107			
Uncertainty $u(x_{mean})$ (k=1) (µm)		0,017			

Table 7 Reported results of participants and results calculated from participants values

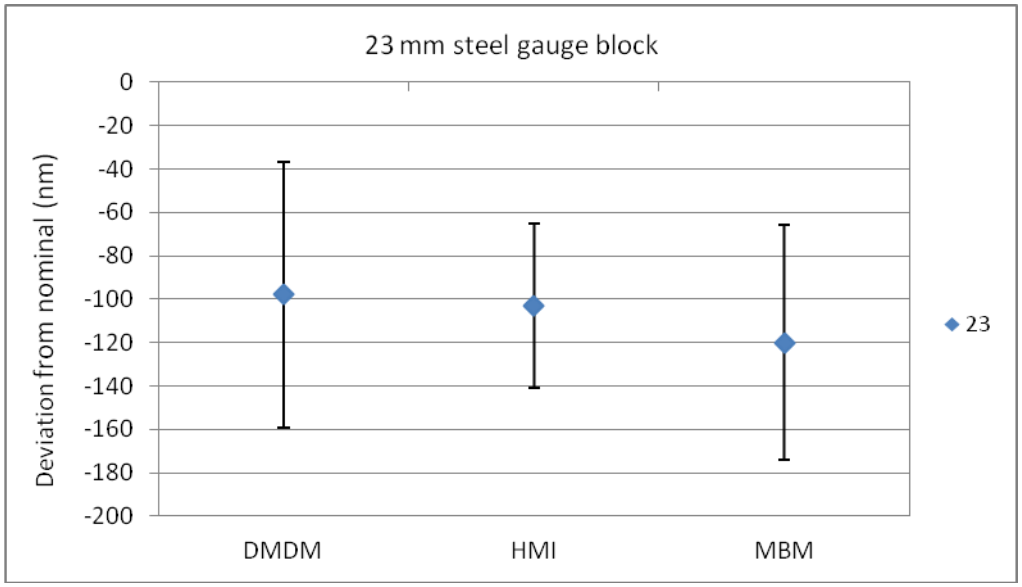

Figure 5 Deviation in central length of 23 mm gauge block (as reported by the participants, k= 2)

7.1.4 Results of the 75 mm gauge block

Participant	Deviation from nominal length	Uncertainty (k=1)	Deviation from arithmetic mean	Uncertainty (k=2)	E_n
	Δl (µm)	$u(\Delta l)$ (µm)	$\Delta x = \Delta l - x_{mean}$ (µm)	$U(\Delta x)$ (µm)	
DMDM	-0,126	0,044	-0,009	0,081	-0,111
HMI	-0,135	0,033	-0,018	0,074	-0,244
MBM	-0,090	0,077	0,027	0,109	0,248
Mean deviation x_{mean} (µm)		-0,117			
Uncertainty $u(x_{mean})$ (k=1) (µm)		0,032			

Table 8 Reported results of participants and results calculated from participants values

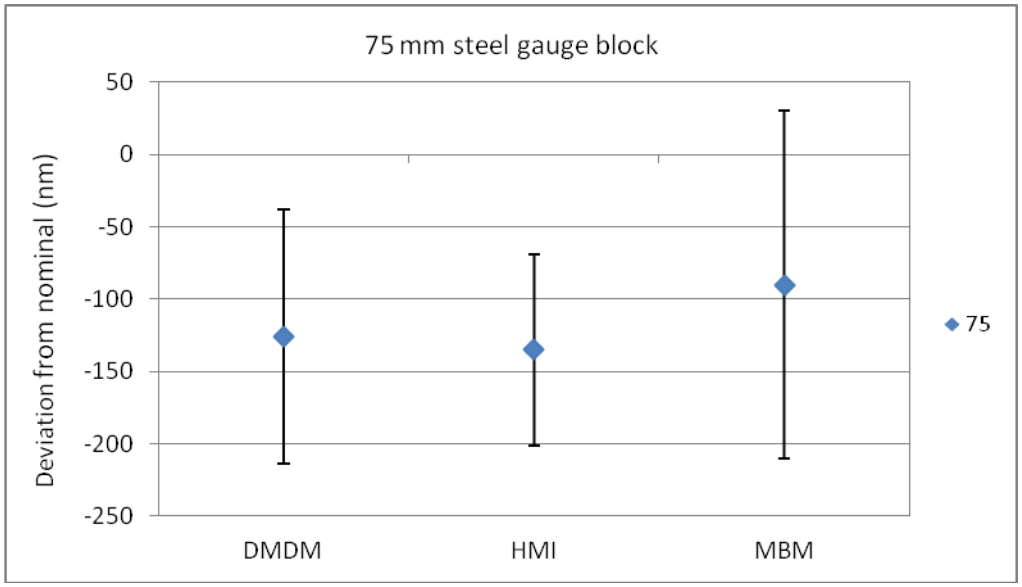

Figure 6 Deviation in central length of 75 mm gauge block (as reported by the participants, k= 2)

7.1.5 Results of the 100 mm gauge block

Participant	Deviation from nominal length	Uncertainty (k=1)	Deviation from arithmetic mean	Uncertainty (k=2)	E_n
	Δl (µm)	$u(\Delta l)$ (µm)	$\Delta x = \Delta l - x_{mean}$ (µm)	$U(\Delta x)$ (µm)	
DMDM	-0,247	0,050	-0,045	0,098	-0,458
HMI	-0,240	0,040	-0,038	0,091	-0,413
MBM	-0,120	0,099	0,082	0,139	0,593
Mean deviation x_{mean} (µm)		-0,202			
Uncertainty $u(x_{mean})$ (k=1) (µm)		0,039			

Table 9(a) Reported results of participants and results calculated from participants values

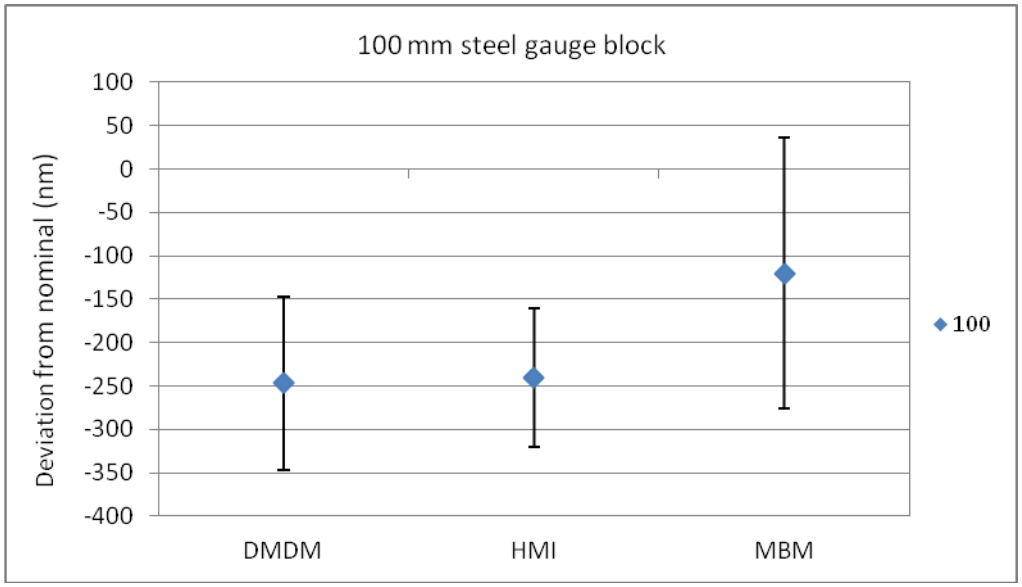

Figure 7 Deviation in central length of 100 mm gauge block (as reported by the participants, k= 2)

8 Conclusion and summary

This comparison involved five NMI laboratories from Western Balkan: Croatia, Montenegro, Albania, Macedonia and Serbia.
Two laboratories are cancelled their participation from comparison due to some problems with their calibration facilities. BOM had problems with mechanical comparator. DPMK had problems with laboratory temperature.
Other three laboratories measured the gauge blocks (HMI, MBM and DMDM). All results are in agreement with the reference value (arithmetic mean) within their $k = 2$ uncertainties with E_n values less then 1. This means, there are therefore no outliers and no further processing is required.
The comparison lasted from October 2012 to September 2013.
Damage in the gauge blocks was not observed and the gauge blocks were stable during the comparison.
The stability was checked by DMDM before and after the measurement campaign. No significant changes were found.
The overall results look reasonable. We can conclude this comparison is valid and partly successful. Unfortunately, not all laboratories took part in the measurements.
We would like to express our sincere gratitude for the participants and all people who have supported this comparison.