MITTATEKNIIKAN KESKUS

CENTRE FOR METROLOGY AND ACCREDITATION

Publication J4/2002

EUROMET PROJECT 639

CALIBRATION OF GAUGE BLOCKS BY MECHANICAL COMPARISON

Northern European Comparison
Final Report

A. Lassila

Helsinki 2002
Finland

Centre for Metrology and Accreditation,
MIKES

Publication J4/2002

Northern European Comparison:
Calibration of gauge blocks by mechanical comparison, final report

A. Lassila

EUROMET Project no.: 639

Helsinki, 25 November 2002

Table of contents

1. Introduction

This comparison was undertaken to verify the competence of participating laboratories in mechanical gauge block calibrations up to 300 mm length. The initiative was taken by the Estonian national measurement institute Metrosert. The protocol used was adapted from EUROMET comparison 601 with small changes. The participants agreed that this would be carried out as a co-operational EUROMET project rather than as a supplementary comparison. Thus the general EUROMET guidelines for comparisons were essentially followed. The EUROMET project reference number is 639.

2. Organisation

MIKES operated as a pilot laboratory for the comparison.

2.1 Participants

The participating institutes with contact information are listed in table 1.

Table 1. List of participants.

Contact person	Institute	
Heikki Lehto	Centre for Metrology and Accreditation (MIKES) Metallimiehenkuja 6 Fin-02150 Espoo Finland	Tel. +358 9 456 5350 Fax +358 9 460 627 e-mail: heikki.lehto@mikes.fi
Toomas Kübarsepp	Metrosert Ltd Nolvaku 12 50002 Tartu Estonia	Tel.: +372 7 302 938 Fax: +372 7 302 931 e-mail: tkubarsepp@metrosert.ee
Edite Turka	Latvian National Metrology Centre (LNMC) Kr. Valdemāra 157 LV-1013 Rīga Latvia	Tel. : +371 2 7378165, Fax : +371 2 7362805 e-mail: edite@lnmc.lv
Lilijana Gaidamoviciute	SC Vilnius metrology centre (VMC) Dariaus ir Gireno 23 2000 Vilnius Lietuva (Lithuania)	Tel: +370 2 306 276 Fax: +370 2 233 727 e-mail: vmc@taide.lt
Stefan Källberg	SP Swedish National Testing and Research Institute Box 857 (Brinellgatan 4) SE-501 15 Borås Sweden	Tel. : +46 33 16 56 26 Fax: +46 33 16 56 20 e-mail: stefan.kallberg@sp.se
Co-ordinator:		
Antti Lassila	Centre for Metrology and Accreditation (MIKES) P.O. Box 239 (Lönnrotinkatu37) FIN-00181 Helsinki Finland	Tel. +358 9 616 7521 Fax +358 9 616 7467 e-mail: antti.lassila@mikes.fi

2.2 Time schedule & transportation

The planned circulation scheme is listed in table 2. The timetable was followed very closely and the gauge blocks were returned to MIKES on 23rd January 2002. No significant damage to the gauge blocks from circulation or measurements was observed. Transportation was delegated to several courier services and the gauge blocks were covered by an ATA Carnet to facilitate customs formalities in the Baltic region. Each laboratory was responsible for organising delivery to the next participant or pilot. Recommended ways for transportation were use of a courier service or delivery by laboratory personnel.

Table 2. Circulation scheme.

Laboratory	**Country**	**Date**
MIKES	FI	1.10.2001-21.10.2001
Metrosert	EE	22.10.2001-11.11.2001
VMC	LT	12.11.2001-2.12.2001
LNMC	LV	3.12.2001-23.12.2001
Transportation via MIKES to SP		
SP	SE	2.1.2002-22.1.2002
MIKES	FI	23.1.2002-12.2.2002

3. Description of standards

Eleven gauge blocks of steel were selected for the comparison. The nominal lengths of the blocks were from 0,5 mm up to 300 mm. The gauge blocks were of grade 0 and rectangular cross section, according to the international standard ISO 3650 [1]. More detailed information is given in table 3.

Table 3. Details of gauge blocks.

Identification	Nominal length [mm]	Expansion coeff. [10^{-6} K^{-1}]	Manufacturer
H26984	0,5	11,7±1	TESA
H15200	1	11,7±1	TESA
G75473	2	11,7±1	TESA
G70327	10	11,7±1	TESA
H22481	25	11,7±1	TESA
H20130	50	11,7±1	TESA
H27164	75	11,7±1	TESA
H33195	100	11,7±1	TESA
100550	150	11,7±1	TESA
100550	200	11,7±1	TESA
100550	300	11,7±1	TESA

4. Measurement instructions & calibration technique

The technical protocol of the comparison gave more detailed instructions for calibration of the gauge blocks. The participants were requested to calibrate the blocks by mechanical comparison with their laboratory's reference gauge blocks as regulated in ISO 3650. The gauge block temperature and/or surface plate temperature was recorded at the beginning and end of the calibration. The recommended orientation of the gauges up to 100 mm was vertical, and for longer gauges horizontal. When calibration was done in the horizontal position the gauge had to be supported from Bessel points (marked on the gauges). The participants were ask to send uncertainty calculations for 100 mm and 300 mm gauge blocks. The participants were also requested to measure the variation in length of the gauge block with additional four measurement points situating at the corners approximately 1,5 mm from the two closest side faces.

Table 4 gives details of the instruments used by each laboratory. All participants used steel reference gauges. The measurement forces of the used devices were also similar.

Table 4. Types of calibration devices.

Laboratory	Instrument 0-100 mm	Position	Instrument >100 mm	Position	Traceability of reference standards
MIKES	TESA UPC, Ch	vert.	TESA, Ch	vert.	MIKES by interferometry
Metrosert	TESA UPC, Ch	vert.	TESA UPC	vert.	Mitutoyo, METAS
VMC	MAHR, De	vert.	IKPV, Ru	hor.	0-100 mm: DFM; >100: TEST-St. Petersborough
LNMC	IKPV, Ru	vert.	IZM-11, Ru	hor.	0-100 mm: DFM, 75 mm, >100mm: VNIIM
SP	TESA UPC, Ch	vert.	TESA UPC, Ch	vert.	SP by interferometry

5. Comparison data

Table 5 lists the reported results with associated uncertainties from each laboratory. The same data are shown in graph form in figures 1 and 2. For interest, the results of interferometric measurements carried out at MIKES before the comparison are included.

Table 5. Reported results of laboratories as deviation from nominal value of the gauge and with associated standard uncertainty. The reported temperature during the measurement is also shown.

Nominal	MIKES1		Metrosert		VMC		LNMC		SP		MIKES2		MIKES
length L		u (k=1)		u (k=1)		u (k=1)		u (k=1)		u (k=1)		u (k=1)	interferometric result
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
0,5	-10	19	0	27	-54	24	-20	40	-30	21	-30	19	-8
1	-35	19	-30	27	-65	23	-40	40	-40	21	-35	19	-32
2	-35	19	-30	28	-52	22	-10 (1	41	0	21	-35	19	-27
10	-95	19	-90	29	-141	23	-120	44	-90	21	-105	19	-108
25	5	20	30	32	-22 (2	26	-40	50	40	22	0	20	26
50	120	23	120	38	72	33	40	60	130	25	120	23	122
75	-180	27	-120	43	-221	41	-260	70	-170	30	-190	27	-168
100	235	31	210	50	167	50	180	80	240	35	225	31	239
150	-230	83	-180	118	-328	152	-380	187	-330	35	-245	83	-314
200	0	102	90	140	-332	189	40	200	0	42	10	102	-5
300	130	143	260	185	-484	263	40	225	70	57	165	143	130
t_g [°C]	19,70	±0,10	20,08	±0,20	19,92	±0,24	20,09	±0,50	19,99	±0,05	19,90	±0,10	

(1 LNMC found out during draft A phase that they had used wrong value for the length of 2 mm reference standard. This is calculated with right value. The old value was +80 nm.

(2 VMC announced during the draft A phase that they had found an arithmetic error in their calculations and had corrected this result. The old value was -94 nm. All participants accepted the correction.

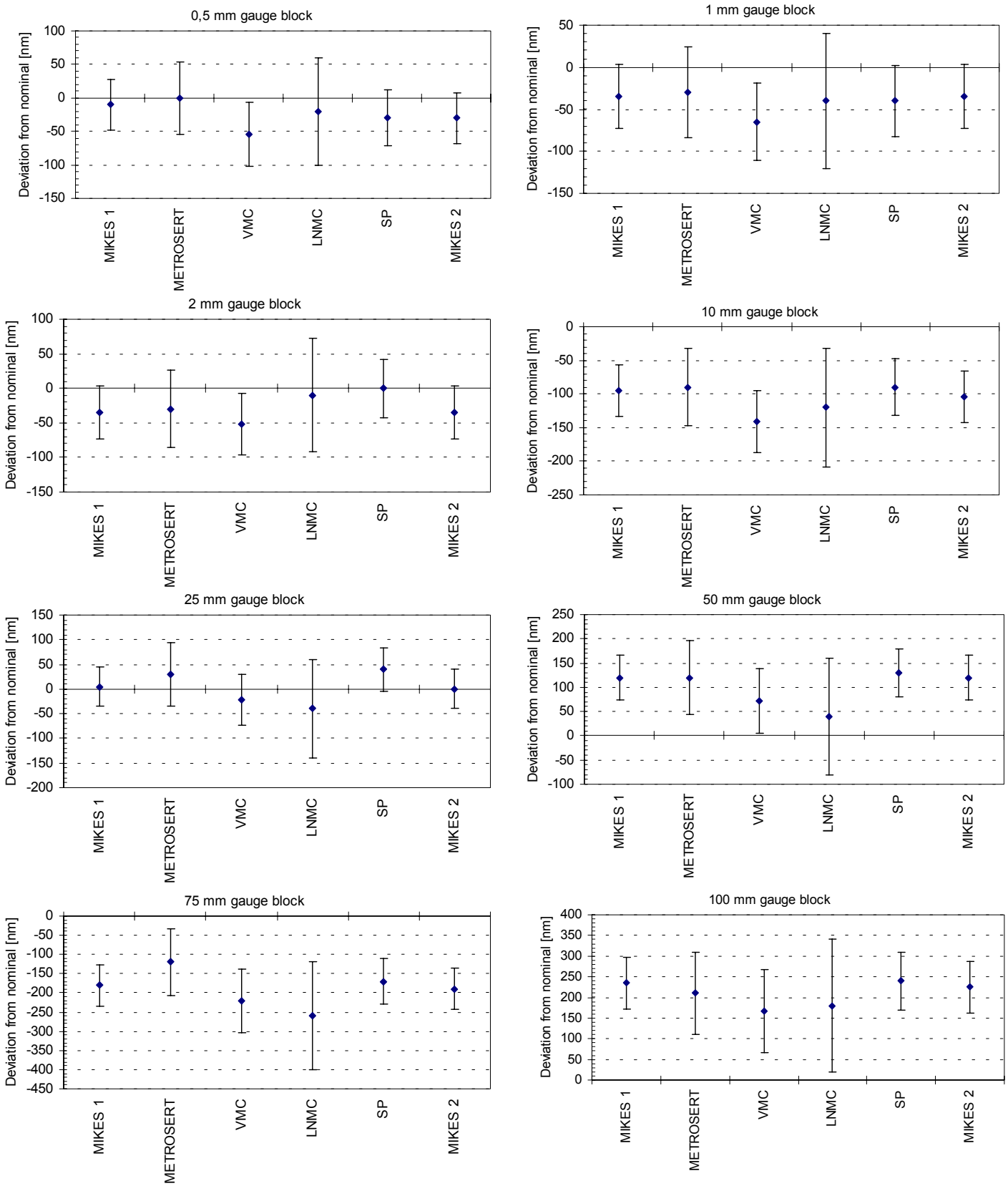

Figure 1. Results for gauge blocks from 0,5 mm to 100 mm. The bars indicate expanded uncertainty (*k*=2).

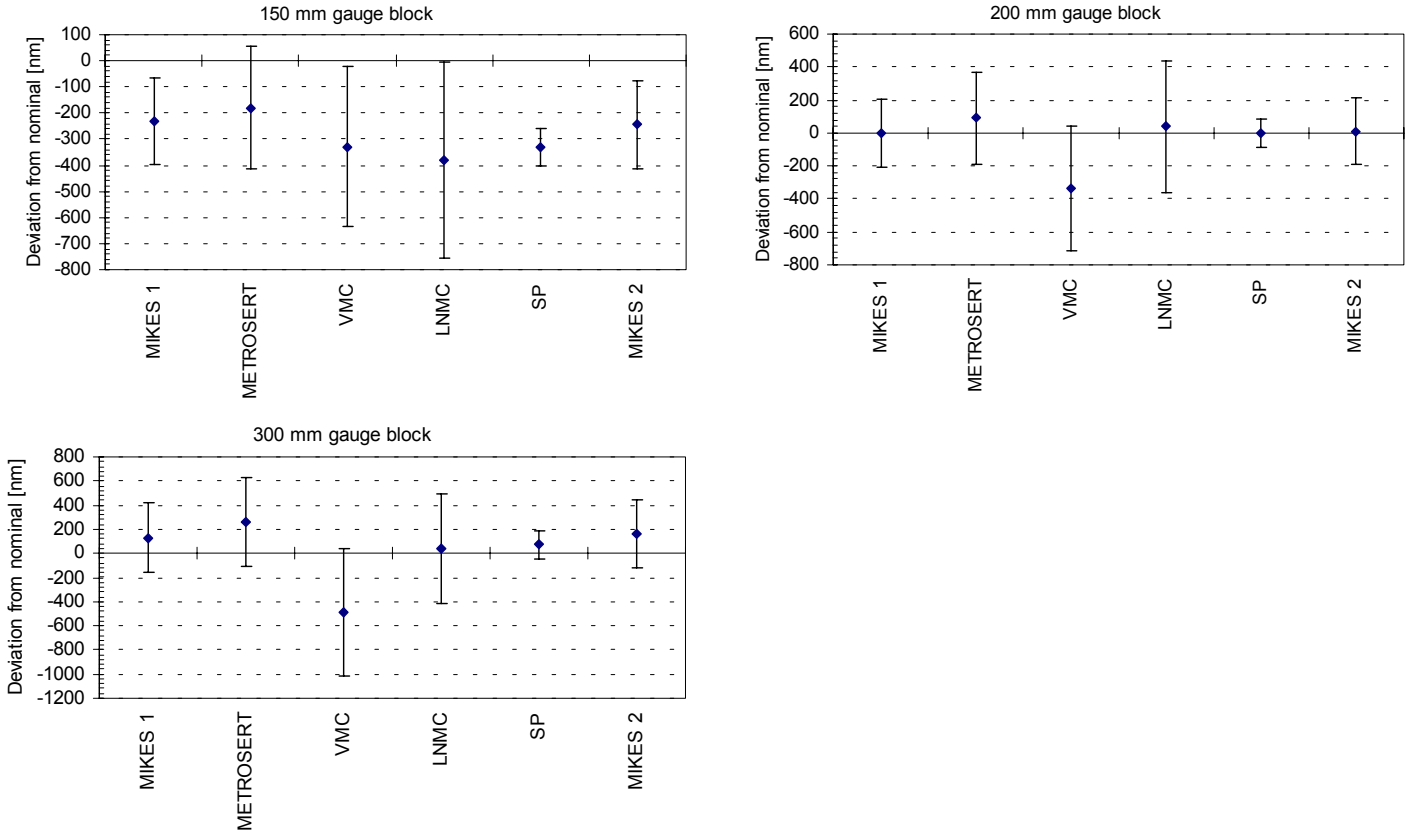

Figure 2. Results for 150, 200 and 300 mm gauge blocks. The bars indicate expanded uncertainty (*k*=2).

The variation in length data is given in table 6. The pilot has calculated f_o and f_u values [1] from the data provided by the participants.

The f_o and f_u values have been calculated from 5 measurement points as follows:

$$f_o = \max\{\delta x_c, \delta x_2, \delta x_3, \delta x_4, \delta x_5\}, \quad (1)$$

$$f_u = \min\{\delta x_c, \delta x_2, \delta x_3, \delta x_4, \delta x_5\}, \quad (2)$$

$$\delta x_i = x_i - x_c, \quad i = (2,...,5); \quad \delta x_c = 0 \quad (3)$$

where x_c is measured deviation from the nominal length at centre of the gauge, when $x_{2,}\, x_{3,}\, x_4$ and x_5 are corresponding readings near the corners.

Table 6. Data of the variation in length measurements.

Gauge block	MIKES1			Metrosert			VMC			LNMC			SP			MIKES2			Average of	Standard deviation of
L	f_o	f_u	$f_o - f_u$	f_o	f_u	$f_o - f_u$	f_o	f_u	$f_o - f_u$	f_o	f_u	$f_o - f_u$	f_o	f_u	$f_o - f_u$	f_o	f_u	$f_o - f_u$	$f_o - f_u$	$f_o - f_u$
[mm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]	[nm]
0,5	20	-20	40	30	-50	80	34	-60	94	40	0	40	50	-80	130	30	-15	45	77	38
1	20	0	20	30	-40	70	78	-60	138	20	-10	30	40	-40	80	20	-10	30	68	47
2	10	-25	35	0	-60	60	0	-72	72	0	-30	30	0	-40	40	5	-30	35	47	18
10	25	-10	35	40	-20	60	28	-24	52	60	0	60	30	-10	40	35	-5	40	49	11
25	45	-20	65	30	-50	80	86	-38	124	90	0	90	30	-50	80	45	-25	70	88	22
50	45	-15	60	30	-40	70	8	-82	90	80	0	80	30	-40	70	50	-45	95	74	11
75	15	-35	50	0	-80	80	0	-130	130	80	0	80	0	-60	60	15	-25	40	80	31
100	20	-50	70	0	-80	80	0	-118	118	110	0	110	0	-80	80	25	-50	75	92	21
150	10	-20	30	80	-20	100	54	-26	80	0	0	0	100	-30	130	55	-45	100	68	53
200	0	-15	15	0	-90	90	72	-28	100	0	-100	100	0	-80	80	85	-35	120	77	36
300	110	-130	240	160	-40	200	220	-146	366	0	-100	100	170	-20	190	130	-30	160	219	97

6. Analysis of the results

6.1. Calculation of the reference value

First the stability of the gauge blocks was considered. The largest deviation between two measurements at MIKES was 35 nm for the 300 mm gauge block. For shorter gauges the maximum difference was 20 nm with a typical difference from 0 to 10 nm. Based on this data there is no reason to believe that the gauge blocks were unstable, and thus no need for time-dependent corrections.

The comparison data were analysed by calculating the weighted mean and corresponding uncertainty for the results of each gauge block. Next the E_n value was used to analyse the statistical consistency of the laboratories' results. Only the first results of MIKES were used when calculating the values.

The weighted mean was calculated as follows:

$$\bar{x}_{cw} = \frac{\sum_{i=1}^{n} u^{-2}(x_{ci}) \cdot x_{ci}}{\sum_{i=1}^{n} u^{-2}(x_{ci})}; \qquad (4)$$

where n is number of laboratories; x_{ci} is results of laboratory i and $u(x_{ci})$ is the associated standard uncertainty. The corresponding standard uncertainty of this value is:

$$u(\bar{x}_{cw}) = \sqrt{\frac{1}{\sum_{i=1}^{n} \frac{1}{u^2(x_{ci})}}}. \qquad (5)$$

The E_n value is given by:

$$E_n = \frac{x_{ci} - \bar{x}_{cw}}{2\sqrt{u^2(x_{ci}) - u^2(\bar{x}_{cw})}} \qquad (6)$$

Since the reference value is calculated as weighted mean from the results of participants, there is clear correlation between reference value and result of a laboratory. This is why in equation 6 squared uncertainty of weighted mean is subtracted from the squared uncertainty of the laboratory. If $|E_n| > 1$ this means that result of the laboratory deviates more from the weighted mean than the combined expanded uncertainty of deviation.

For the three longest gauge blocks, SP clearly had the largest weight. At any rate, these SP values are very close to the arithmetic mean and can be considered not to cause any misinterpretation. Table 7 lists the calculated weighted mean values and corresponding uncertainties, calculated deviation and E_n values for each gauge block and laboratory.

6.2. Discussion

In table 7 there is one results which does not meet the E_n criterion. For this gauge block the weighted mean value calculated without outlier is also given. The two values corrected by LNMC and VMC during the preparation of report draft A would have been also outliers. This number of outliers is statistically not significant. Given the number of samples the likelihood was fairly high of finding 3 values outside the 95% probability limits if the uncertainties were calculated correctly. Nonetheless, the laboratories had good reason to check whether they could trace the reason for these results. For the rest of the data there seems to be good agreement between the results and associated uncertainties.

The results of VMC for short gauge blocks (up to 100 mm) agree well with the E_n criteria but are quite consistently ~35 nm shorter than the weighted mean of the comparison. Reason for this observation is not yet discovered.

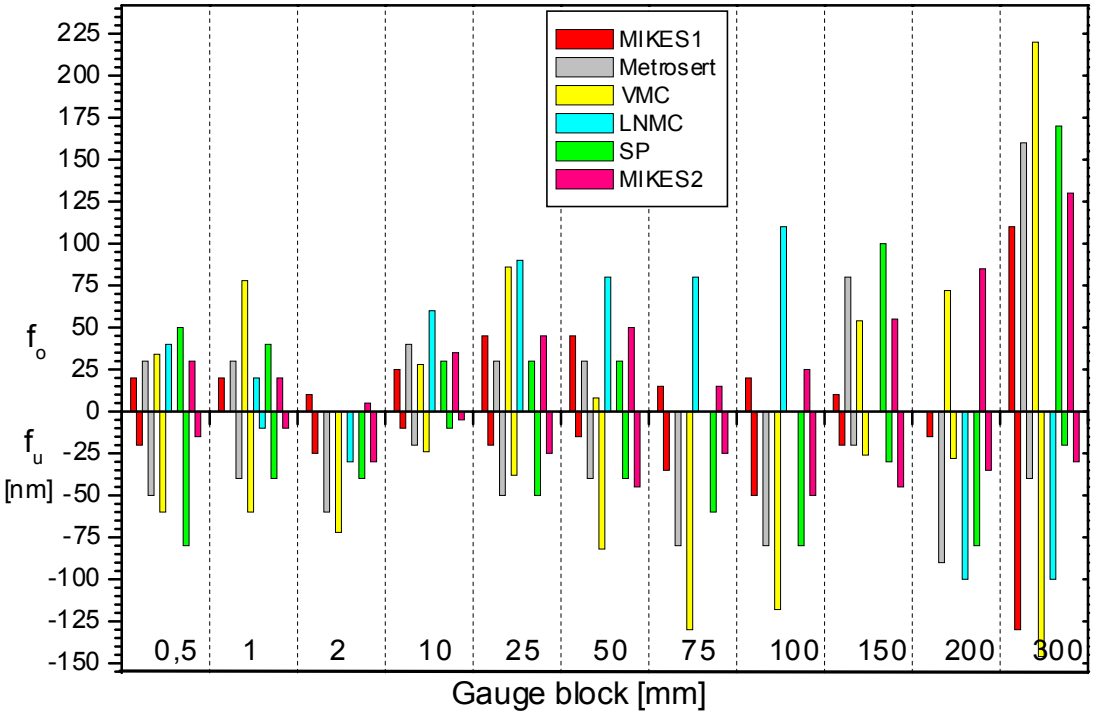

Figure 3. Illustration of the variation in length data.

In Figure 3 is illustration of the variation in length data. Since the values are calculated from data of 5 parallel measurement it is clear that they are only approximation for the variation in length of the gauge blocks. It is not likely that these five measurement points give maximum variation in length of a gauge block. The inaccuracy of location of the measurement points together with strong form variations near the edges increases fluctuation of the results.

Table 7. Deviations from the weighted mean value and corresponding E_n value.

Nominal length	MIKES1		Metrosert		VMC		LNMC		SP		MIKES2		Weighted mean		|En|>1 excl.	
L	$x_{ci} - x_{cw}$	E_n	$x_{ci} - x_{cw}$	E_n	$x_{ci} - x_{cw}$	E_n	$x_{ci} - x_{cw}$	E_n	$x_{ci} - x_{cw}$	E_n	$x_{ci} - x_{cw}$	E_n	x_{cw}	$u(x_{cw})$	x'_{cw}	$u(x'_{cw})$
[mm]	[nm]		[nm]		[nm]		[nm]		[nm]		[nm]		[nm]	[nm]	[nm]	[nm]
0,5	13	0,41	23	0,46	-31	-0,72	3	0,04	-7	-0,19	-7	-0,22	-23	11	-	-
1	7	0,23	12	0,25	-23	-0,56	2	0,03	2	0,06	7	0,23	-42	11	-	-
2	-13	-0,23	-8	-0,04	-30	-0,63	18	0,22	22	0,76	-13	-0,23	-28	11	-	-
10	10	0,30	15	0,27	-36	-0,90	-15	-0,18	15	0,41	0	-0,01	-105	11	-	-
25	-5	-0,16	20	0,33	-32	-0,69	-50	-0,52	30	0,80	-10	-0,31	10	12	-	-
50	9	0,25	9	0,13	-39	-0,64	-71	-0,61	19	0,46	9	0,25	111	14	-	-
75	-1	-0,02	59	0,74	-42	-0,55	-81	-0,59	9	0,18	-11	-0,25	-179	16	-	-
100	15	0,30	-10	-0,11	-53	-0,57	-40	-0,26	20	0,34	5	0,10	220	19	-	-
150	78	0,50	128	0,56	-20	-0,07	-72	-0,19	-22	-0,60	63	0,41	-308	30	-	-
200	5	0,03	95	0,35	-327	-0,88	45	0,11	5	0,11	15	0,08	-5	36	-	-
300	60	0,23	190	0,54	-554	-1,08	-30	-0,07	0	0,00	95	0,36	70	56	89	50

As can be seen from the table 6 and from the figure 3. The f_o-f_u values of the laboratories are quite similar for the gauges from 2 mm to 100 mm. The standard deviation of the values is around 20 nm. The 300 mm gauge has clearly largest variation in length. This causes also largest standard deviation of the results. VMC and LNMC measured the long gauge blocks in horizontal position. This is likely the reason for largest variation values with longer gauge blocks. Results of LNMC have some strange behaviour for gauges from 10 mm to 100 mm: all f_o-f_u variation is on f_o side. No more detailed analysis of the length variation data was done.

7. Conclusion

The Northern European comparison ‘Calibration of gauge blocks by mechanical comparison’ has been completed. The circulation of artefacts among the participants took approximately 5 months. The main purpose of the comparison was to test the ability of the participating laboratories to carry out mechanical gauge block calibrations.

The results of the comparison show that the laboratories agree well with the uncertainties they announce, with statistically insignificant exception. The variation in length values f_o-f_u were quite consistent for most of the gauges.

This comparison was carried out as a co-operational EUROMET project at the request of one participant. The guidelines of EUROMET and MRA for comparisons were essentially followed. The results of this comparison offer additional evidence for new corresponding applicants of EUROMET.

References:

[1] ISO 3650:1998, Geometrical Product Specifications (GPS) -- Length standards -- Gauge blocks, ISO Geneva.

J1/1999	Nordic Intercomparison in Barometric Pressure
J2/1999	Automaattisten punnustenvaihtimien suunnittelu, toteutus ja käyttö
J3/1999	Intercomparison of Gauge Pressure Measurements between SP/FFA and MIKES in the Range 32 kPa ... 132 kPa
J4/1999	Ainemäärän kansallisen mittanormaalijärjestelmän toteuttamista ja organisaatiota koskeva selvitys
J5/1999	Mikrobiologisen metrologian tilanneselvitys ja kehittämissuunnitelma
J6/1999	Finnish National Standards Laboratories FINMET. Annual Report 1998
J7/1999	Lämpötilan vertailumittaus L10, S-tyypin termoelementin kalibrointi
J8/1999	Mekaanisten värähtelyiden mittausten kartoitus
J9/1999	Intercomparison of the Hydrometer Calibration Systems at the IMGC and the MIKES
J10/1999	National Basis for Traceability in Humidity Measurements
J1/2000	Intercomparison of Temperature Standards of Lithuania and Finland
J2/2000	Finnish National Standards Laboratories FINMET. Annual Report 1999
J3/2000	Mass Comparison M3
J4/2000	Mass and Volume Comparisons at MIKES
J5/2000	Nanometritason mittaukset, kartoitus
J6/2000	Nordic Intercomparison in Gauge Pressure Range 0 ... 2 MPa
J1/2001	Mikrobiologian kvantitatiivisten viljelymääritysten mittausepävarmuus
J2/2001	Finnish National Standards Laboratories. Annual Report 2000
J3/2001	Lämpötilan vertailumittaus L11, PT100-anturin sovitusmenetelmän kehittäminen
J4/2001	High Precision Roundness. Euromet Project 533. Final Report
J5/2001	Kaasun kosteuden mittaaminen
J6/2001	Intercomparison of Humidity Standards
J7/2001	Comparisons in the Pressure Range from 50 kPa to 350 kPa
J1/2002	Lämpötilan mittaus
J2/2002	Annual Report 2001
J3/2002	Uncertainty of quantitative Determinations derived by Cultivation of Microorganisms
J4/2002	Calibration of gauge blocks by mechanical comparison. Final Report

Tilaukset toimistosihteeri Kirsi Tuomisto, puh. (09) 6167 457,
e-mail kirsi.tuomisto@mikes.fi.

MITTATEKNIIKAN KESKUS
CENTRE FOR METROLOGY AND ACCREDITATION
P.O. Box 239
FIN- 00181 HELSINKI
Tel. +358 9 616 761
Telefax +358 9 616 7467

ISBN 952-5209-70-9
ISSN 1235-5704