Hrvatski mjeriteljski institut
Croatian Metrology Institute

LABORATORIJ ZA PRECIZNA MJERENJA DUŽINA
LABORATORY FOR PRECISE LENGTH MEASUREMENTS

University of Zagreb
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Laboratory for precise measurements of length

EURAMET comparison of gauge blocks by interferometry

EURAMET #1138
EURAMET.L-K1.2

Final report

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Contents

1 INTRODUCTION

During the EURAMET annual TCL meeting in Lisbon in October 2009 it was agreed to start a EURAMET key comparison of gauge blocks by interferometry between a small number of laboratories (institutes), in order to test the performance of new equipment or confirm existing measurement procedures. It was the intention of Croatian National Laboratory for Length and Egyptian National Institute of Standards to apply CMC values based on the results of this comparison.
Initiative for this key comparison came from Croatian National Laboratory for Length (HMI/FSB-LPMD), which acted as pilot laboratory, with participation of 4 other institutes:

- MKEH (HU)
- DFM (DK)
- GUM (PL)
- NIS (EG)

2 ORGANIZATION

2.1 Participants

Country (code)	Laboratory	Name of contact	Address	
1 - Denmark (DK)	DFM	Joergen Garnaes	Danish Fundamental Metrology Matematiktorvet 307 DK-2800 Kongens Lyngby	Tel : 45 45 93 11 44 Fax : 45 45 93 11 37 e-mail : jg@dfm.dtu.dk
2 - Hungary (HU)	MKEH	Edit Bánréti	Hungarian Trade Licensing Office Németvölgyi ut 37-39 HU-1124 Budapest XII.	Tel : 36 1 4585 997 Fax : 36 1 4585 927 e-mail : banretie@mkeh.hu
3 - Egypt (EG)	NIS	Mohamed Amer	Tersa Street EG-12211 El Haram, Giza	Tel : + 202 0123 676 372 Fax : +202 33 889 744 e-mail : amer@nis.sci.eg
4 - Croatia (HR)	HMI/FSB-LPMD	Vedran Mudronja	Laboratory for Precise Measurements of Length Ivana Lučića 5 10000 Zagreb	Tel : +385 1 616 8327 Fax : +385 1 616 8599 e-mail : vedran.mudronja@fsb.hr
5 – Poland (PL)	GUM	Zbigniew Ramotowski	Central Office of Measures Glówny Urzad Miar (GUM) P.O. Box 10 ul. Elektoralna 2 00-950 WARSZAWA	Tel : 48 22 620 54 38 Fax : 48 22 620 83 78 e-mail : gum@gum.gov.pl

2.2 Time schedule

Each laboratory had four weeks for measurement, including transportation. With its confirmation to participate, each laboratory has confirmed that it is capable to perform the measurements in the limited time allocated to him. It guaranteed that the standards would arrive in the country of the next participant at the beginning of the next week. If for some reason the measurement facility is not ready or customs clearance takes too much time in a country, the laboratory had to contact the coordinator immediately and – according to the arrangement made - eventually had to send the standards directly to the next participant before finishing the measurements or even without doing any measurements.

Country	Laboratory	Date
Croatia	HMI/FSB-LPMD	15.02. – 12.03.10.
Poland	GUM	15.03. – 09.04.10.
Denmark	DFM	12.04. – 07.05.10.
Hungary	MKEH	10.05. – 04.06.10.
Egypt	NIS	07.06. – 02.07.10.
Croatia	HMI/FSB-LPMD	05.07. – 30.07.10.

3 DESCRIPTION OF THE STANDARDS

8 steel gauge blocks were measured. The gauge blocks were of rectangular cross section, according to the international standard ISO 3650:1998.

Table 3.1. Steel gauge blocks:

Serial number	Nominal length, mm	Thermal expansion coeff. 10^{-6} K^{-1}	Manufacturer
87656	1	11,9 ± 0,5	KOBA
87656	5		
87656	8		
87623	10		
87680	25		
87680	40		
87680	60		
87623	90		

4 MEASUREMENT INSTRUCTIONS

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

Measurement item was the central length of the gauge blocks, as defined in the International Standard ISO 3650:1998. The gauge blocks had to be measured by interferometry, in their vertical position wrung to a flat plate. The central length of a gauge block is the perpendicular distance between the centre point of the free measuring surface and the plane surface of an auxiliary plate of the same material and surface texture upon which the other measuring surface has been wrung.

The measurement result had to be reported as the deviation of central length from nominal length,

$$\Delta l = l_{\text{measured}} - L_{\text{nominal}}$$

The results of the measurements on both sides (Δl_1 and Δl_2) by wringing each measurement face in turn upon the reference flat and the average of the two wringings had to be reported.

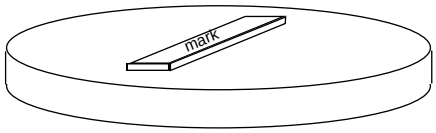

Figure 4.1a :
Position of the gauge block for Δl_1
The upper face is face 1

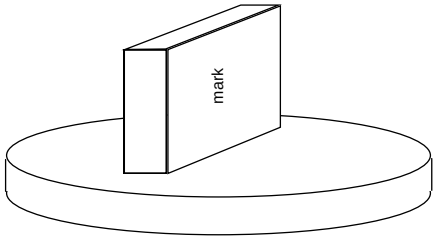

Figure 4.1b :
Position of the gauge block for Δl_1 ($L > 6$ mm)
The upper face is face 1

The uncertainty of measurement had to be estimated according to the *ISO Guide for the Expression of Uncertainty in Measurement (ISO/IEC Guide 98-3:2008)*.

5 MEASUREMENT EQUIPMENT USED BY PARTICIPANTS

Table 5.1 Measurement equipment used in comparison

Lab.	Measurement device	Platen material	Applied phase correction, nm
DFM	NPL-TESA Automatic gauge block interferometer, Twyman-Green Type	Steel	-18,7
MKEH	CARL ZEISS JENA, Kösters Type	Glass	30
NIS	CARL ZEISS JENA, Kösters Type	Steel	-23
HMI/FSB-LPMD	CARL ZEISS JENA, Kösters Type	Glass	30
GUM	NPL-TESA / HEXAGON Automatic gauge block interferometer, Twyman-Green Type	Steel	-1

6 STABILITY OF THE GAUGE BLOCKS

6.1. Stability of the 1 mm gauge block

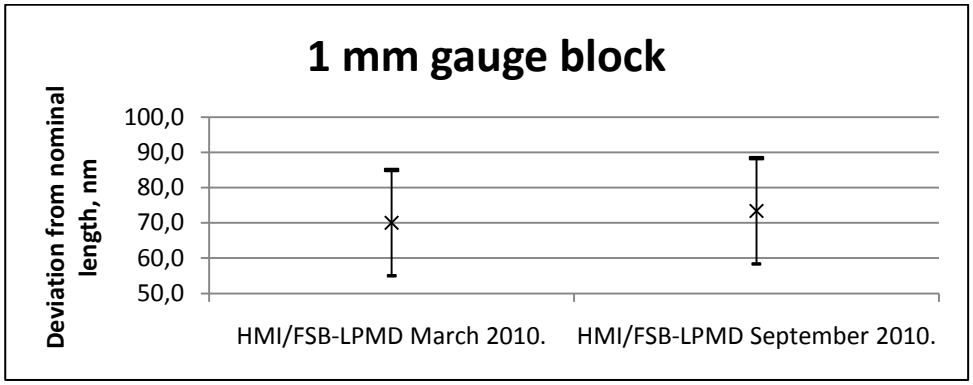

Figure 6.1 Stability of the 1 mm gauge block

6.2. Stability of the 5 mm gauge block

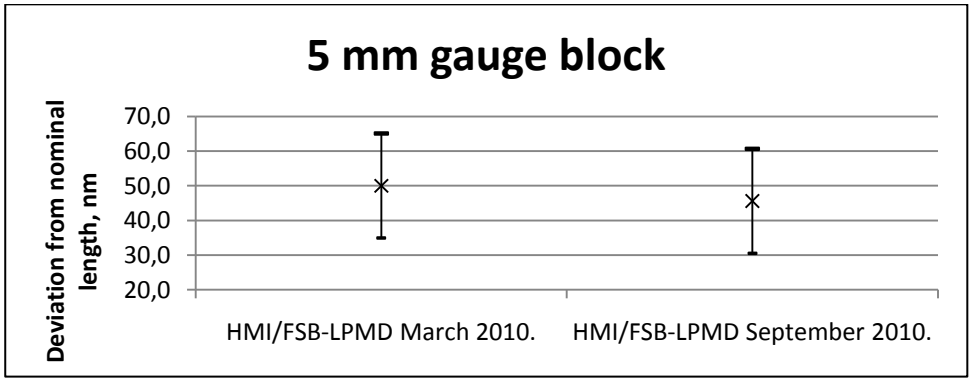

Figure 6.2 Stability of the 5 mm gauge block

6.3. Stability of the 8 mm gauge block

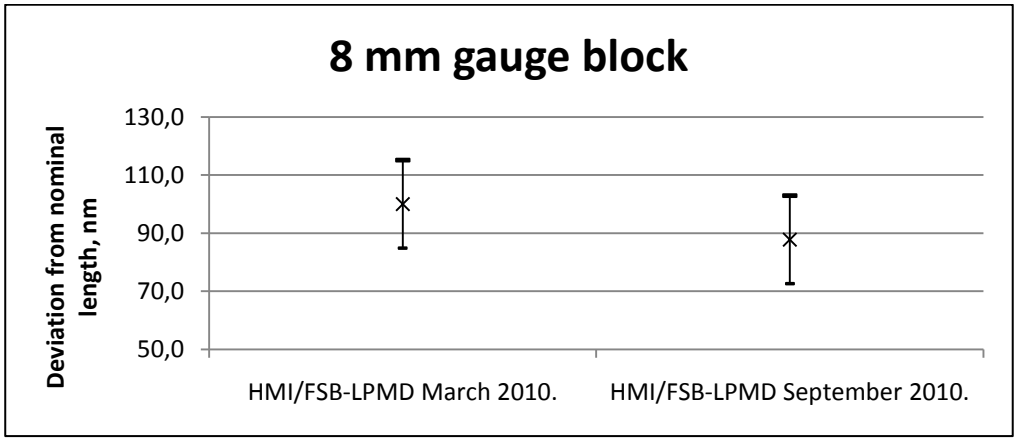

Figure 6.3 Stability of the 8 mm gauge block

6.4. Stability of the 10 mm gauge block

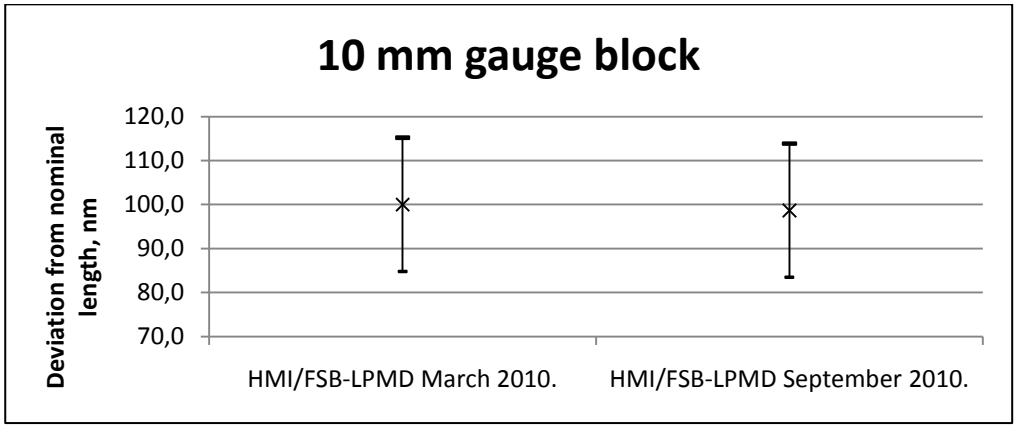

Figure 6.4 Stability of the 10 mm gauge block

6.5. Stability of the 25 mm gauge block

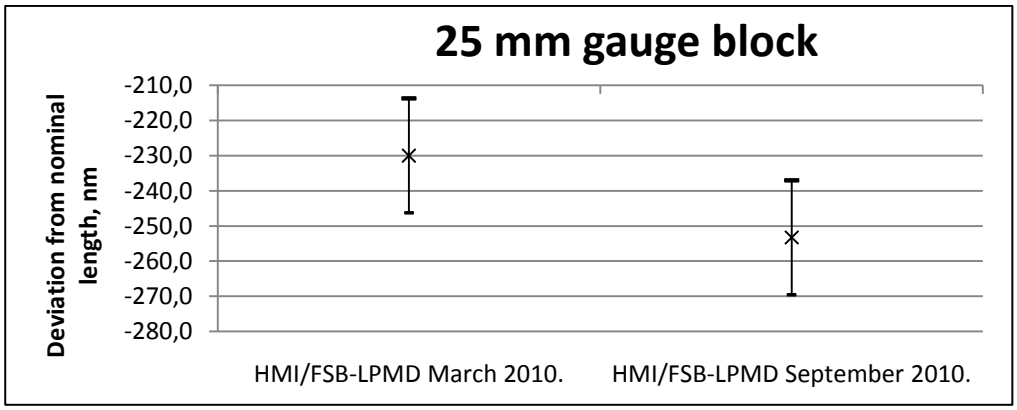

Figure 6.5 Stability of the 25 mm gauge block

6.6. Stability of the 40 mm gauge block

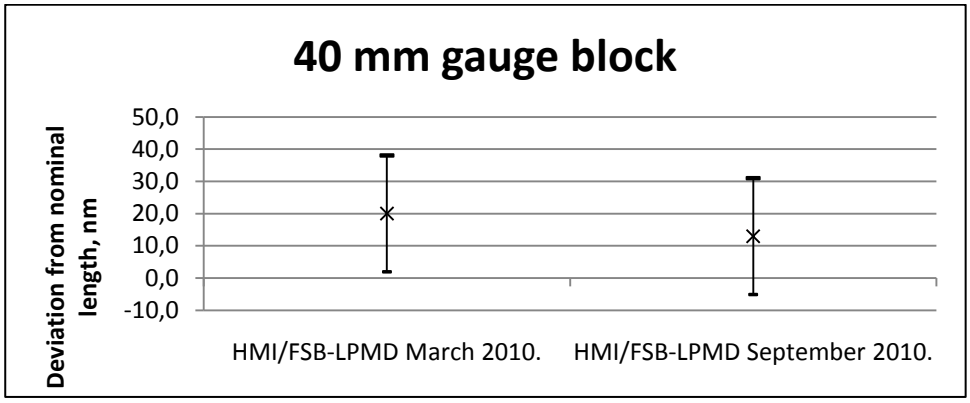

Figure 6.6 Stability of the 40 mm gauge block

6.7. Stability of the 60 mm gauge block

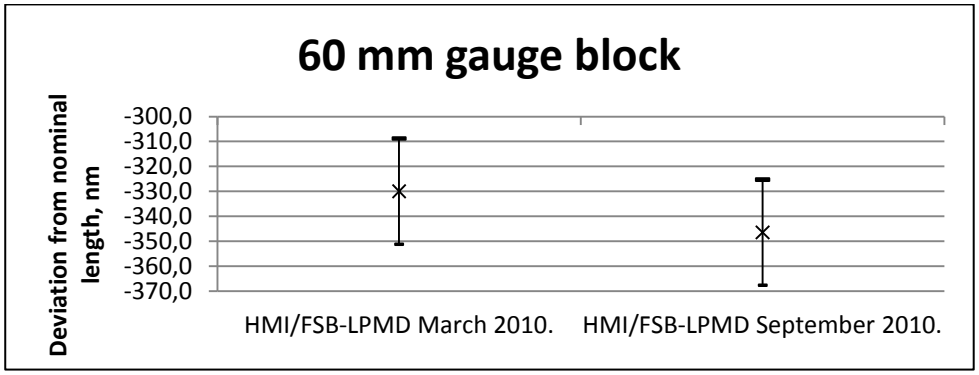

Figure 6.7 Stability of the 60 mm gauge block

6.8. Stability of the 90 mm gauge block

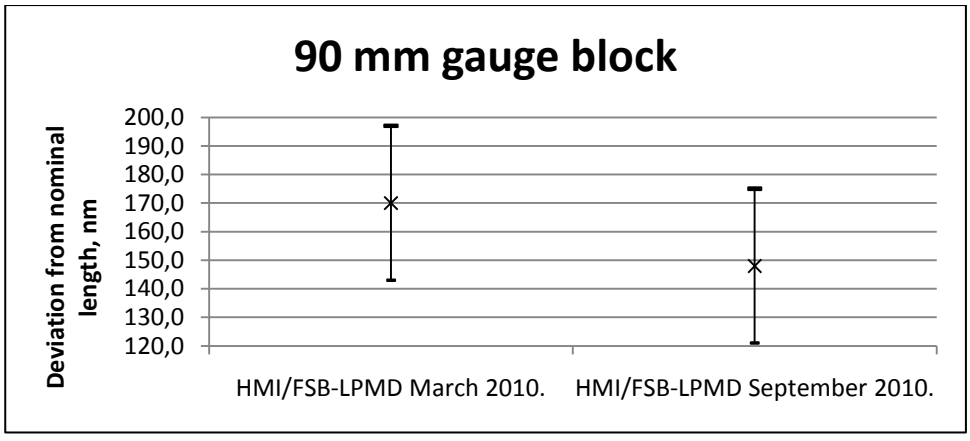

Figure 6.8 Stability of the 90 mm gauge block

7 CONDITION OF GAUGE BLOCK SURFACES

Gauge blocks were essentially free of scratches when they left HMI/FSB-LPMD. During the course of intercomparison all participants were asked to report the condition of gauge block surfaces. It is obvious that some scratches occured due to repeated wringing, but it can be concluded that they did not influence the measurements.

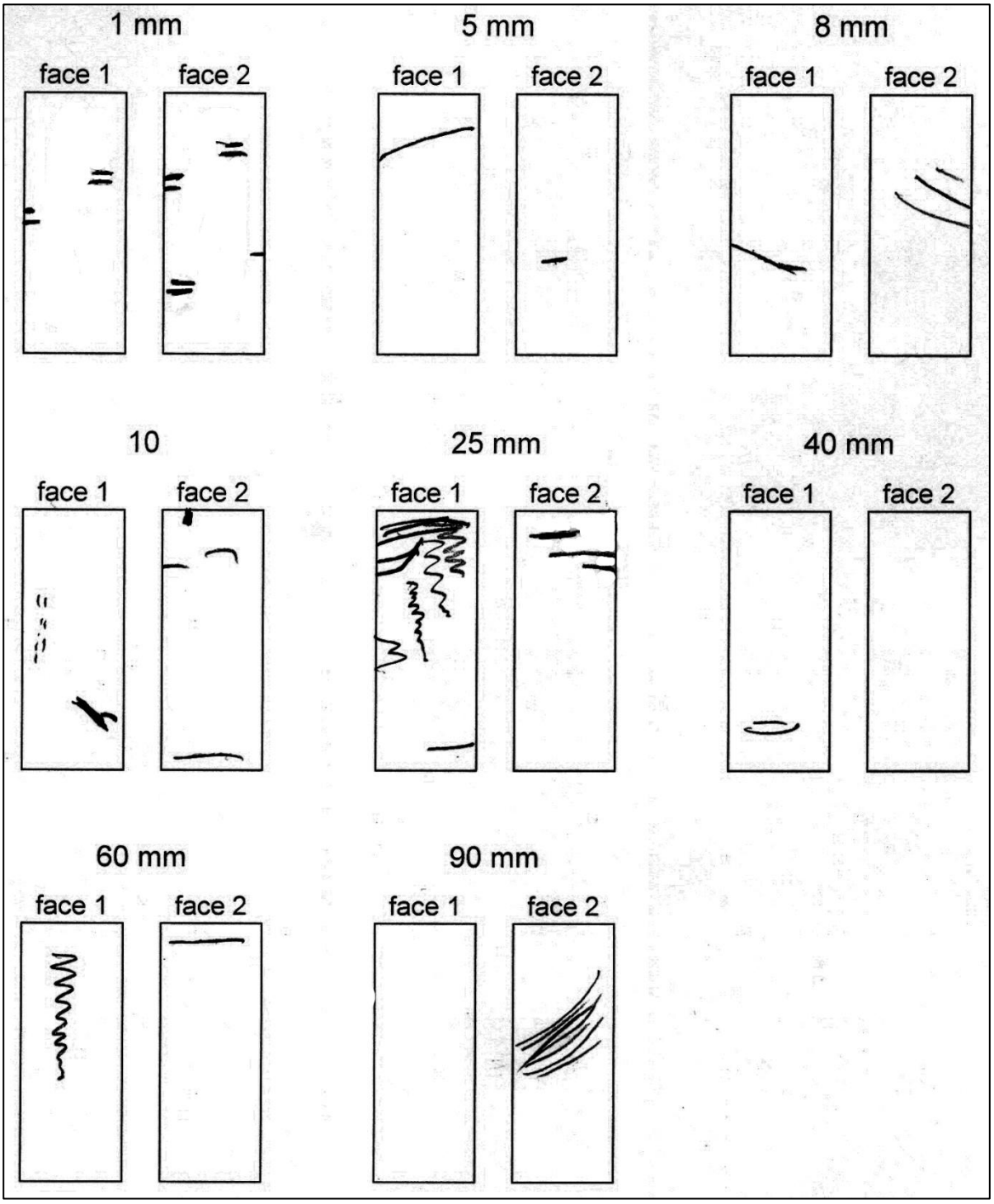

Figure 7.1 Gauge blocks surface condition reported by HMI/FSB-LPMD after the conclusion of comparison

8 ANALYSIS OF RESULTS

The weighted mean is used as the reference value in the comparison.
For each laboratory (i) the normalised weight, w_i was calculated by the following formula:

$$w_i = C \cdot \frac{1}{u^2(x_i)} \qquad (1)$$

where $u(x_i)$ is the standard uncertainty given by the laboratory "i" and C is the normalizing factor and is calculated by the following formula:

$$C = \frac{1}{\sum_{i=1}^{n} \frac{1}{u^2(x_i)}} \qquad (2)$$

where n is the number of the laboratories.

The weighted mean (reference value) is:

$$\bar{x}_w = \sum_{i=1}^{n} w_i \cdot x_i \qquad (3)$$

The uncertainty of the deviation from the weighted mean is:

$$u(x_i - \bar{x}_w) = \sqrt{u^2(x_i) - u_{\text{int}}{}^2(\bar{x}_w)} \qquad (4)$$

The analysis of the results of each participant can be done by calculating the deviation of the given result from the weighted mean ($x_i - \bar{x}_w$) and the uncertainty of this deviation.

The statistical consistency of the results with the uncertainties given by the participants can be checked by the E_n value for each laboratory.

$$E_n = \frac{x_i - \bar{x}_w}{2\sqrt{u^2(x_i) - u_{\text{int}}^2(\bar{x}_w)}} \qquad \text{(k=2)} \quad (5)$$

where $x_i - \bar{x}_w$ is the deviation from the weighted mean for a result of a laboratory, u_{int} is the so called internal standard deviation that is based on the estimated standard uncertainties as reported by the participants:

$$u_{\text{int}}(\bar{x}_w) = \sqrt{C} \qquad (6)$$

En values are expected to be less than 1 for a coverage factor of k=2.

The statistical consistency of the comparison can be analysed by the so called Birge ratio test. The Birge ratio compares the observed spread of the results with the spread expected from the individual reported uncertainties.

The Birge ratio is:

$$R_B = \frac{u_{ext}(\bar{x}_w)}{u_{\text{int}}(\bar{x}_w)} \qquad (7)$$

where u_{ext} is the so called external standard deviation and can be calculated by the following formula:

$$u_{ext}(\bar{x}_w) = \sqrt{\frac{1}{I-1} \cdot \frac{\sum_{i=1}^{n} \frac{(x_i - \bar{x}_w)^2}{u^2(x_i)}}{\sum_{i=1}^{n} \frac{1}{u^2(x_i)}}} \qquad (8)$$

The Birge ratio has an expectation value of R_B=1, when considering standard uncertainties.
For a coverage factor of k = 2, the expectation value is increased and the data in a comparison are consistent provided that

$$R_B < \sqrt{1+\sqrt{8/(I-1)}} \qquad (9)$$

where I is the number of the results that are taken in the calculation.

If the calculation of a gauge shows inconsistent dataset, the largest consistent subset is determined by elimination, starting with excluding the result having the largest E_n value that makes the largest contribution to the overall chi-squared value.
The iteration runs until $R_B < R_{B\ crit}$.

When a result x_i is excluded from the reference value, it is not correlated to it and its E_n value is calculated by:

$$E_n = \frac{x_i - \bar{x}_w}{2\sqrt{u^2(x_i) + u^2_{\text{int}}(\bar{x}_w)}} \qquad (10)$$

9 RESULTS AS REPORTED BY THE PARTICIPANTS

Overview of measurement results as they were reported by the participating laboratories is given in Table 9.1. Weighted mean and its difference from reported results were calculated, along with corresponding En values (k=2), for each gauge block.
A statistical consistency check was performed as described in Chapter 8. Results that were excluded from calculation in order to form a consistent subset are marked in colour, and their E_n values are given according to (10).

Table 9.1 Reported measurement results, in nm, k=1

	GUM		DFM		MKEH		NIS		HMI/FSB-LPMD	
	ΔL	u_c	ΔL	u_c	ΔL	u_c	ΔL	u_c	ΔL	u_c
1 mm	56	11	82,3	11,5	30	15	41	16	73	15
5 mm	37	11	57,3	11,5	10	15	10,5	18	46	15
8 mm	90	11	112,3	11,6	70	15	50	19	88	15
10 mm	90	11	112,8	11,6	70	15	54	19	99	15
25 mm	-258	14	-254,2	12,3	-250	19	-60	25	-253	16
40 mm	-2	12	23,3	13,6	250	19	-149	30	14	18
60 mm	-354	13	-313,7	15,8	300	24	59	36	-346	21
90 mm	147	14	194,3	19,9	210	32	-96	47	148	27

9.1 Results of the 1 mm gauge block

Table 9.1.1 Results as reported by the participants

Nominal 1 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	57	56	56	11
DFM	73,3	91,3	82,3	11,5
MKEH	30	20	30	15
NIS	42	40	41	16
HMI/FSB-LPMD	70	76	73	15

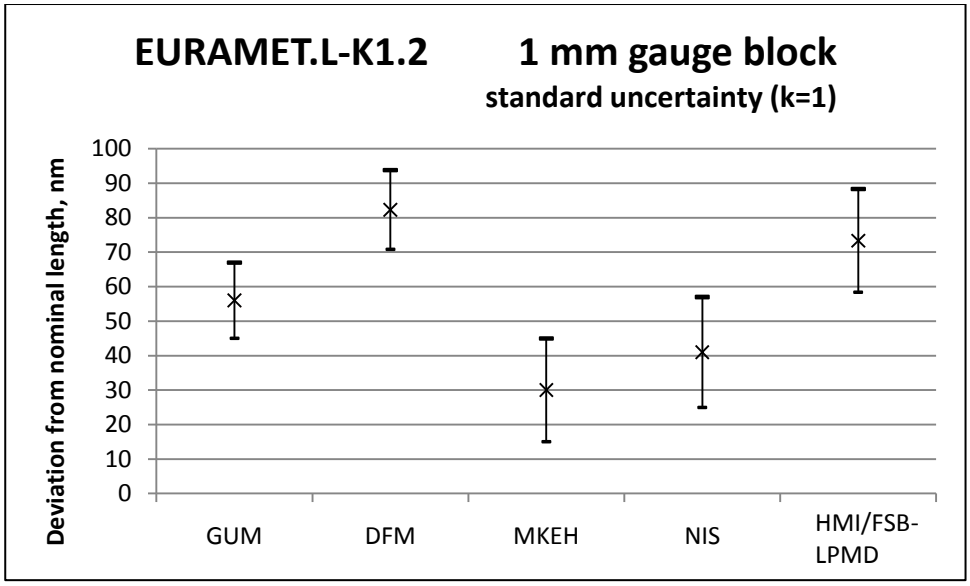

Figure 9.1.1 Graphical representation of results

Table 9.1.2 Results calculated from participants' values

1 mm	x_i-x_w	En		
GUM	-3,5	-0,19	u_{int}, nm	5,91
DFM	22,8	1,16	u_{ext}, nm	9,37
MKEH	-29,5	-1,07	R_B	1,58
NIS	-18,5	-0,62	$R_{B,crit}$	**1,55**
HMI/FSB-LPMD	13,5	0,49	x_w, nm	59,50

Table 9.1.3 Results calculated from largest consistent subset

1 mm	x_i-x_w	En		
GUM	4,7	0,27	u_{int}, nm	6,89
DFM	31,0	1,68	u_{ext}, nm	8,63
MKEH	-21,3	-0,80	R_B	1,25
NIS	-10,3	-0,36	$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	21,7	0,81	x_w, nm	51,32

9.2 Results of the 5 mm gauge block

Table 9.2.1 Results as reported by the participants

Nominal 5 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	38	35	37	11
DFM	48,3	66,3	57,3	11,5
MKEH	10	10	10	15
NIS	9	12	10,5	18
HMI/FSB-LPMD	48	42	46	15

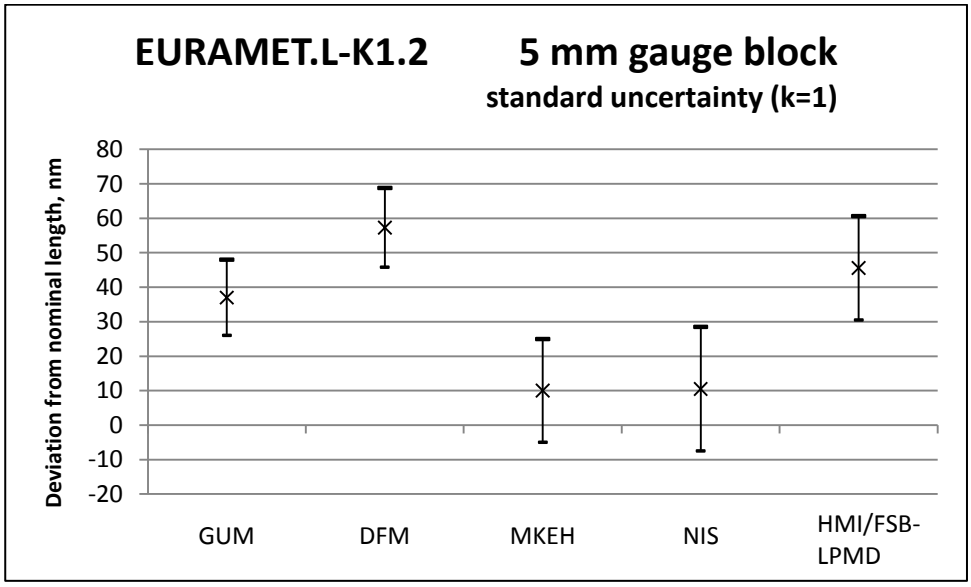

Figure 9.2.1 Graphical representation of results

Table 9.2.2 Results calculated from participants' values (=largest consistent subset)

5 mm	x_i-x_w	En			
GUM	0,3	0,02		u_{int}, nm	6,00
DFM	20,6	1,05		u_{ext}, nm	8,94
MKEH	-26,7	-0,97		R_B	1,49
NIS	-26,2	-0,77		$R_{B,crit}$	**1,55**
HMI/FSB-LPMD	9,3	0,34		x_w, nm	36,70

9.3 Results of the 8 mm gauge block

Table 9.3.1 Results as reported by the participants

Nominal 8 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	92	89	90	11
DFM	102,3	122,3	112,3	11,6
MKEH	70	60	70	15
NIS	52	48	50	19
HMI/FSB-LPMD	87	88	88	15

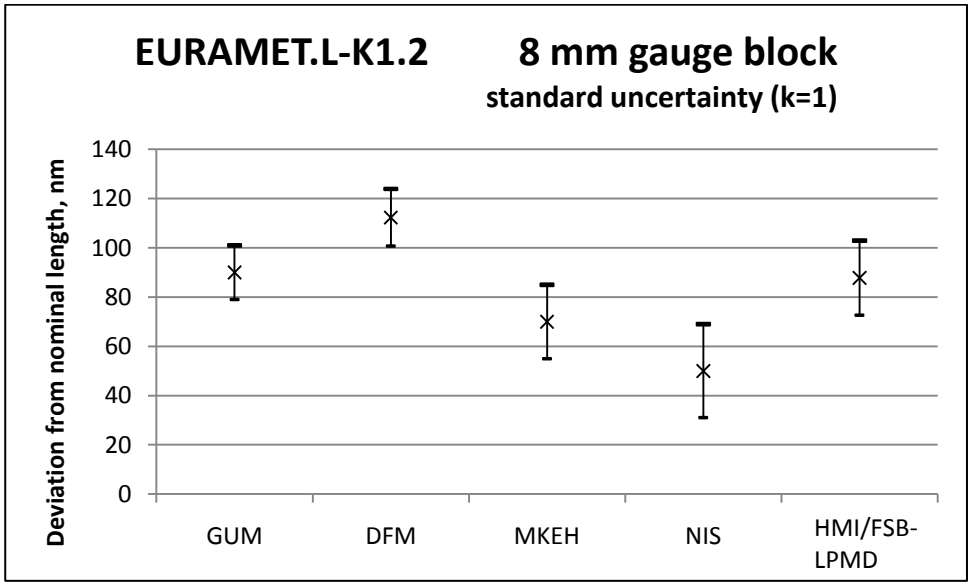

Figure 9.3.1 Graphical representation of results

Table 9.3.2 Results calculated from participants' values

8 mm	x_i-x_w	En		
GUM	1,6	0,09	u_{int}, nm	6,05
DFM	23,9	1,21	u_{ext}, nm	9,49
MKEH	-18,4	-0,67	R_B	1,57
NIS	-38,4	-1,07	$R_{B,crit}$	**1,55**
HMI/FSB-LPMD	-0,4	-0,02	x_w, nm	88,43

Table 9.3.3 Results calculated from largest consistent subset

8 mm	x_i-x_w	En		
GUM	10,5	0,62	u_{int}, nm	7,08
DFM	32,8	1,78	u_{ext}, nm	8,23
MKEH	-9,5	-0,36	R_B	1,16
NIS	-29,5	-0,84	$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	8,5	0,32	x_w, nm	79,53

9.4 Results of the 10 mm gauge block

Table 9.4.1 Results as reported by the participants

Nominal 10 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	87	93	90	11
DFM	111,3	114,3	112,8	11,6
MKEH	80	70	70	15
NIS	56	51	54	19
HMI/FSB-LPMD	107	90	99	15

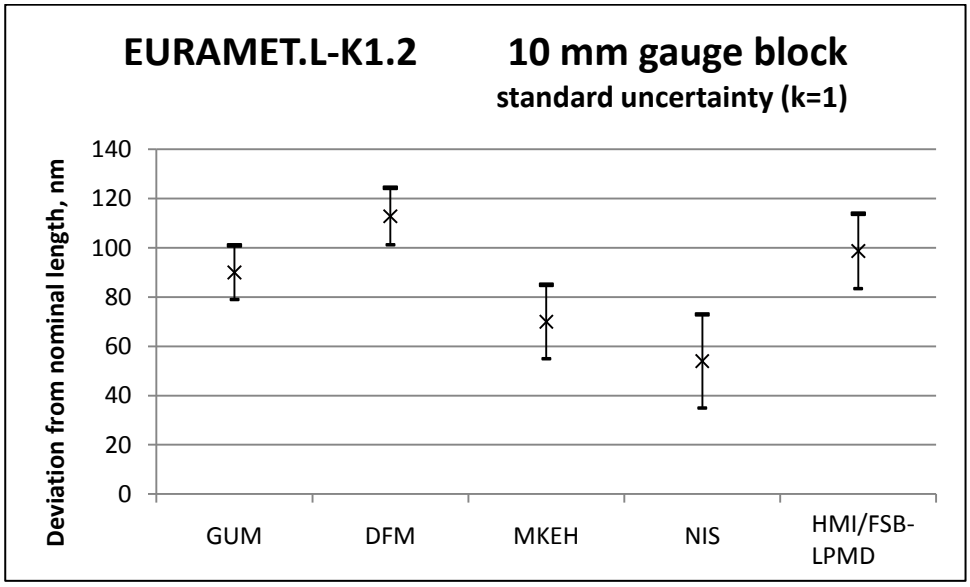

Figure 9.4.1 Graphical representation of results

Table 9.4.2 Results calculated from participants' values

10 mm	x_i-x_w	En		
GUM	-0,8	-0,04	u_{int}, nm	6,05
DFM	22,0	1,11	u_{ext}, nm	9,35
MKEH	-20,8	-0,76	R_B	1,55
NIS	-36,8	-1,02	$R_{B,crit}$	**1,55**
HMI/FSB-LPMD	8,2	0,30	x_w, nm	90,76

Table 9.4.3 Results calculated from largest consistent subset

10 mm	x_i-x_w	En		
GUM	7,5	0,44	u_{int}, nm	7,08
DFM	30,3	1,65	u_{ext}, nm	8,79
MKEH	-12,5	-0,47	R_B	1,24
NIS	-28,5	-0,81	$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	16,5	0,62	x_w, nm	82,54

9.5 Results of the 25 mm gauge block

Table 9.5.1 Results as reported by the participants

Nominal 25 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	-275	-240	-258	14
DFM	-254,7	-253,7	-254,2	12,3
MKEH	-260	-250	-250	19
NIS	-58	-62	-60	25
HMI/FSB-LPMD	-263	-243	-253	16

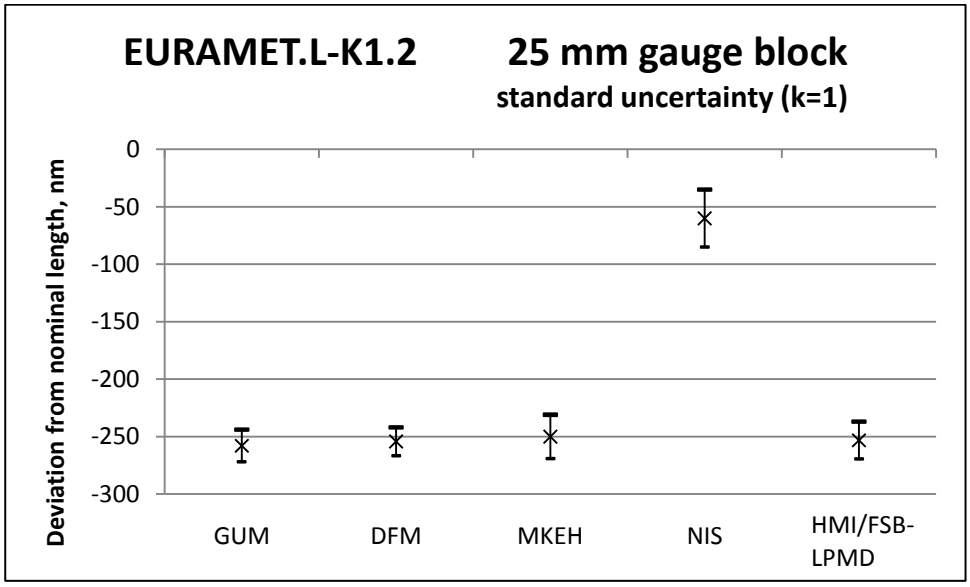

Figure 9.5.1 Graphical representation of results

Table 9.5.2 Results calculated from participants' values

25 mm	x_i-x_w	En		
GUM	-19,2	-0,79	u_{int}, nm	7,07
DFM	-15,4	-0,76	u_{ext}, nm	26,40
MKEH	-11,2	-0,32	R_B	3,73
NIS	178,8	3,73	$R_{B,crit}$	**1,55**
HMI/FSB-LPMD	-14,2	-0,49	x_w, nm	-238,81

Table 9.5.3 Results calculated from largest consistent subset

25 mm	x_i-x_w	En		
GUM	-3,6	-0,15	u_{int}, nm	7,37
DFM	0,2	0,01	u_{ext}, nm	1,52
MKEH	4,4	0,12	R_B	0,21
NIS	194,4	4,07	$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	1,4	0,05	x_w, nm	-254,37

9.6 Results of the 40 mm gauge block

Table 9.6.1 Results as reported by the participants

Nominal 40 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	-3	-1	-2	12
DFM	25,3	21,3	23,3	13,6
MKEH	250	250	250	19
NIS	-147	-151	-149	30
HMI/FSB-LPMD	26	-1	14	18

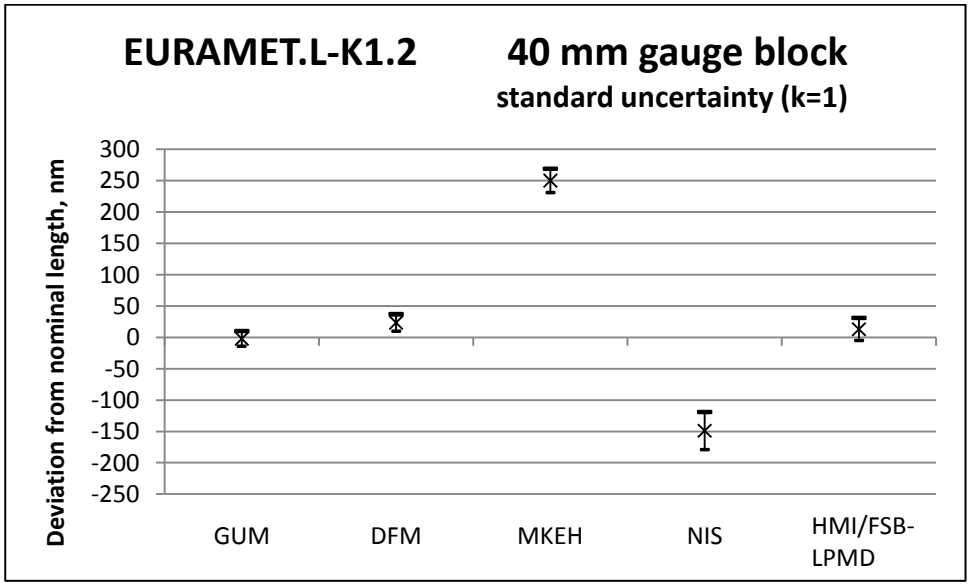

Figure 9.6.1 Graphical representation of results

Table 9.6.2 Results calculated from participants' values

40 mm	x_i-x_w	En		
GUM	-37,3	-1,94	u_{int}, nm	7,19
DFM	-12,0	-0,52	u_{ext}, nm	47,90
MKEH	214,7	6,10	R_B	6,66
NIS	-184,3	-3,16	$R_{B,crit}$	**1,55**
HMI/FSB-LPMD	-21,3	-0,65	x_w, nm	35,32

Table 9.6.3 Results calculated from largest consistent subset

40 mm	x_i-x_w	En		
GUM	-12,1	-0,68	u_{int}, nm	8,05
DFM	13,2	0,60	u_{ext}, nm	8,06
MKEH	239,9	6,97	R_B	1,00
NIS	-159,1	-2,75	$R_{B,crit}$	**1,73**
HMI/FSB-LPMD	3,9	0,12	x_w, nm	10,06

9.7 Results of the 60 mm gauge block

Table 9.7.1 Results as reported by the participants

Nominal 60 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	-357	-350	-354	13
DFM	-304,7	-322,7	-313,7	15,8
MKEH	310	300	300	24
NIS	60	58	59	36
HMI/FSB-LPMD	-341	-351	-346	21

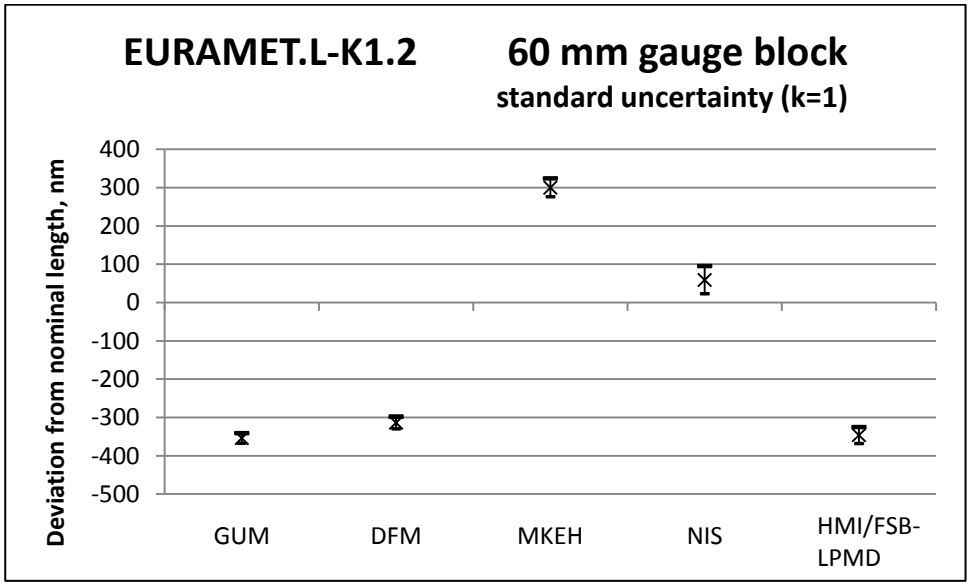

Figure 9.7.1 Graphical representation of results

Table 9.9.2 Results calculated from participants' values

60 mm	x_i-x_w	En		
GUM	-111,1	-5,53	u_{int}, nm	8,25
DFM	-70,8	-2,63	u_{ext}, nm	109,06
MKEH	542,9	12,04	R_B	13,22
NIS	301,9	4,31	$R_{B,crit}$	**1,55**
HMI/FSB-LPMD	-103,1	-2,67	x_w, nm	-242,85

Table 9.7.3 Results calculated from largest consistent subset

60 mm	x_i-x_w	En		
GUM	-14,7	-0,79	u_{int}, nm	9,06
DFM	25,6	0,99	u_{ext}, nm	12,82
MKEH	639,3	14,38	R_B	1,42
NIS	398,3	5,72	$R_{B,crit}$	**1,73**
HMI/FSB-LPMD	-6,7	-0,18	x_w, nm	-339,27

9.8 Results of the 90 mm gauge block

Table 9.8.1 Results as reported by the participants

Nominal 90 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	142	151	147	14
DFM	201,3	187,3	194,3	19,9
MKEH	210	210	210	32
NIS	-87	-105	-96	47
HMI/FSB-LPMD	142	154	148	27

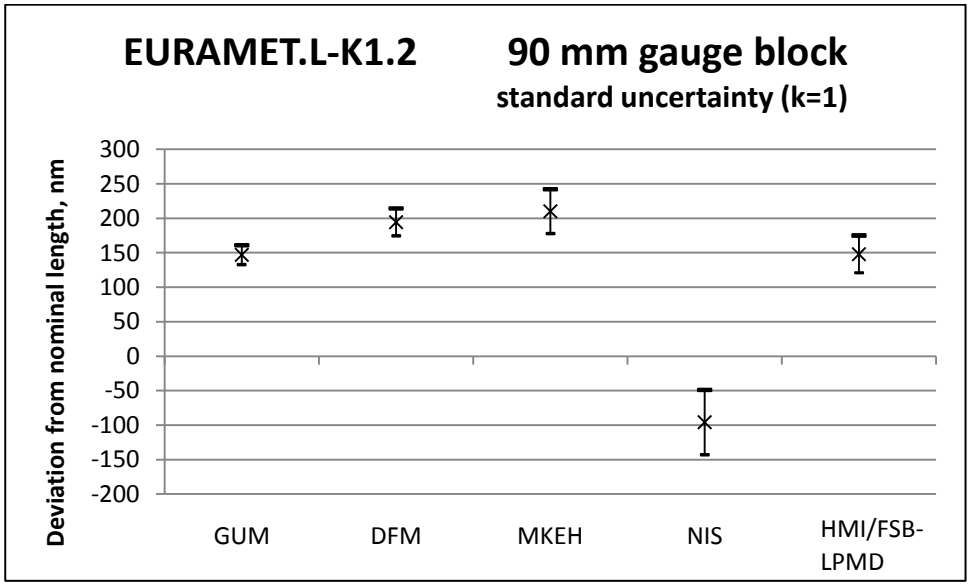

Figure 9.8.1 Graphical representation of results

Table 9.8.2 Results calculated from participants' values

90 mm	x_i-x_w	En		
GUM	-6,9	-0,35	u_{int}, nm	9,79
DFM	40,4	1,16	u_{ext}, nm	29,28
MKEH	56,1	0,92	R_B	2,99
NIS	-249,9	-2,72	$R_{B,crit}$	**1,55**
HMI/FSB-LPMD	-5,9	-0,12	x_w, nm	153,94

Table 9.8.3 Results calculated from largest consistent subset

90 mm	x_i-x_w	En		
GUM	-18,3	-0,93	u_{int}, nm	10,01
DFM	29,0	0,84	u_{ext}, nm	14,39
MKEH	44,7	0,74	R_B	1,44
NIS	-261,3	-2,84	$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	-17,3	-0,34	x_w, nm	165,28

10 FINAL RESULTS

10.1 Changes to the measurement results

After analysis of measurement results as they were submitted by the participants it was clear that the results as a whole were not consistent With respect to the measurement results published in Draft A1 report, MKEH was asked to clarify their measurement uncertainties. Measurement results reported by MKEH seemed to be rounded to 10 nm, and after consultation with other participants it was suggested to MKEH to increase their uncertainty to account for this rounding of the results. In response, MKEH increased their measurement uncertainties, as shown in Table 10.2.
MKEH also reported that they committed an error in reporting their measurement results for 40 mm and 60 mm gauge blocks, and requested that their corrected results be accepted. According to MKEH, the error was made because of manual copying of results from computer to paper- a clerical error which ordinarily could not happen because calibration results are usually reported electronically.
Their request, along with supporting documentation regarding the measurement of these gauge blocks, was communicated to other participants. After consultation it was decided that MKEH's corrections to 40 mm and 60 mm gauge block results shall be accepted.
During this time NIS was also asked to explain the nature of large En values in some of their measurements, since such large deviations with different signs seemed suspicious. After consultation NIS announced that they suspect that certain influences (possibly temperature) where unaccounted for in their measurements. Consequently, after agreement was reached with other participants, it was decided that all of NIS results will be treated as outliers and shall not be included in calculation of Reference Values.

The original measurement results, as reported by the participants, are given in Chapter 9, sections 9.1-9.8. Final measurement results, reflecting the changes in MKEH's measurement results and uncertainties are shown in Table 10.2. Detailed calculation for each gauge block is given in sections 10.3- 10.10.
Discussion about the impact of the changes that were made to the measurement results is given in Chapter 11.

10.2 Final measurement results

Table 10.2 Final measurement results, in nm, k=1

	GUM		**DFM**		**MKEH**		**NIS**		**HMI/FSB-LPMD**	
	ΔL	u_c	ΔL	u_c	ΔL	u_c	ΔL	u_c	ΔL	u_c
1 mm	56	11	82,3	11,5	30	20	41	16	73	15
5 mm	37	11	57,3	11,5	10	20	10,5	18	46	15
8 mm	90	11	112,3	11,6	70	20	50	19	88	15
10 mm	90	11	112,8	11,6	70	20	54	19	99	15
25 mm	-258	14	-254,2	12,3	-250	20	-60	25	-253	16
40 mm	-2	12	23,3	13,6	20	20	-149	30	14	18
60 mm	-354	13	-313,7	15,8	-300	30	59	36	-346	21
90 mm	147	14	194,3	19,9	210	40	-96	47	148	27

10.3 Results of the 1 mm gauge block

Table 10.3.1 Final results

Nominal 1 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	57	56	56	11
DFM	73,3	91,3	82,3	11,5
MKEH	30	20	30	20
HMI/FSB-LPMD	70	76	73,0	15

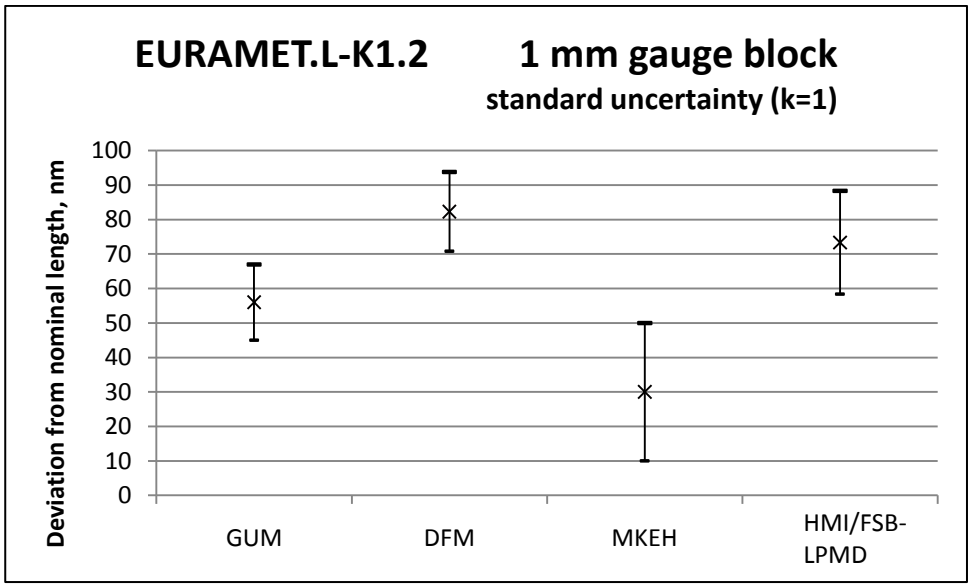

Figure 10.3.1 Graphical representation of results

Table 10.3.2 Results calculated from participants' values (=largest consistent subset)

1 mm	x_i-x_w	En		u_{int}, nm	6,63
GUM	-9,2	-0,52		u_{ext}, nm	9,59
DFM	17,1	0,91		R_B	1,45
MKEH	-35,2	-0,93		$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	7,8	0,29		x_w, nm	65,20
NIS	-24,2	-0,83			

10.4 Results of the 5 mm gauge block

Table 10.4.1 Final results

Nominal 5 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	38	35	37	11
DFM	48,3	66,3	57,3	11,5
MKEH	10	10	10	20
HMI/FSB-LPMD	48	42	46,0	15

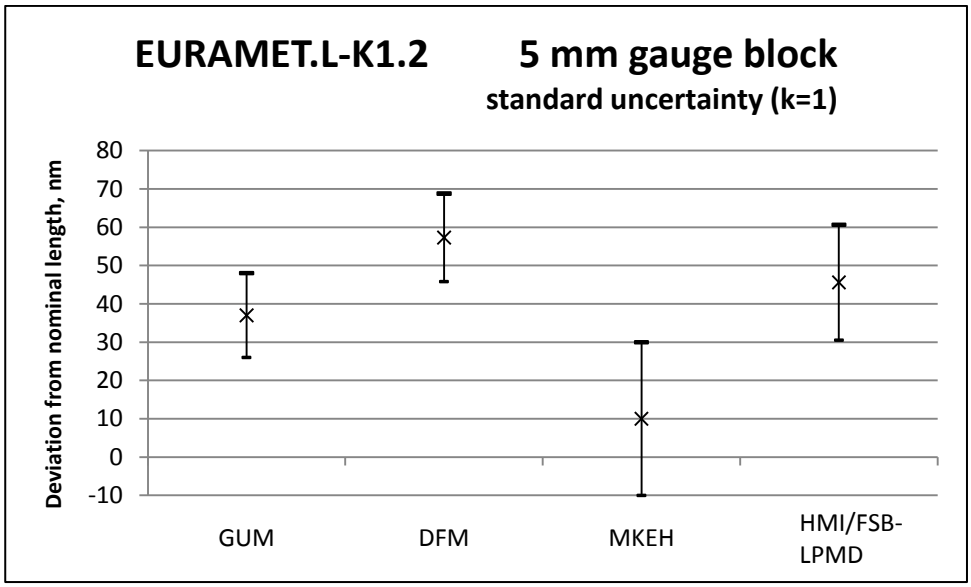

Figure 10.4.1 Graphical representation of results

Table 10.4.2 Results calculated from participants' values (=largest consistent subset)

5 mm	x_i-x_w	En		u_{int}, nm	6,63
GUM	-5,5	-0,32		u_{ext}, nm	8,21
DFM	14,8	0,79		R_B	1,24
MKEH	-32,5	-0,86		$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	3,5	0,13		x_w, nm	42,53
NIS	-32,0	-0,96			

10.5 Results of the 8 mm gauge block

Table 10.5.1 Final results

Nominal 8 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	92	89	90	11
DFM	102,3	122,3	112,3	11,6
MKEH	70	60	70	20
HMI/FSB-LPMD	87	88	88,0	15

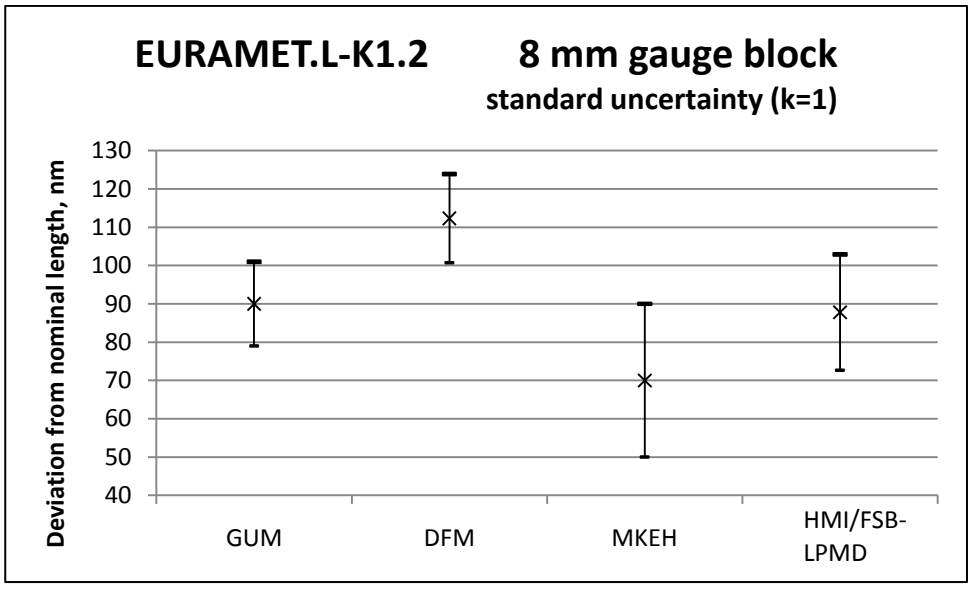

Figure 10.5.1 Graphical representation of results

Table 10.5.2 Results calculated from participants' values (=largest consistent subset)

8 mm	x_i-x_w	En		u_{int}, nm	6,65
GUM	-4,7	-0,27		u_{ext}, nm	7,87
DFM	17,6	0,92		R_B	1,18
MKEH	-24,7	-0,66		$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	-6,7	-0,25		x_w, nm	94,72
NIS	-44,7	-1,26			

10.6 Results of the 10 mm gauge block

Table 10.6.1 Final results

Nominal 10 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	87	93	90	11
DFM	111,3	114,3	112,8	11,6
MKEH	80	70	70	20
HMI/FSB-LPMD	107	90	99,0	15

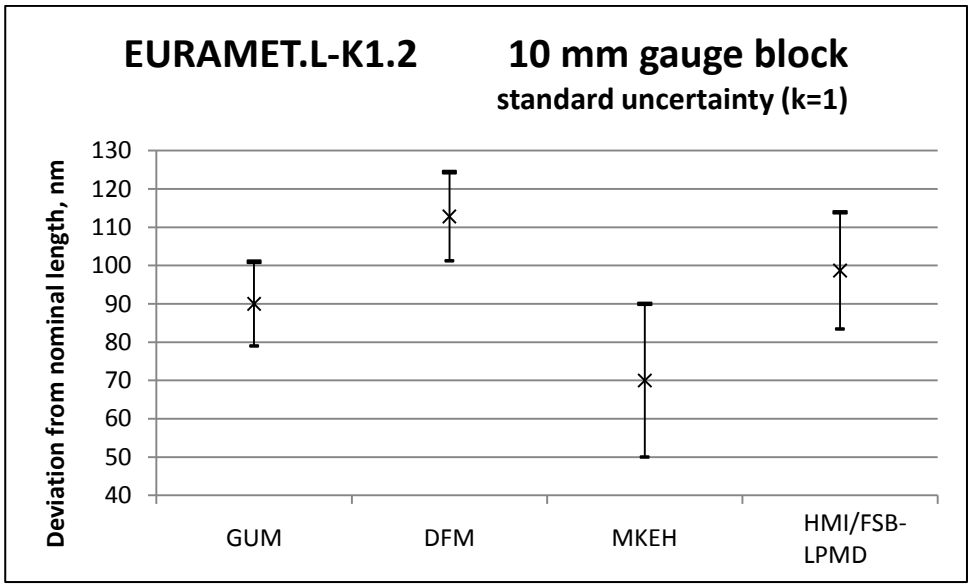

Figure 10.6.1 Graphical representation of results

Table 10.6.2 Results calculated from participants' values (=largest consistent subset)

10 mm	x_i-x_w	En		u_{int}, nm	6,65
GUM	-7,0	-0,40		u_{ext}, nm	7,77
DFM	15,8	0,83		R_B	1,17
MKEH	-27,0	-0,72		$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	2,0	0,07		x_w, nm	97,04
NIS	-43,0	-1,21			

10.7 Results of the 25 mm gauge block

Table 10.7.1 Final results

Nominal 25 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	-275	-240	-258	14
DFM	-254,7	-253,7	-254,2	12,3
MKEH	-260	-250	-250	20
HMI/FSB-LPMD	-263	-243	-253,0	16

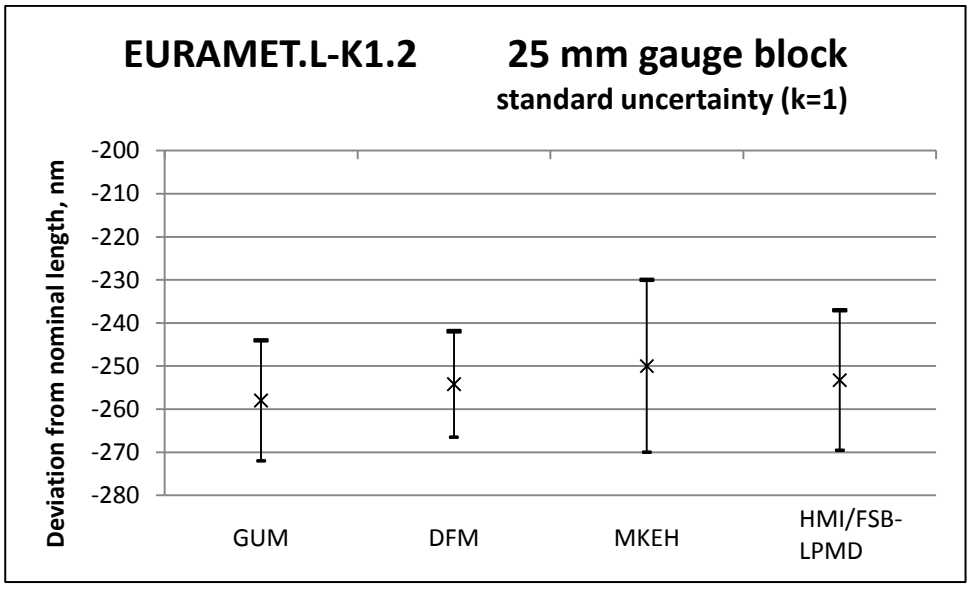

Figure 10.7.1 Graphical representation of results

Table 10.7.2 Results calculated from participants' values (=largest consistent subset)

25 mm	x_i-x_w	En		u_{int}, nm	7,43
GUM	-3,6	-0,15		u_{ext}, nm	1,50
DFM	0,2	0,01		R_B	0,20
MKEH	4,4	0,12		$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	1,4	0,05		x_w, nm	-254,43
NIS	194,4	4,07			

10.8 Results of the 40 mm gauge block

Table 10.8.1 Final results

Nominal 40 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	-3	-1	-2	12
DFM	25,3	21,3	23,3	13,6
MKEH	30	20	20	20
HMI/FSB-LPMD	26	-1	14,0	18

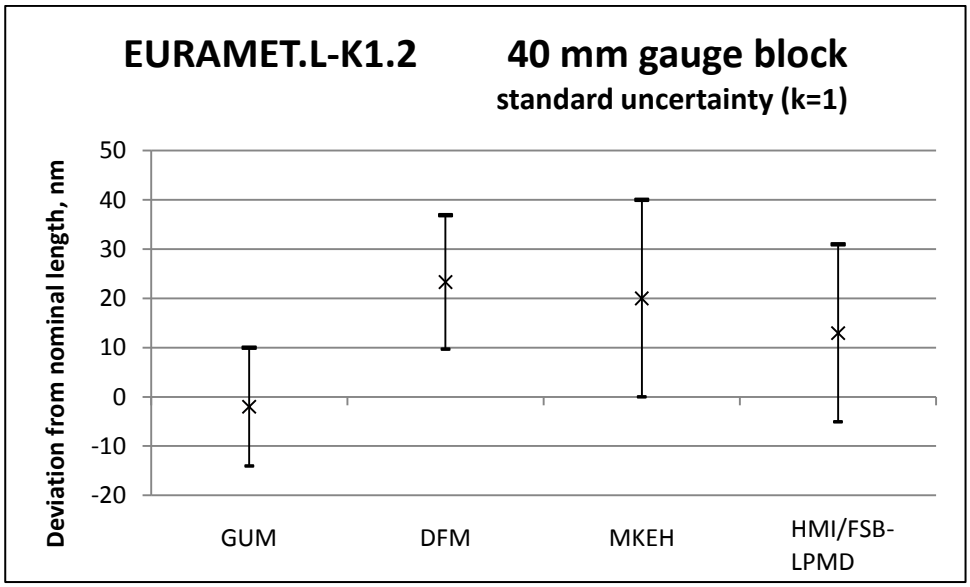

Figure 10.8.1 Graphical representation of results

Table 10.8.2 Results calculated from participants' values (=largest consistent subset)

40 mm	x_i-x_w	En		u_{int}, nm	7,47
GUM	-13,4	-0,72		u_{ext}, nm	6,42
DFM	11,9	0,52		R_B	0,86
MKEH	8,6	0,23		$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	2,6	0,08		x_w, nm	11,45
NIS	-160,4	-2,76			

10.9 Results of the 60 mm gauge block

Table 10.9.1 Final results

Nominal 60 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	-357	-350	-354	13
DFM	-304,7	-322,7	-313,7	15,8
MKEH	-310	-300	-300	30
HMI/FSB-LPMD	-341	-351	-346,0	21

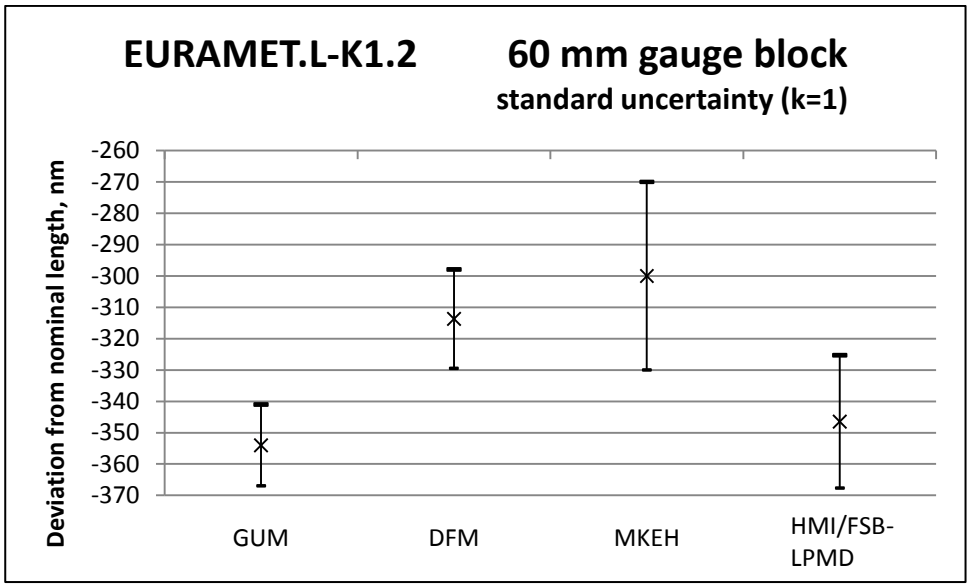

Figure 10.9.1 Graphical representation of results

Table 10.9.2 Results calculated from participants' values (=largest consistent subset)

60 mm	x_i-x_w	En		u_{int}, nm	8,67
GUM	-18,0	-0,93		u_{ext}, nm	11,82
DFM	22,3	0,84		R_B	1,36
MKEH	36,0	0,63		$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	-10,0	-0,26		x_w, nm	-335,99
NIS	395,0	5,65			

10.10 Results of the 90 mm gauge block

Table 10.10.1 Final results

Nominal 90 mm	L1 nm	L2 nm	L nm	u, k=1 nm
GUM	142	151	147	14
DFM	201,3	187,3	194,3	19,9
MKEH	210	210	210	40
HMI/FSB-LPMD	142	154	148,0	27

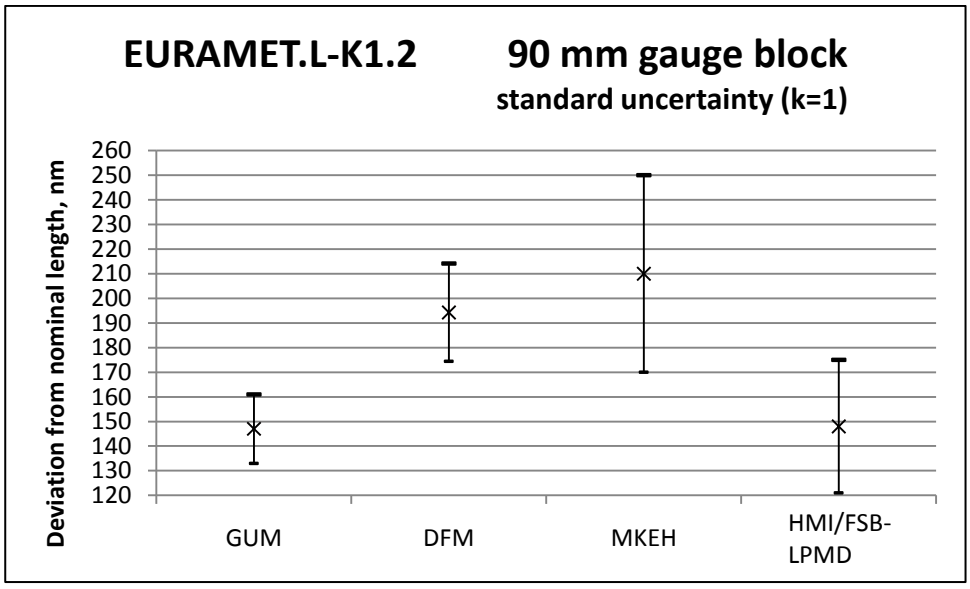

Figure 10.10.1 Graphical representation of results

Table 10.10.2 Results calculated from participants' values (=largest consistent subset)

90 mm	x_i-x_w	En		u_{int}, nm	10,19
GUM	-16,6	-0,87		u_{ext}, nm	13,76
DFM	30,7	0,90		R_B	1,35
MKEH	46,4	0,60		$R_{B,crit}$	**1,62**
HMI/FSB-LPMD	-15,6	-0,31		x_w, nm	163,64
NIS	-259,6	-2,83			

11 DISCUSSION OF FINAL MEASUREMENT RESULTS

As a result of changes described in 10.2, it is obvious that just by excluding NIS results (highlighted in yellow in Sections 10.3- 10.10.) from calculation of Reference Values the dataset became substantially more consistent. En values for NIS were calculated as uncorrelated according to Section 8- (10).

After inclusion of MKEH's increased uncertainties and corrected results for 40 mm and 60 mm gauge blocks, the entire set of measurement results became statistically consistent, without the need for additional iterations on any of the gauge blocks.

Figures 11.1 and 11.2 show differences between wringing faces and deviations from weighted mean for the final results. It can be seen that the difference between wringing faces increased slightly during the course of the intercomparison, which can be attributed to mechanical wear of the measurement surfaces. Deviations from weighted mean indicate that certain conclusions can be derived with regard to the sign of deviation per laboratory, meaning that some laboratories deviated from reference value in the positive direction, and some in the negative direction. This can indicate the existence of a systematic difference between the laboratories, most probably the phase correction value.

Figure 11.3 shows a comparison histogram of E_n values, for original results as reported by the participants and for the final results. It is obvious from Figure 11.3 that in the final result set all E_n values fall within ±1 range, with k=2.

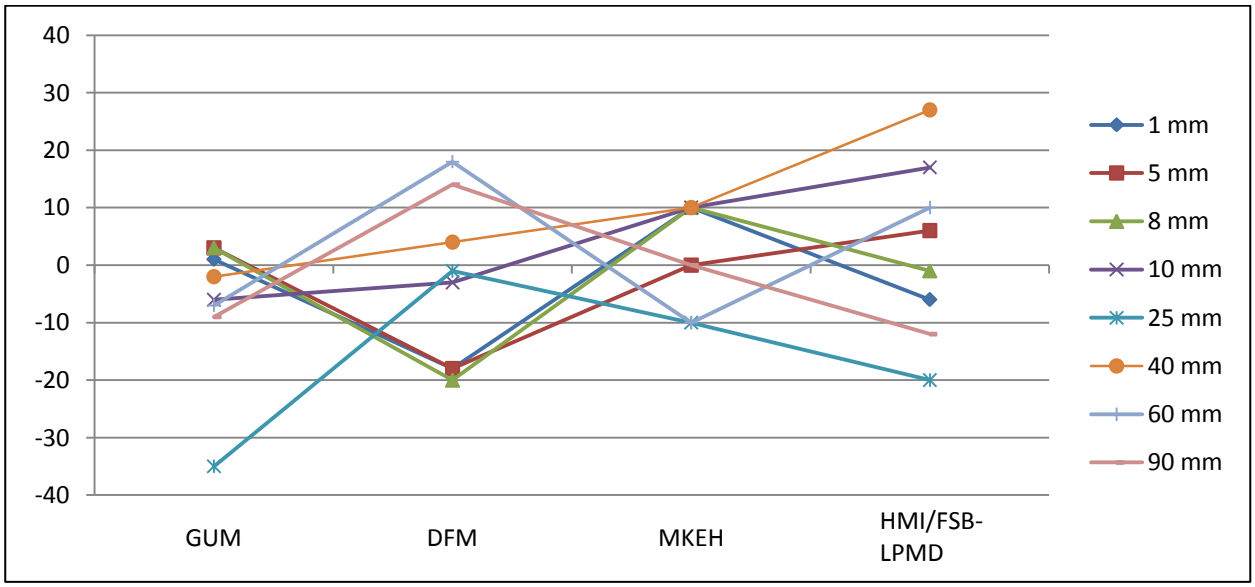

Figure 11.1 Difference between left and right wringing.

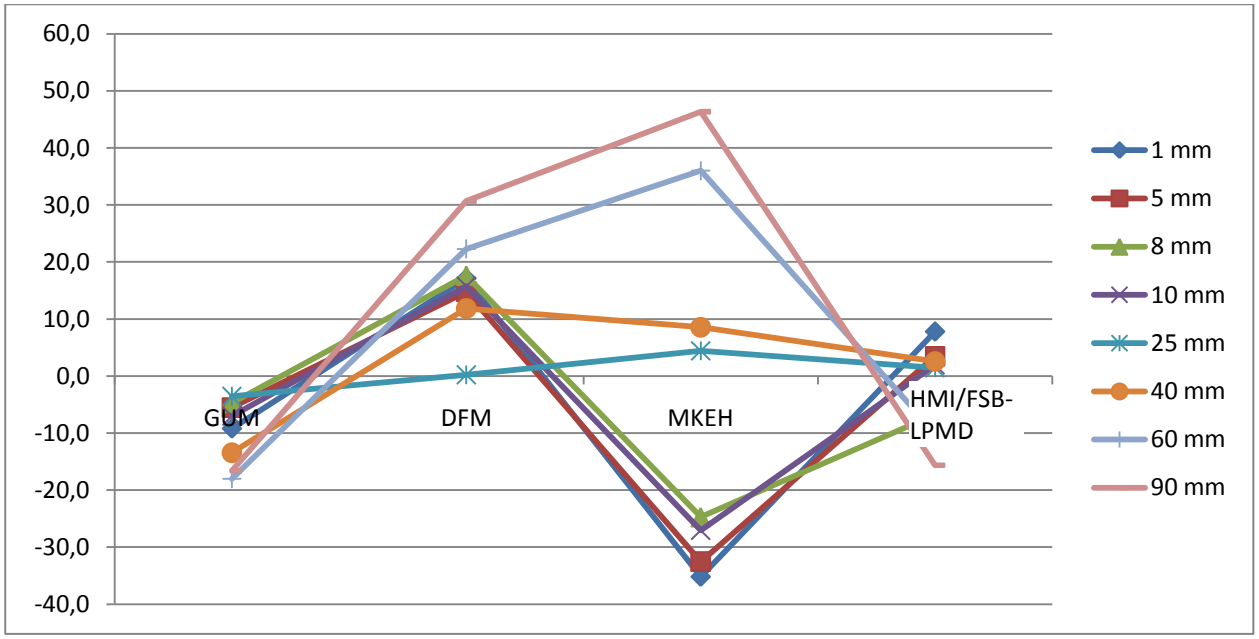

Figure 11.2 Deviations from weighted means.

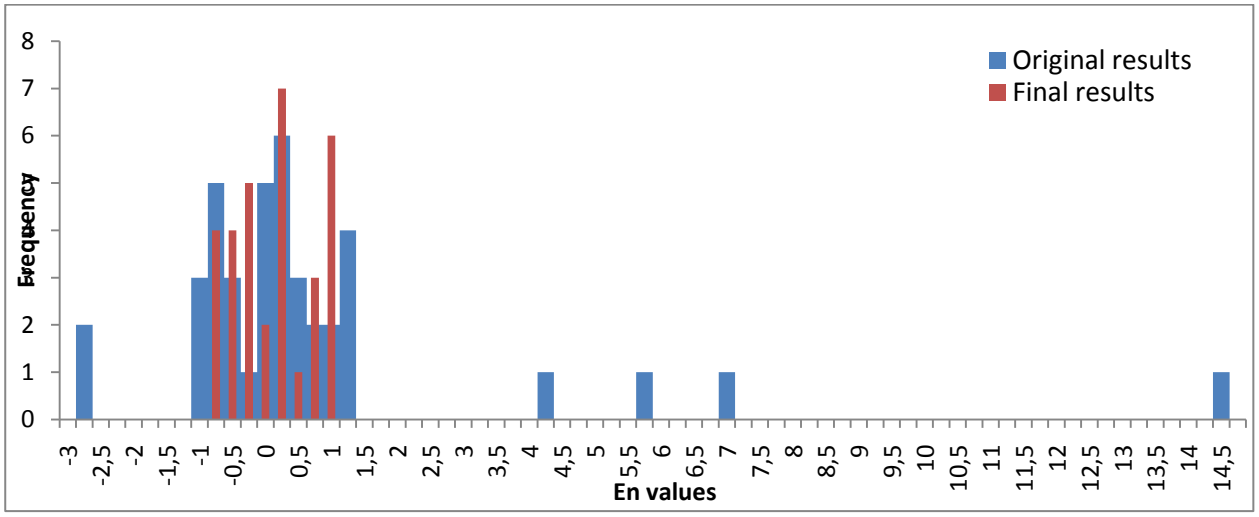

Figure 11.3 Histogram of En values

APPENDIX 1: KEY COMPARISON REFERENCE VALUES

In order to satisfy the requirements of the Mutual Recognition Arrangement, the 'Key Comparison Reference Values' have been evaluated according to the method described in Chapter 8: the weighted mean was determined and the deviations from the weighted mean were then calculated. The uncertainty of the weighted mean is based on the internal standard deviation of the final measurement results.
The results of the pilot laboratory contribute only once to the calculation of the reference values. This excludes the preliminary 'stability' measurements of the gauge blocks, performed by the pilot laboratory.
Table A1 shows the Key Comparison Reference Values and their standard uncertainties.

Table A1 Key Comparison Reference Values and associated standard uncertainty (k=1).

Serial number	Nominal length (mm)	Reference value (nm)	Reference value uncertainty (nm)
87656	1	65,2	6,6
87656	5	42,5	6,6
87656	8	94,7	6,7
87623	10	97	6,7
87680	25	-254,4	7,4
87680	40	11,5	7,5
87680	60	-336	8,7
87623	90	163,6	10,2

APPENDIX 2: COMPARISON WITH REFERENCE VALUES

Table A2 shows the differences of measured values with respect to Key Comparison Reference Values and the expanded (k=2) uncertainties of these differences, calculated by:

$$U(x_i - \bar{x}_{ref}) = 2\sqrt{u^2(x_i) - u^2(\bar{x}_{ref})}$$

where $u(x_i)$ is the standard uncertainty of the laboratory result x_i and $u(x_{ref})$ is the standard uncertainty of the reference value x_{ref}.

Table A2 Differences of measured values and KCRV's, with expanded uncertainties (k=2)

Gauge block \ Lab.		GUM	DFM	MKEH	HMI/FSB -LPMD
1 mm	x_i-x_{ref}	-9,2	17,1	-35,2	7,8
	$U(x_i$-$x_{ref})$	17,6	18,8	37,7	26,9
5 mm	x_i-x_{ref}	-5,5	14,8	-32,5	3,5
	$U(x_i$-$x_{ref})$	17,6	18,8	37,7	26,9
8 mm	x_i-x_{ref}	-4,7	17,6	-24,7	-6,7
	$U(x_i$-$x_{ref})$	17,5	19	37,7	26,9
10 mm	x_i-x_{ref}	-7,0	15,8	-27,0	2,0
	$U(x_i$-$x_{ref})$	17,5	19	37,7	26,9
25 mm	x_i-x_{ref}	-3,6	0,2	4,4	1,4
	$U(x_i$-$x_{ref})$	23,7	19,6	37,1	28,3
40 mm	x_i-x_{ref}	-13,4	11,9	8,6	2,6
	$U(x_i$-$x_{ref})$	18,8	22,7	37,1	32,8
60 mm	x_i-x_{ref}	-18,0	22,3	36,0	-10,0
	$U(x_i$-$x_{ref})$	19,4	26,4	57,4	38,3
90 mm	x_i-x_{ref}	-16,6	30,7	46,4	-15,6
	$U(x_i$-$x_{ref})$	19,2	34,2	77,4	50

Figures A2.1 through A2.8 show the graphs of Degrees of Equivalence for the eight gauge blocks.

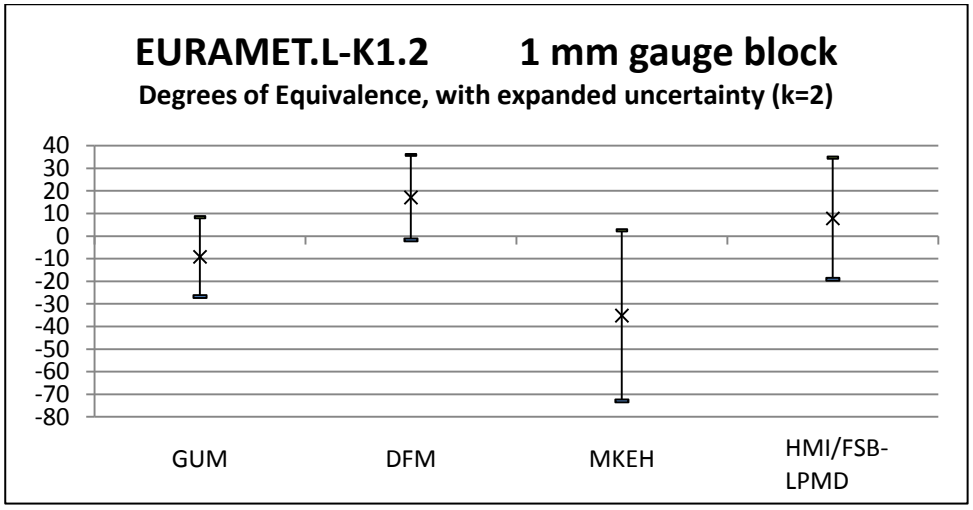

Figure A2.1 Degrees of Equivalence for 1 mm gauge block

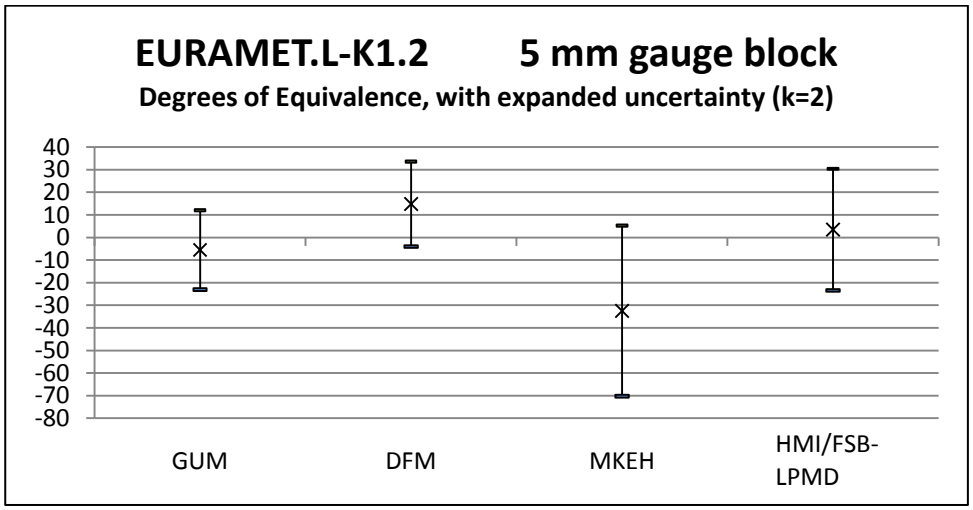

Figure A2.2 Degrees of Equivalence for 5 mm gauge block

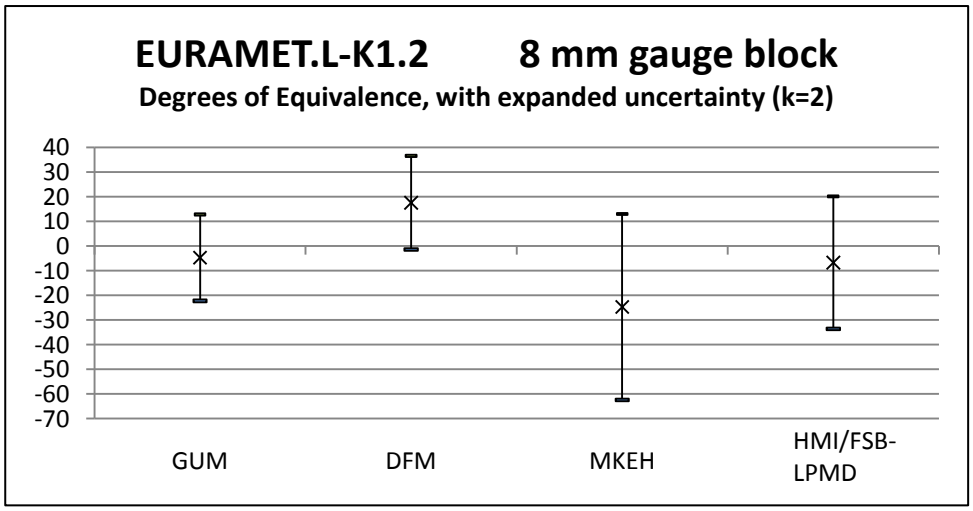

Figure A2.3 Degrees of Equivalence for 8 mm gauge block

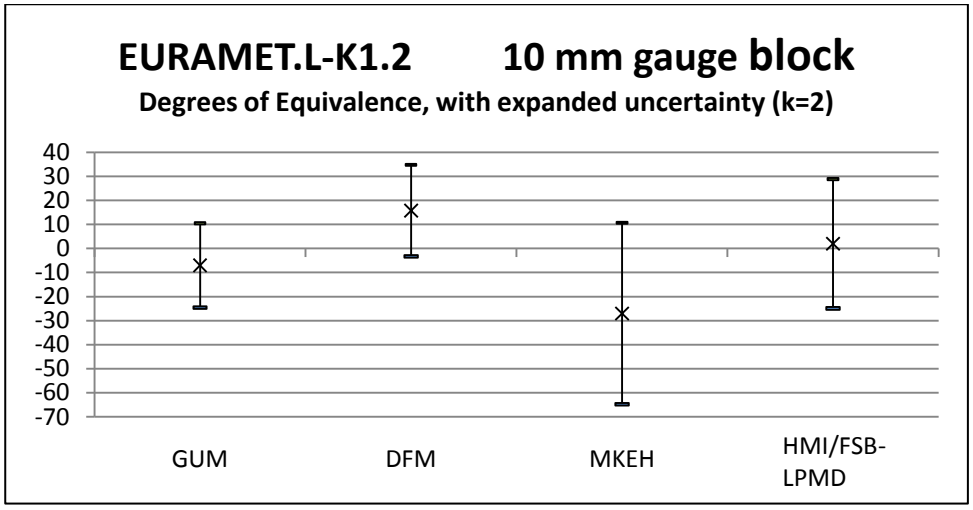

Figure A2.4 Degrees of Equivalence for 10 mm gauge block

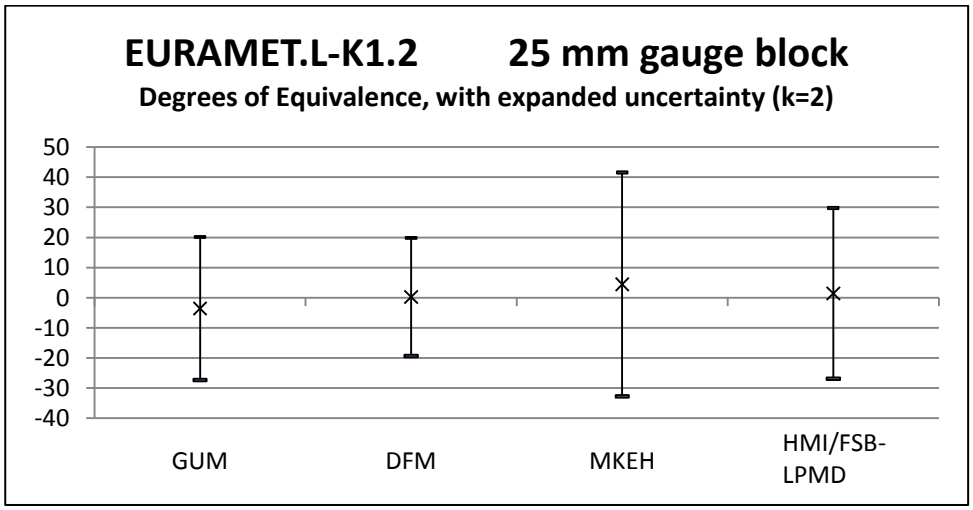

Figure A2.5 Degrees of Equivalence for 25 mm gauge block

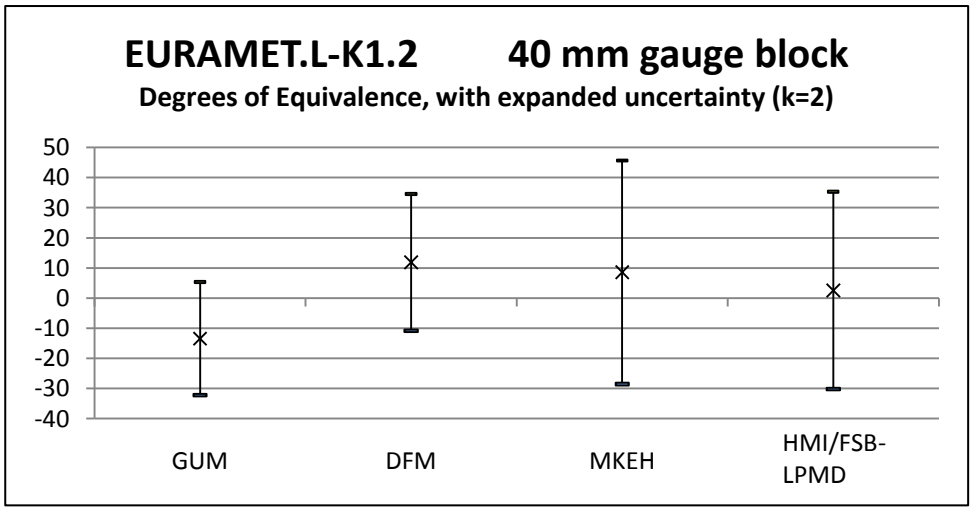

Figure A2.6 Degrees of Equivalence for 40 mm gauge block

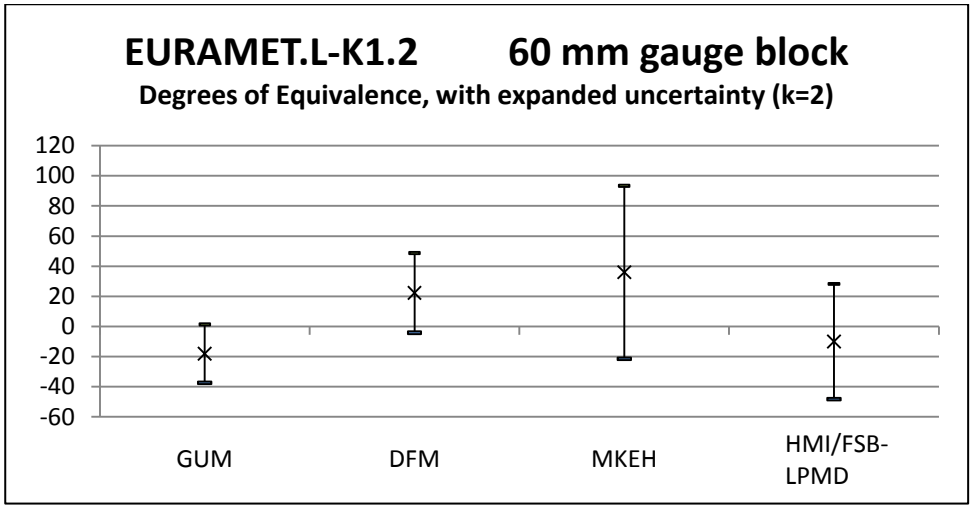

Figure A2.7 Degrees of Equivalence for 60 mm gauge block

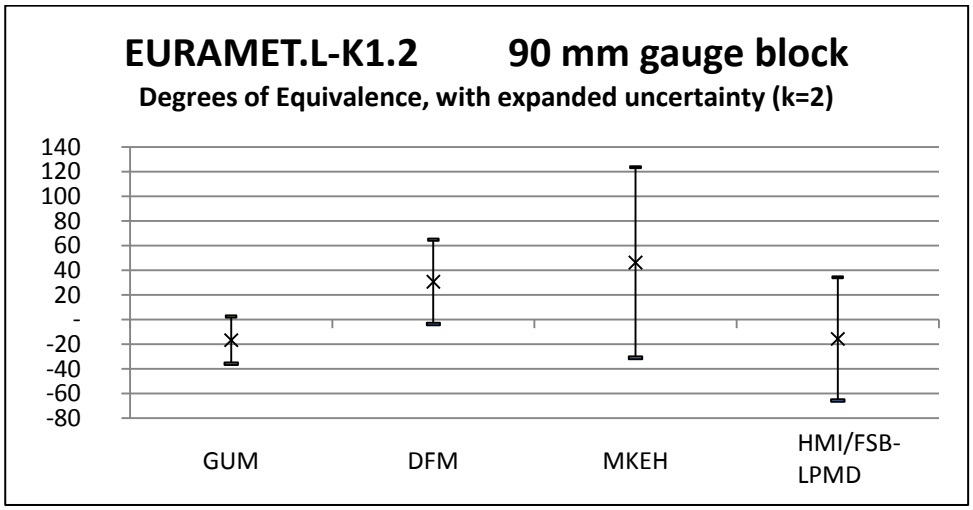

Figure A2.8 Degrees of Equivalence for 90 mm gauge block

APPENDIX 2.1: EFFECT OF THE RESULTS TO CMC CLAIMS

In order to asses the impact of results given in Appendix 2 to published CMCs of participating laboratories, or the possibility of future claims of CMCs, an analysis of participants' results has been performed. Table A2.1.1 shows the CMC claims of participants that are published in the KCDB compared against their results in this intercomparison.

Table A2.1.1: Comparison of existing CMC claims and performance in EURAMET.L-K1.2

Laboratory	CMC value, k=2	Uncertainty reported in EURAMET.L-K1.2, k=2	Supports CMC claims/ future submission
GUM	Q[34, 0.44*L*]	Q[21, 0.2*L*]	YES
DFM	Q[23, 0.36*L*]	Q[23, 0.36*L*]	YES
MKEH	Q[50, 0.8*L*]	Q[40, 0.6*L*]	YES
NIS	-	Q[32, 0.68*L*]	NO
HMI/FSB-LPMD	-	Q[30, 0.5*L*]	YES

In conclusion it can be stated that, due to good performance of participating laboratories, an Executive Report is not neccessary. The results of EURAMET.L-K1.2 support the CMC claims made by GUM, DFM and MKEH, as well as future CMC submission of HMI/FSB-LPMD.
Due to problems with NIS results (as described in Section 10.1), the uncertainty claim made by NIS is not supported by this Key Comparison.