EUROMET Supplementary Comparison

EUROMET.L-S16

Calibration of gauge blocks by mechanical comparison

(EUROMET Project No. 797)

Final Report

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January 2009

Contents

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.

After its meeting in October 2003 the EUROMET Technical Committee for Length, TC-L, decided upon a supplementary comparison on gauge block measurement by mechanical comparison, numbered EUROMET.L-S16, with the Malta Standards Authority as the pilot, assisted by the National Physical Laboratory (NPL) which would provide a link to EUROMET.L-K1. This comparison would be a follow on comparison to EUROMET.L-S12. The results of this international comparison contribute to the Mutual Recognition Arrangement (MRA) between the national metrology institutes of the Metre Convention [1].

2 Organisation

The protocol document for this comparison and this report have been based on the corresponding documents for previous comparison EUROMET.L-S12. The protocol document was issued to all participants at the start of the comparison.

2.1 Participants

All members of EUROMET TC-L were invited to participate. Ten EUROMET laboratories expressed an interest and INPL (Israel) joined at the later date. The list of participants is given in table 1.

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Table 1 - participating laboratories

2.2 Schedule

The comparison was organised in a single loop with each laboratory allowed approximately one month in which to make its measurements and to prepare for transportation to the next participant. The schedule was designed to fit with the preferences of the laboratories for scheduling the measurements and any changes to the schedule, after the start of the circulation, were discussed and agreed among the participants and the TC-L chairman. The co-pilot laboratory, NPL made several measurements to check the stability of the artefacts, but only its first set of comparison measurements is reported in the main results.

Laboratory	Country	Final schedule
NPL	GB	19 JUN – 18 JUL 2004
MSA	MT	19 JUL – 22 AUG 2004
METROSERT	EE	13 SEP – 17 OCT 2004
MIRS	SI	1 NOV – 5 DEC 2004
UoZ	HR	6 DEC – 9 JAN 2005
SMD	BE	24 JAN – 27 FEB 2005
NML	IE	28 FEB – 27 MAR 2005
JV	NO	28 MAR – 1 MAY 2005
LNMC	LV	2 MAY – 5 JUN 2005
NPL	GB	6 JUN – 10 JUL 2005
INM	RO	20 SEP - 10 OCT 2005
NPL	GB	11 OCT – 31 OCT 2005
INPL	IL	1 NOV – 31 NOV 2005
NPL	GB	1 DEC 2005

Table 2 - time schedule of the comparison

2.3 Standards

The circulated artefacts were 8 gauge blocks of steel and 8 gauge blocks of tungsten carbide. The gauge blocks were of grade K and of rectangular cross section, nominally according to the international standard ISO 3650. However it was noticed by one participant (MIRS) early in the circulation that the steel gauges were slightly too large in cross-section to fit into the standard gauge block comparator templates. This was due to the age of the gauges, being older than ISO 3650, and being based on an earlier British Standard. MIRS supplied a replacement template for others to use, and their help is recognised by the pilot and co-pilot.

The reason these gauges were chosen is that they were NPL master gauge blocks of long history and known stability.

Only the nominal manufacturer values for thermal expansion coefficient were supplied.

Steel gauge blocks:

Identification	Nominal length (mm)	Expansion coefficient (10^{-6} K^{-1})	Manufacturer
189C	0.5	10.7	Pitter (PVE)
189C	1	10.7	Pitter (PVE)
189C	6	10.7	Pitter (PVE)
189C	7	10.7	Pitter (PVE)
189C	9	10.7	Pitter (PVE)
189C	19	10.7	Pitter (PVE)
189C	50	10.7	Pitter (PVE)
189C	100	10.7	Pitter (PVE)

Table 3(a) - details of the steel gauge blocks

Tungsten carbide gauge blocks:

Identification	Nominal length (mm)	Expansion coefficient (10^{-6} K^{-1})	Manufacturer
T2	2	4.23	Select
T2	3	4.23	Select
T2	4	4.23	Select
T2	5	4.23	Select
T2	10	4.23	Select
T2	25	4.23	Select
T2	40	4.23	Select
T2	75	4.23	Select

Table 3(b) - details of the tungsten carbide gauge blocks

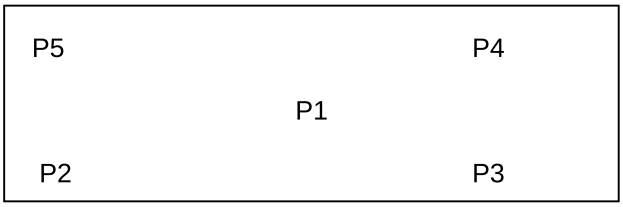
3 Measurement instructions and reporting of results

Before calibration, the gauge blocks had to be inspected for damage of the measurement surfaces. Any scratches, rusty spots or other damage had to be documented by a drawing using forms appended to the instructions.

The gauge blocks had to be measured by mechanical comparison with the participant laboratory's reference gauge blocks, using the normal calibration procedure.

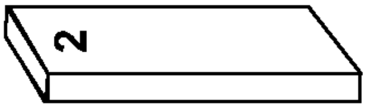
The following were the measurands for each gauge block:

- Deviation of the central length (at P1 in figure below) from the nominal length, d_1;
- Where possible, deviation from nominal length, measured at points P2 to P5 (d_2 to d_5). These values will be used by the pilot to calculate f_o and f_u, for each gauge, according to ISO 3650.

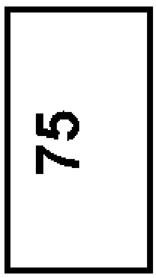


The gauges had to be positioned as follows:-

- 0.5, 1, 2 3, 4, 5, 6, 7, 8 and 10 mm gauge blocks – the measuring face with the nominal size markings should face upwards with the nominal size mark on the left side of the gauge facing the operator:



- 20, 30, 40, 50, 75 and 100 mm gauge blocks – the side of the gauge with the nominal size marking should be standing vertically, facing the operator with the numerals running up the gauge side:



4 Stability and condition of the gauge blocks

The co-pilot laboratory, NPL, made interferometric calibrations before the start of the comparison as well as measurements by mechanical comparison at various points during the circulation. Plotting the NPL results for all gauge blocks reveals that the gauges' central length values appeared stable, within the expanded uncertainties of the NPL measurements.

Rather than show all graphs, only those for the 7 mm steel gauge and the 9 mm steel gauge (the least stable) are shown. Both the 7 mm and 9 mm steel gauges appear to show instability at the one sigma level. The majority of the gauges showed stability of results within the one sigma level, and all showed stability within the two sigma level, based on the NPL measurements.

The NPL mechanical comparison results agreed with the interferometric results for all gauges, at the start of the comparison.

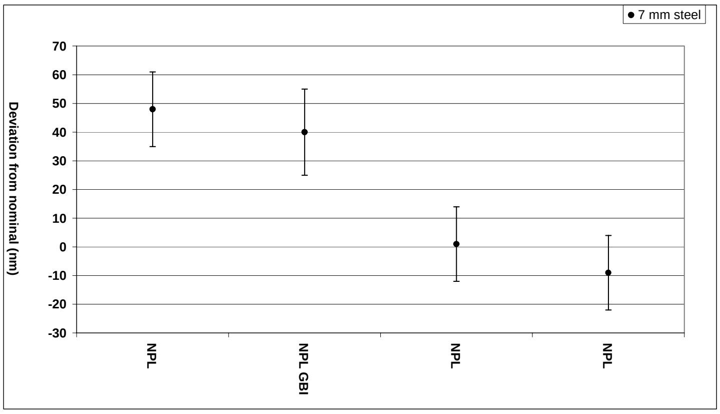


Figure 1 - stability measurement results on the 1 mm steel gauge block (NPL GBI is the interferometric result at the start of the comparison). Uncertainties are at one sigma.

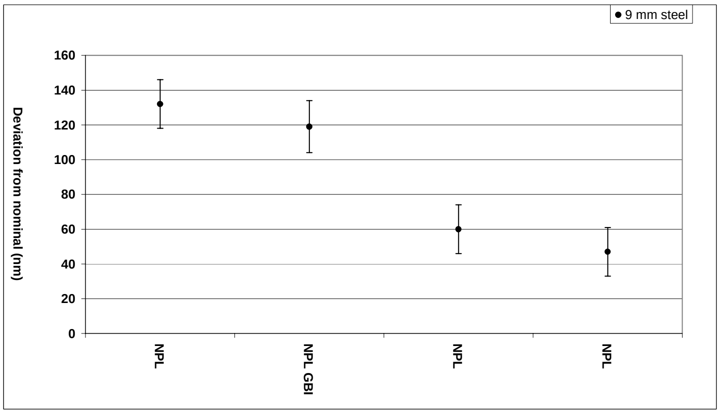


Figure 2 - stability measurement results on the 9 mm steel gauge block (NPL GBI is the interferometric result at the start of the comparison). Uncertainties are at one sigma.

4.1 Condition of the gauge blocks

The gauge blocks were essentially free of major damage at the beginning of the comparison, though they had a few signs of long term use as master standards.

In June 2005, during one of the NPL re-calibrations, damage on one edge of the 5 mm tungsten carbide gauge block was noticed.

Figure 3 - damage to the 5 mm tungsten carbide gauge block

5 Laboratory measurements

The principal equipment used by the participants were a selection of gauge block comparators manufactured by TESA (6 participants), Mahr (2 participants), Cary (2 participants) and Kalibr (1 participant). All instruments, except the one made by Kalibr, had 10 nm resolution (the Kalibr had 50 nm resolution). Three participants used steel maser gauges for the measurements on the tungsten carbide gauges (one did not perform any measurements on the tungsten carbide gauges). The greatest reported temperature deviation from the reference 20 °C was +1 °C.

6 Measurement results, as reported by participants

The results reported by the participants are given in tables 4 through 19 and figures 4 through 19 show the reported deviations from nominal length, with standard (*k*=1) uncertainties.

JV reported that they were unable to measure several of the steel gauge blocks due to the gauges not fitting within the templates of their comparator. INPL reported that they do not usually measure tungsten carbide gauge blocks and so did not measure these gauges.

0.5 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	**-128**	**-147**	**-84**	**-140**	**-80**	**-91**	**-70**	**-89**	**-90**	**-73**	**-126**
$u(d_1)$	13	35	26	25	25	17	39	34	70	21	22.8
d_2		-161		-150	-140	-109	-70	-49	-70	-83	-141
d_3		-153		-160	-90	-108	-50	-102	-110	-77	-146
d_4		-153		-180	-90	-75	-70	-116	-110	-57	-146
d_5		-155		-150	-130	-101	-60	-39	-80	-62	-126
$u(d_i)$		35		25	25	17	39	34	70	20	28.8
v	**0**	**14**	**0**	**40**	**60**	**34**	**20**	**77**	**40**	**26**	**20**
u(v)	0	49	0	35	35	24	55	48	99	28	41

Table 4 - 0.5 mm steel gauge results

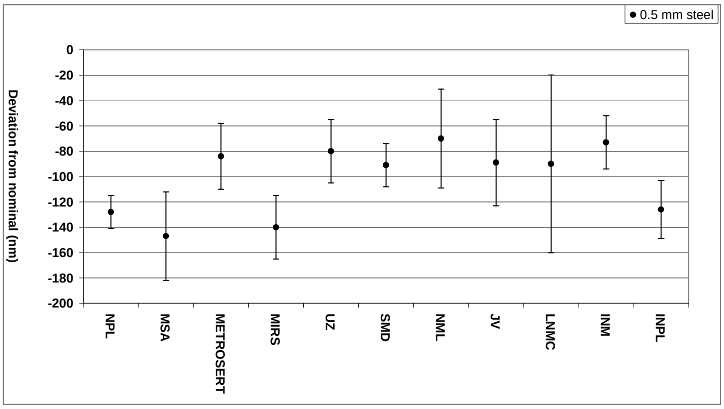


Figure 4 - 0.5 mm steel gauge results (k=1)

1 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	**79**	**49**	**78**	**70**	**60**	**84**	**110**	**78**	**60**	**59**	**80**
$u(d_1)$	13	35	26	25	26	17	39	34	70	21	22.8
d_2		27		40	45	57	100	51	50	36	39
d_3		30		60	35	63	130	78	50	11	80
d_4		27		50	45	56	120	74	50	41	80
d_5		31		40	55	63	90	54	40	60	46
$u(d_i)$		35		25	25	17	39	34	70	20	28.8
v	**0**	**22**	**0**	**30**	**25**	**28**	**40**	**27**	**20**	**49**	**41**
u(v)	0	49	0	35	35	24	55	48	99	28	41

Table 5 - 1 mm steel gauge results

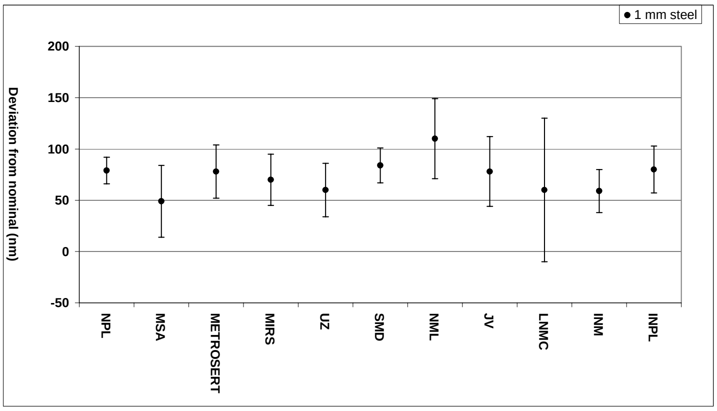


Figure 5 - 1 mm steel gauge results (k=1)

6 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	**-1**	**-39**	**-42**	**-30**	**-20**	**-16**	**0**		**-50**	**6**	**0**
$u(d_1)$	13	35	28	25	28	17	39		70	22	23.3
d_2		-20	22	-20	-10	5	30		-20	2	10
d_3		-13	2	-10	-30	8	40		-10	-6	24
d_4		-20	8	-30	-30	13	20		-20	13	10
d_5		-34	8	-30	-40	-5	-10		-20	21	0
$u(d_i)$		35	80	25	28	17	39		70	20	29.3
v	**0**	**26**	**64**	**20**	**30**	**29**	**50**	**0**	**40**	**27**	**24**
u(v)	0	49	113	35	40	24	55	0	99	28	41

Table 6 - 6 mm steel gauge results

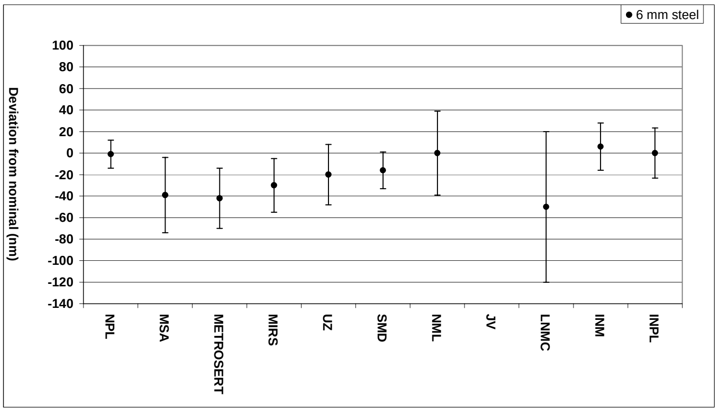


Figure 6 - 6 mm steel gauge results (k=1)

7 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	**48**	**12**	**30**	**30**	**10**	**17**	**-10**		**40**	**36**	**34**
$u(d_1)$	13	35	28	25	29	17	39		70	22	23.4
d_2		-6	-8	40	-10	10	0		40	-18	22
d_3		18	-12	30	20	34	40		70	16	55
d_4		36	19	30	30	33	20		70	78	72
d_5		4	7	0	-20	14	0		50	52	22
$u(d_i)$		35	80	25	29	17	39		70	20	29.3
v	**0**	**42**	**42**	**40**	**50**	**24**	**50**	**0**	**30**	**96**	**50**
u(v)	0	49	113	35	41	24	55	0	99	28	41

Table 7 - 7 mm steel gauge results

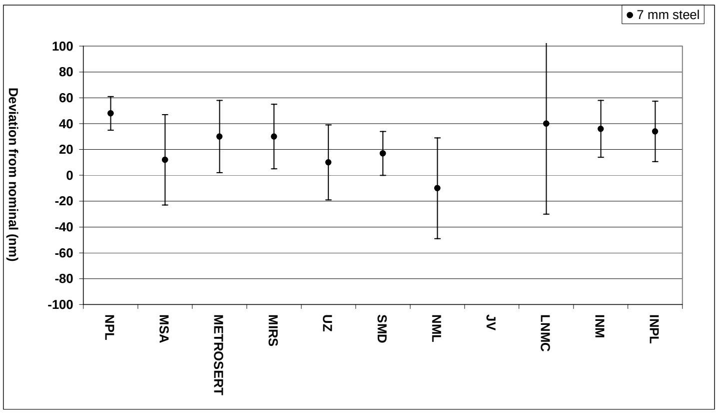


Figure 7 - 7 mm steel gauge results (k=1)

9 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	**132**	**97**	**93**	**110**	**100**	**109**	**90**		**120**	**129**	**110**
$u(d_1)$	14	37	29	25	30	18	39		70	22	23.7
d_2		35	-58	40	10	37	30		90	68	60
d_3		103	-58	120	60	115	110		140	106	117
d_4		104	2	100	100	115	110		140	168	117
d_5		34	-4	40	10	44	40		90	114	50
$u(d_i)$		37	80	25	30	18	39		70	20	29.5
v	**0**	**70**	**151**	**80**	**90**	**78**	**80**	**0**	**50**	**100**	**67**
u(v)	0	52	113	35	42	25	55	0	99	28	42

Table 8 - 9 mm steel gauge results

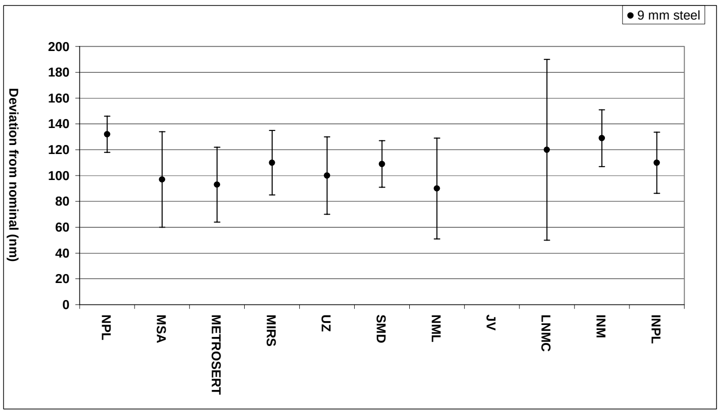


Figure 8 - 9 mm steel gauge results (k=1)

19 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	**145**	**107**	**98**	**140**	**90**	**128**	**130**	**103**	**70**	**145**	**164**
$u(d_1)$	14	40	32	25	35	18	42	38	80	24	25.3
d_2		163	62	210	150	203	180	158	150	192	222
d_3		143	44	190	140	194	170	138	100	179	214
d_4		124	26	160	100	150	150	115	110	180	189
d_5		144	46	180	120	182	170	135	130	200	214
$u(d_i)$		40	80	25	35	18	42	38	80	20	30.8
v	**0**	**56**	**72**	**70**	**60**	**75**	**50**	**55**	**80**	**55**	**58**
u(v)	0	57	113	35	49	25	59	54	113	28	44

Table 9 - 19 mm steel gauge results

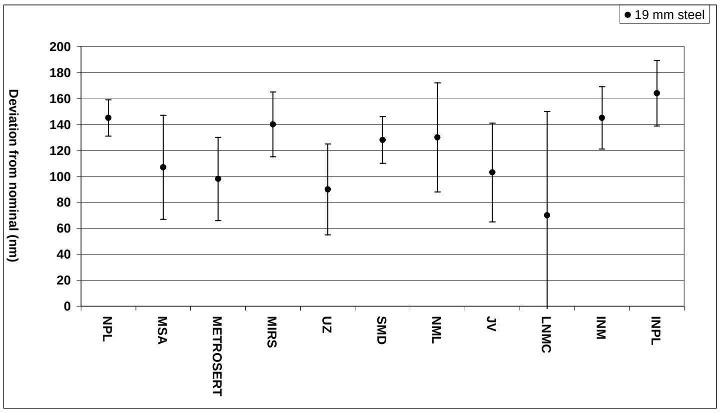


Figure 9 -19 mm steel gauge results (k=1)

50 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	**182**	**144**	**145**	**160**	**140**	**160**	**160**	**128**	**80**	**170**	**180**
$u(d_1)$	20	45	44	28	53	22	55	57	100	25	32.4
d_2		184	35	200	150	206	190	153	150	202	215
d_3		278	-145	300	270	326	310	263	220	311	340
d_4		105	-15	110	90	117	150	97	90	161	230
d_5		-8	143	-20	-40	-14	10	-37	0	48	20
$u(d_i)$		45	80	28	53	22	55	57	100	20	36.9
v	**0**	**286**	**290**	**320**	**310**	**340**	**300**	**300**	**220**	**263**	**320**
u(v)	0	64	113	40	75	31	78	81	141	28	52

Table 10 - 50 mm steel gauge results

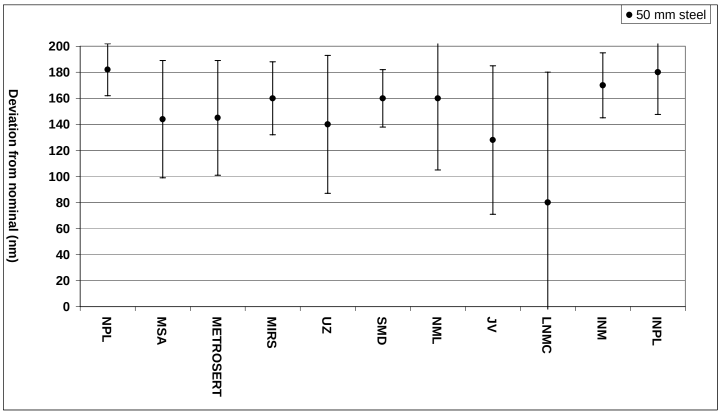


Figure 10 - 50 mm steel gauge results (k=1)

100 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	**50**	**7**	**22**	**10**	**-20**	**-4**	**-10**	**-13**	**20**	**86**	**45**
$u(d_1)$	33	60	64	36	80	30	88	98	130	35	47.5
d_2		56	32	20	-20	30	10	30	170	118	75
d_3		-23	30	-20	-50	-27	-10	-37	70	93	45
d_4		39	42	50	20	33	30	30	120	128	87
d_5		52	-20	20	-20	3	0	-3	170	114	45
$u(d_i)$		60	80	36	80	30	88	98	130	20	50.8
v	**0**	**79**	**62**	**70**	**70**	**60**	**40**	**67**	**150**	**42**	**42**
u(v)	0	85	113	51	113	42	124	139	184	28	72

Table 11 - 100 mm steel gauge results

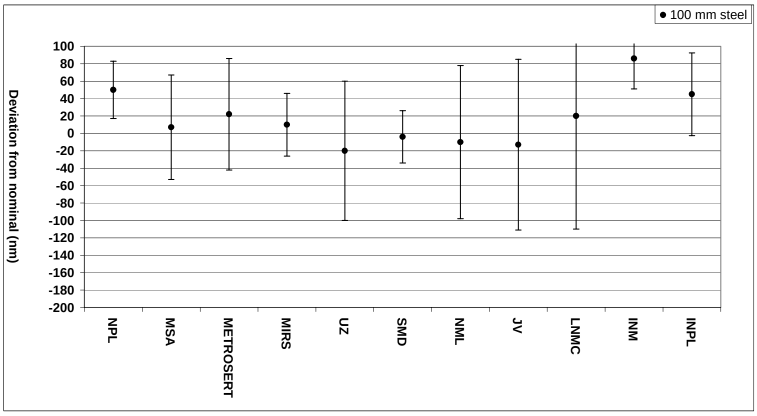


Figure 11 - 100 mm steel gauge results (k=1)

2 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	**-22**	**-11**	**23**	**0**	**-10**	**-8**	**-30**	**-33**	**50**	**26**
$u(d_1)$	13	30	30	46	37	16	34	34	70	21
d_2		-15	20	0	-20	-17	-10	-43	70	16
d_3		-31	10	-20	-30	-32	-30	-43	50	-24
d_4		-33	17	-50	-40	-14	-50	-39	50	6
d_5		-28	20	-20	-40	-29	-50	-53	50	27
$u(d_i)$		30	80	46	37	16	34	34	70	20
v	**0**	**22**	**13**	**50**	**30**	**24**	**40**	**20**	**20**	**51**
u(v)	0	42	113	65	52	23	48	48	99	28

Table 12 - 2 mm tungsten carbide gauge results

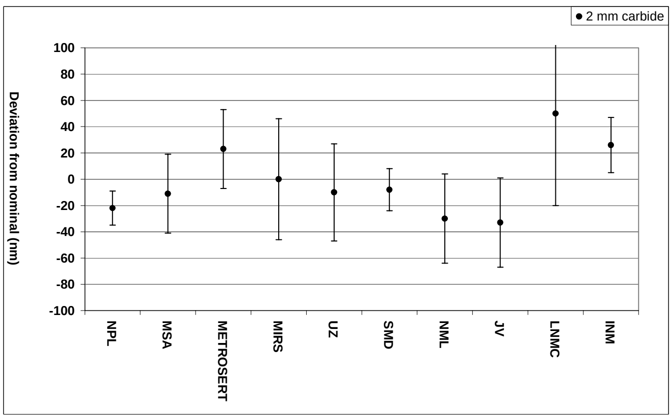


Figure 12 - 2 mm tungsten carbide gauge results (k=1)

3 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	**-164**	**-154**	**-110**	**-170**	**-150**	**-155**	**-200**	**-172**	**-100**	**-114**
$u(d_1)$	13	30	31	46	38	17	34	34	79	21
d_2		-148	-2	-180	-150	-168	-200	-186	-90	-109
d_3		-155	0	-180	-150	-164	-200	-179	-90	-127
d_4		-160	2	-190	-150	-108	-210	-172	-90	-91
d_5		-128	-2	-190	-150	-166	-220	-186	-90	-73
$u(d_i)$		30	80	46	38	17	34	34	70	20
v	**0**	**32**	**112**	**20**	**0**	**60**	**20**	**14**	**10**	**54**
$u(v)$	0	42	113	65	54	24	48	48	99	28

Table 13 - 3 mm tungsten carbide gauge results

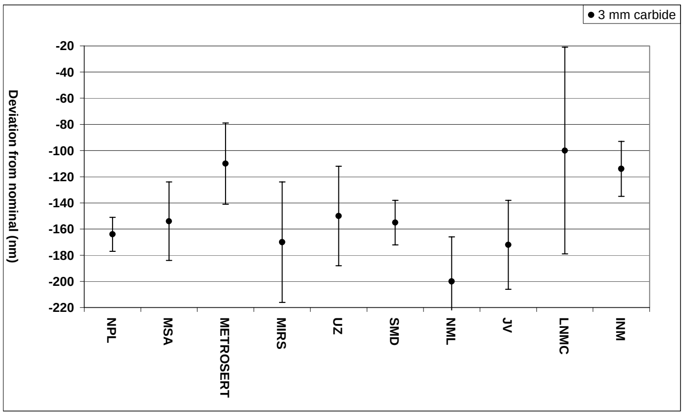


Figure 13 - 3 mm tungsten carbide gauge results (k=1)

4 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	**-75**	**-59**	**-23**	**-70**	**-40**	**-53**	**-100**	**-52**	**10**	**-22**
$u(d_1)$	13	30	31	46	39	17	34	34	84	21
d_2		-53	-1	-70	-50	-56	-80	-52	30	-28
d_3		-82	14	-110	-70	-79	-100	-78	0	-76
d_4		-77	-16	-110	-60	-63	-100	-82	0	-29
d_5		-53	-31	-90	-50	-62	-90	-55	30	-2
$u(d_i)$		30	80	46	39	17	34	34	84	20
v	**0**	**29**	**45**	**40**	**30**	**26**	**20**	**30**	**30**	**74**
$u(v)$	0	42	113	65	55	24	48	48	119	28

Table 14 - 4 mm tungsten carbide gauge results

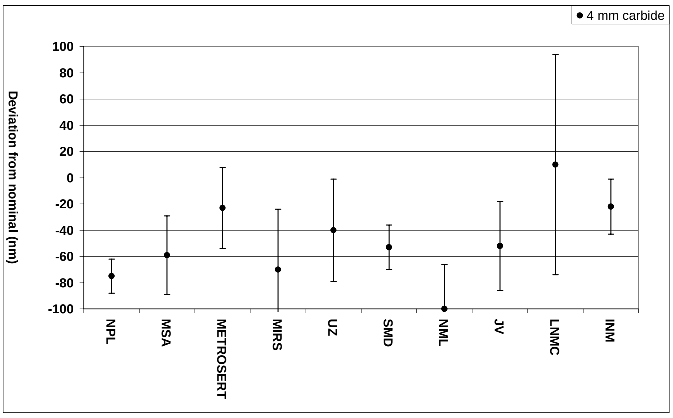


Figure 14 - 4 mm tungsten carbide gauge results (k=1)

5 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	**-156**	**-132**	**-80**	**-150**	**-120**	**-145**	**-170**	**-138**	**-60**	**-104**
$u(d_1)$	13	30	31	47	40	17	34	34	88	22
d_2		-129	-7	-140	-130	-157	-150	-140	-40	-112
d_3		-103	-23	-120	-100	-125	-130	-123	-40	-122
d_4		-122	17	-150	-110	-107	-150	-126	-40	-94
d_5		-167	37	-170	-160	-181	-200	-173	-70	-116
$u(d_i)$		30	80	47	40	17	34	34	88	20
v	**0**	**64**	**117**	**50**	**60**	**74**	**70**	**50**	**30**	**28**
u(v)	0	42	113	66	57	24	48	48	124	28

Table 15 - 5 mm tungsten carbide gauge results

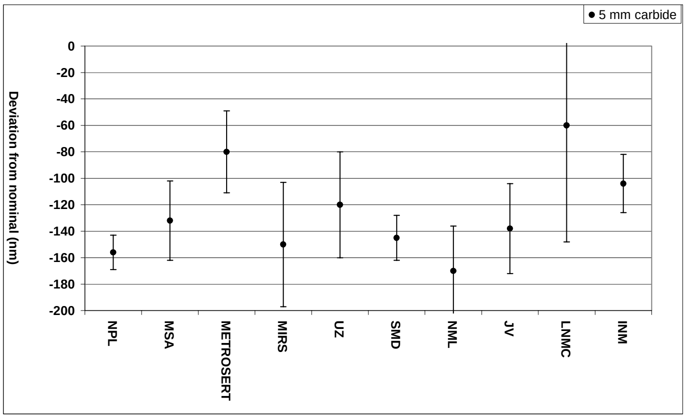


Figure 15 - 5 mm tungsten carbide gauge results (k=1)

10 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	**-193**	**-171**	**-148**	**-180**	**-160**	**-185**	**-230**	**-178**	**-140**	**-147**
$u(d_1)$	14	30	33	48	46	17	34	35	112	22
d_2		-211	-43	-230	-200	-229	-260	-220	-140	-188
d_3		-196	-31	-200	-190	-202	-230	-193	-130	-176
d_4		-163	15	-190	-170	-146	-210	-167	-100	-125
d_5		-201	-23	-220	-210	-220	-250	-213	-140	-156
$u(d_i)$		30	80	48	46	17	34	35	112	20
v	**0**	**30**	**163**	**50**	**50**	**83**	**50**	**53**	**40**	**63**
u(v)	0	42	113	68	65	24	48	49	158	28

Table 16 - 10 mm tungsten carbide gauge results

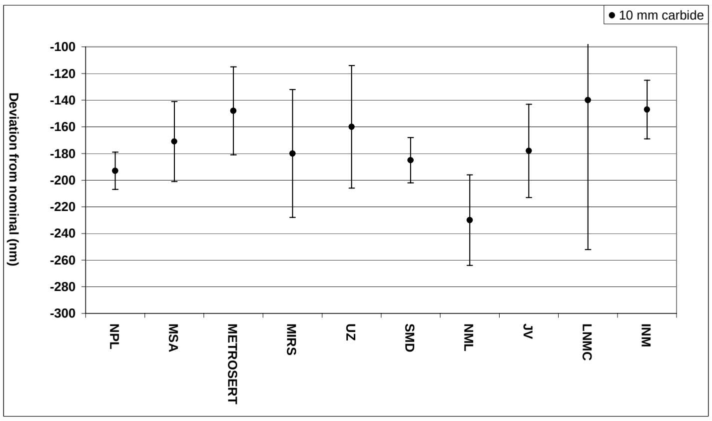


Figure 16 - 10 mm tungsten carbide gauge results (k=1)

25 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	**-85**	**-36**	**-98**	**-90**	**-70**	**-83**	**-110**	**-82**	**-130**	**-78**
$u(d_1)$	15	35	39	53	61	18	42	41	181	25
d_2		-81	-52	-130	-120	-137	-150	-139	-140	-121
d_3		-58	-58	-100	-100	-96	-110	-105	-120	-80
d_4		-48	-4	-110	-90	-65	-110	-99	-110	-82
d_5		-88	-20	-140	-130	-151	-150	-149	-140	-120
$u(d_i)$		35	80	53	61	18	42	41	181	20
v	**0**	**52**	**94**	**50**	**60**	**86**	**40**	**67**	**30**	**43**
u(v)	0	49	113	75	86	25	59	58	256	28

Table 17 - 25 mm tungsten carbide gauge results

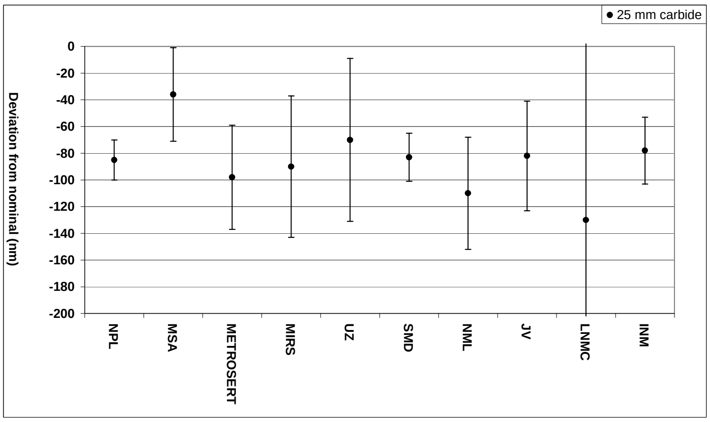


Figure 17 - 25 mm tungsten carbide gauge results (k=1)

40 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	**45**	**105**	**111**	**110**	**20**	**76**	**40**	**74**	**10**	**99**
$u(d_1)$	18	40	45	57	77	20	42	50	251	26
d_2		74	-36	80	-30	36	20	34	40	89
d_3		59	-16	70	-40	37	20	31	10	68
d_4		72	-38	80	-20	23	30	41	10	65
d_5		98	-38	90	-10	45	30	51	40	88
$u(d_i)$		40	80	57	77	20	42	50	251	20
v	**0**	**46**	**149**	**40**	**60**	**53**	**20**	**43**	**30**	**34**
u(v)	0	57	113	81	109	28	59	71	355	28

Table 18 - 40 mm tungsten carbide gauge results

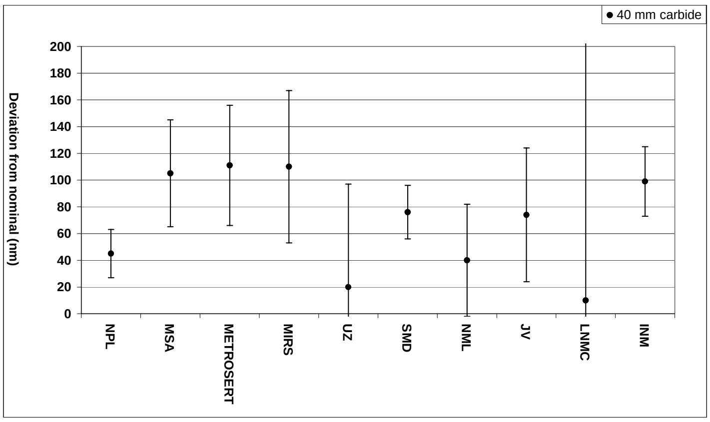


Figure 18 - 40 mm tungsten carbide gauge results (k=1)

75 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	**-51**	**-19**	**-42**	**-10**	**-20**	**-35**	**-120**	**-30**	**-170**	**20**
$u(d_1)$	27	50	59	68	114	23	71	77	414	32
d_2		-65	-66	-70	-90	-102	-170	-101	-170	-12
d_3		-17	-26	0	-40	-19	-80	-25	-140	41
d_4		-16	12	0	-10	-4	-70	-15	-120	32
d_5		-41	2	-40	-50	-70	-150	-65	-140	-12
$u(d_i)$		50	80	68	114	23	71	77	414	20
v	**0**	**49**	**78**	**70**	**80**	**98**	**100**	**86**	**50**	**53**
u(v)	0	71	113	96	161	33	100	109	585	28

Table 19 - 75 mm tungsten carbide gauge results (k=1)

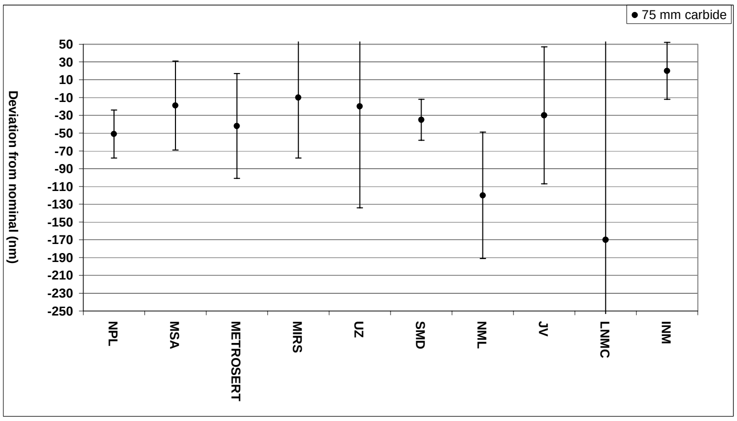


Figure 19 - 75 mm tungsten carbide gauge results (k=1)

7 Measurement uncertainties

7.1 Model equations

The participants were asked to supply sample uncertainty calculations for the 2 mm tugsten carbide and 100 mm steel gauge blocks, according to the GUM [2]. The uncertainties in the determination of the following model parameters were taken into account by the majority of the participants:

Δt_{20} difference of the gauge block temperatures from the reference temperature of 20 °C;

Δt_G temperature difference between reference and test gauge blocks

α_G linear coefficient of thermal expansion difference between reference and test gauge blocks

δl_G correction accounting for flatness deviation variation in length of the gauge block & centering;

δl_D correction for deformation difference between reference and test gauge blocks

l_r length of the reference gauge block;

σ_l spread in the results;

δ_m machine uncertainty.

Model parameter	**NPL**	**MSA**	**METROSERT**	**MIRS**	**UZ**	**SMD**	**NML**	**JV**	**LNMC**	**INM**	**INPL**
Δt_{20}	11.4	34	1	6.1	-	13.2	-	56.4	-	15	5.0
Δt_G	13.5	18	19	13	66.7	12.8	58	47.1	33	12	33.8
α_G	11.5	-	-	6.7	23.6	0	33	-	47	16	0
δl_G	-	8.5	2	-	3.9	1.3	3.9	3.9	34	2.1	-
δl_D	-	-	-	-	-	3.2	-	-	3	-	2.9
l_r	25	39.5	60	23	30.9	21.8	50.5	60.9	100	21	28.1
σ_l	3	10	7	-	-	-	20	4.2	20	-	8.7
δ_m	-	19.1	11	16	18.5	8.6	18.5	23.1	23	13	15.3
other	-	-	6	16	2.5	4.9	-	2.9	-	3.2	-
u_c	**33**	**60**	**64**	**36**	**80**	**31**	**88**	**98**	**125**	**35**	**48**

Table 20 - standard uncertainties (in nm) quoted for a 100 mm steel gauge block, by the different laboratories and combined uncertainty calculated from these values. The quadrature summed standard uncertainties (u_c) have been rounded up to the nearest nm

8 Analysis of the reported results

The reported measurement results are now analysed by simple statistical means to allow identification of any significant bias or outliers, and to investigate the statistical distribution of the results.

From tables 4 though 19 and figures 4 through 19 it is clear that the uncertainties quoted by the participants are different from one participant to another, and that the uncertainties depend on the length of the gauge block being measured. Thus analysis via use of the simple arithmetic mean as an estimator of the true mean is not suitable and instead, the weighted mean should be used. This approach requires that the participants have made correct estimates of their uncertainty of measurement otherwise a too low uncertainty will place undue emphasis on the result of that particular laboratory.

8.1 Derivations

For each laboratory, i, which measures each gauge block, j, let the measured deviation from nominal size (after making all required corrections) be denoted x_{ij}. The number of laboratories, I, is 10 or 11 (steel or carbide gauges) and the number of gauge blocks, J, is 16. Since the sixteen gauge blocks are sixteen physically different length artefacts with sixteen different lengths, thermal expansion coefficients, material properties *etc*, it is reasonable to expect that the data x_{ij} come from sixteen separate populations (one per gauge block) and so analysis should be on a gauge-by-gauge basis. Note that not all laboratories measured all gauge blocks.

Thus, for a particular gauge block, j :

Each laboratory reports a measured value, x_i , and its associated standard uncertainty $u(x_i)$.

The normalised weight, w_i , for the result x_i is given by:

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

where the normalising factor, C, is given by:

$$C = \frac{1}{\sum_{i=1}^{I} \left(\frac{1}{u(x_i)} \right)^2} \tag{2}$$

Then the weighted mean, $\bar{x}_w$, is given by:

$$\bar{x}_w = \sum_{i=1}^{I} w_i \cdot x_i \tag{3}$$

The uncertainty of the weighted mean can be calculated as either the so-called internal or external standard deviation, $u_{\text{int}}(\bar{x}_w)$ and $u_{ext}(\bar{x}_w)$, respectively. The internal standard deviation is based on the estimated uncertainties $u(x_i)$ as reported by the participants, whereas the external standard deviation is the standard deviation of the spread of the actual results, x_i, weighted by the uncertainties $u(x_i)$:

$$u_{\text{int}}(\bar{x}_w) = \sqrt{\frac{1}{\sum_{i=1}^{I} \left(\frac{1}{u(x_i)} \right)^2}} = \sqrt{C} \tag{4}$$

$$u_{ext}(\bar{x}_w) = \sqrt{\frac{1}{(I-1)} \cdot \frac{\sum_{i=1}^{I} w_i (x_i - \bar{x}_w)^2}{\sum_{i=1}^{I} w_i}} \tag{5}$$

Substituting (1) into (5) gives:

$$u_{ext}(\bar{x}_w) = \sqrt{\frac{1}{(I-1)} \cdot \frac{\sum_{i=1}^{I} \frac{1}{[u(x_i)]^2}(x_i - \bar{x}_w)^2}{\sum_{i=1}^{I} \frac{1}{[u(x_i)]^2}}} \tag{6}$$

After deriving the weighted mean and its associated uncertainty, the deviation of each laboratory's result from the weighted mean is determined simply as $x_i - \bar{x}_w$. The uncertainty of this deviation is calculated as a combination of the uncertainties of the result, $u(x_i)$, and the uncertainty of the weighted mean. In this case, the uncertainty of the weighted mean is taken as $u_{\text{int}}(\bar{x}_w)$. The uncertainty of the deviation from the weighted mean is given by equation (7), which includes a minus sign to take into account the correlation between the two uncertainties (it would be a plus sign if dealing with uncorrelated uncertainties, such as when comparing data from two separate laboratories).

$$u(x_i - \bar{x}_w) = \sqrt{[u(x_i)]^2 - [u_{int}(\bar{x}_w)]^2} \tag{7}$$

Values for the weighted mean, internal standard deviation, deviation from weighted mean and its corresponding uncertainty and are calculated for each gauge block, and reported in section 8.3.

8.2 Analysis using E_n values

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

$$E_n = \frac{x_i - \bar{x}_w}{\sqrt{[u(x_i)]^2 - [u_{int}(\bar{x}_w)]^2}} \tag{8}$$

E_n values for each laboratory have been calculated and are also reported in section 8.3.

8.3 Results of all participants

0.5 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	-128	-147	-84	-140	-80	-91	-70	-89	-90	-73	-126
$u(d_1)$	13	35	26	25	25	17	39	34	70	21	22.8
w_i	0.285	0.039	0.071	0.077	0.077	0.166	0.032	0.042	0.010	0.109	0.093
x_i-Wt mean	**-21.3**	**-40.3**	**22.7**	**-33.3**	**26.7**	**15.7**	**36.7**	**17.7**	**16.7**	**33.7**	**-19.3**
En (95%)	**-0.97**	**-0.59**	**0.45**	**-0.69**	**0.56**	**0.50**	**0.48**	**0.27**	**0.12**	**0.85**	**-0.44**
										C	**48.1**
										Wt mean	**-106.7**

Table 21 - analysis of results for 0.5 mm steel gauge block

1 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	79	49	78	70	60	84	110	78	60	59	80
$u(d_1)$	13	35	26	25	26	17	39	34	70	21	22.8
w_i	0.286	0.039	0.072	0.077	0.072	0.167	0.032	0.042	0.010	0.110	0.093
x_i-Wt mean	**3.8**	**-26.2**	**2.8**	**-5.2**	**-15.2**	**8.8**	**34.8**	**2.8**	**-15.2**	**-16.2**	**4.8**
En (95%)	**0.17**	**-0.38**	**0.06**	**-0.11**	**-0.30**	**0.28**	**0.45**	**0.04**	**-0.11**	**-0.41**	**0.11**
										C	**48.4**
										Wt mean	**75.2**

Table 22 - analysis of results for 1 mm steel gauge block

6 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	LNMC	INM	INPL
d_1	-1	-39	-42	-30	-20	-16	0	6	0	0
$u(d_1)$	13	35	28	25	28	17	39	22	23.3	0
w_i	0.310	0.043	0.067	0.084	0.067	0.181	0.034	0.108	0.096	0.000
x_i-Wt mean	**10.4**	**-27.6**	**-30.6**	**-18.6**	**-8.6**	**-4.6**	**11.4**	**-38.6**	**17.4**	**11.4**
En (95%)	**0.48**	**-0.40**	**-0.57**	**-0.39**	**-0.16**	**-0.15**	**0.15**	**-0.28**	**0.42**	**0.26**
									C	**52.3**
									Wt mean	**-11.4**

Table 23 - analysis of results for 6 mm steel gauge block

7 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	LNMC	INM	INPL
d_1	48	12	30	30	10	17	-10	36	34	0
$u(d_1)$	13	35	28	25	29	17	39	22	23.4	0
w_i	0.311	0.043	0.067	0.084	0.063	0.182	0.035	0.109	0.096	0.000
x_i-Wt mean	**17.0**	**-19.0**	**-1.0**	**-1.0**	**-21.0**	**-14.0**	**-41.0**	**9.0**	**5.0**	**3.0**
En (95%)	**0.79**	**-0.28**	**-0.02**	**-0.02**	**-0.37**	**-0.45**	**-0.53**	**0.06**	**0.12**	**0.07**
									C	**52.6**
									Wt mean	**31.0**

Table 24 - analysis of results for 7 mm steel gauge block

9 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	LNMC	INM	INPL
d_1	132	97	93	110	100	109	90	120	129	110
$u(d_1)$	14	37	29	25	30	18	39	70	22	23.7
w_i	0.291	0.042	0.068	0.091	0.063	0.176	0.038	0.118	0.102	0.000
x_i-Wt mean	**16.5**	**-18.5**	**-22.5**	**-5.5**	**-15.5**	**-6.5**	**-25.5**	**4.5**	**13.5**	**-5.5**
En (95%)	**0.70**	**-0.26**	**-0.40**	**-0.12**	**-0.27**	**-0.20**	**-0.33**	**0.03**	**0.33**	**-0.12**
									C	**57.1**
									Wt mean	**115.5**

Table 25 - analysis of results for 9 mm steel gauge block

19 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	145	107	98	140	90	128	130	103	70	145	164
$u(d_1)$	14	40	32	25	35	18	42	38	80	24	25.3
w_i	0.302	0.037	0.058	0.095	0.048	0.182	0.034	0.041	0.009	0.103	0.092
x_i-Wt mean	**11.5**	**-26.5**	**-35.5**	**6.5**	**-43.5**	**-5.5**	**-3.5**	**-30.5**	**-63.5**	**11.5**	**30.5**
En (95%)	**0.49**	**-0.34**	**-0.57**	**0.14**	**-0.64**	**-0.17**	**-0.04**	**-0.41**	**-0.40**	**0.25**	**0.63**
										C	**59.1**
										Wt mean	**133.5**

Table 26 - analysis of results for 19 mm steel gauge block

50 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	182	144	145	160	140	160	160	128	80	170	180
$u(d_1)$	20	45	44	28	53	22	55	57	100	25	32.4
w_i	0.238	0.047	0.049	0.121	0.034	0.197	0.031	0.029	0.010	0.152	0.091
x_i-Wt mean	**17.3**	**-20.7**	**-19.7**	**-4.7**	**-24.7**	**-4.7**	**-4.7**	**-36.7**	**-84.7**	**5.3**	**15.3**
En (95%)	**0.50**	**-0.24**	**-0.23**	**-0.09**	**-0.24**	**-0.12**	**-0.04**	**-0.33**	**-0.43**	**0.11**	**0.25**
										C	**95.2**
										Wt mean	**164.7**

Table 27 - analysis of results for 50 mm steel gauge block

100 mm steel	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM	INPL
d_1	50	7	22	10	-20	-4	-10	-13	20	86	45
$u(d_1)$	33	60	64	36	80	30	88	98	130	35	47.5
w_i	0.183	0.055	0.049	0.153	0.031	0.221	0.026	0.021	0.012	0.162	0.088
x_i-Wt mean	**21.8**	**-21.2**	**-6.2**	**-18.2**	**-48.2**	**-32.2**	**-38.2**	**-41.2**	**-8.2**	**57.8**	**16.8**
En (95%)	**0.36**	**-0.18**	**-0.05**	**-0.28**	**-0.31**	**-0.61**	**-0.22**	**-0.21**	**-0.03**	**0.90**	**0.18**
										C	**198.8**
										Wt mean	**28.2**

Table 28 - analysis of results for 100 mm steel gauge block

2 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	-22	-11	23	0	-10	-8	-30	-33	50	26
$u(d_1)$	13	30	30	46	37	16	34	34	70	21
w_i	0.339	0.064	0.064	0.027	0.042	0.224	0.050	0.050	0.012	0.130
x_i-Wt mean	**-13.9**	**-2.9**	**31.1**	**8.1**	**-1.9**	**0.1**	**-21.9**	**-24.9**	**58.1**	**34.1**
En (95%)	**-0.66**	**-0.05**	**0.54**	**0.09**	**-0.03**	**0.00**	**-0.33**	**-0.38**	**0.42**	**0.87**
									C	**57.3**
									Wt mean	**-8.1**

Table 29 - analysis of results for 2 mm carbide gauge block

3 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	-164	-154	-110	-170	-150	-155	-200	-172	-100	-114
$u(d_1)$	13	30	31	46	38	17	34	34	79	21
w_i	0.351	0.066	0.062	0.028	0.041	0.205	0.051	0.051	0.010	0.135
x_i-Wt mean	**-11.3**	**-1.3**	**42.7**	**-17.3**	**2.7**	**-2.3**	**-47.3**	**-19.3**	**52.7**	**38.7**
En (95%)	**-0.54**	**-0.02**	**0.71**	**-0.19**	**0.04**	**-0.08**	**-0.71**	**-0.29**	**0.33**	**0.99**
									C	**59.3**
									Wt mean	**-152.7**

Table 30 - analysis of results for 3 mm carbide gauge block

4 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	-75	-59	-23	-70	-40	-53	-100	-52	10	-22
$u(d_1)$	13	30	31	46	39	17	34	34	84	21
w_i	0.352	0.066	0.062	0.028	0.039	0.206	0.051	0.051	0.008	0.135
x_i-Wt mean	**-18.1**	**-2.1**	**33.9**	**-13.1**	**16.9**	**3.9**	**-43.1**	**4.9**	**66.9**	**34.9**
En (95%)	**-0.86**	**-0.04**	**0.56**	**-0.14**	**0.22**	**0.13**	**-0.65**	**0.07**	**0.40**	**0.89**
									C	**59.5**
									Wt mean	**-56.9**

Table 31 - analysis of results for 4 mm carbide gauge block

5 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	-156	-132	-80	-150	-120	-145	-170	-138	-60	-104
$u(d_1)$	13	30	31	47	40	17	34	34	88	22
w_i	0.358	0.067	0.063	0.027	0.038	0.209	0.052	0.052	0.008	0.125
x_i-Wt mean	**-17.7**	**6.3**	**58.3**	**-11.7**	**18.3**	**-6.7**	**-31.7**	**0.3**	**78.3**	**34.3**
En (95%)	**-0.85**	**0.11**	**0.97**	**-0.13**	**0.23**	**-0.22**	**-0.48**	**0.00**	**0.45**	**0.83**
									C	**60.5**
									Wt mean	**-138.3**

Table 32 - analysis of results for 5 mm carbide gauge block

10 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	-193	-171	-148	-180	-160	-185	-230	-178	-140	-147
$u(d_1)$	14	30	33	48	46	17	34	35	112	22
w_i	0.333	0.073	0.060	0.028	0.031	0.226	0.056	0.053	0.005	0.135
x_i-Wt mean	**-12.7**	**9.3**	**32.3**	**0.3**	**20.3**	**-4.7**	**-49.7**	**2.3**	**40.3**	**33.3**
En (95%)	**-0.55**	**0.16**	**0.51**	**0.00**	**0.22**	**-0.16**	**-0.75**	**0.03**	**0.18**	**0.81**
									C	**65.3**
									Wt mean	**-180.3**

Table 33 - analysis of results for 10 mm carbide gauge block

25 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	-85	-36	-98	-90	-70	-83	-110	-82	-130	-78
$u(d_1)$	15	35	39	53	61	18	42	41	181	25
w_i	0.358	0.066	0.053	0.029	0.022	0.248	0.046	0.048	0.002	0.129
x_i-Wt mean	**-3.0**	**46.0**	**-16.0**	**-8.0**	**12.0**	**-1.0**	**-28.0**	**0.0**	**-48.0**	**4.0**
En (95%)	**-0.12**	**0.68**	**-0.21**	**-0.08**	**0.10**	**-0.03**	**-0.34**	**0.00**	**-0.13**	**0.09**
									C	**80.5**
									Wt mean	**-82.0**

Table 34 - analysis of results for 25 mm carbide gauge block

40 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	45	105	111	110	20	76	40	74	10	99
$u(d_1)$	18	40	45	57	77	20	42	50	251	26
w_i	0.320	0.065	0.051	0.032	0.017	0.259	0.059	0.041	0.002	0.153
x_i-Wt mean	**-26.1**	**33.9**	**39.9**	**38.9**	**-51.1**	**4.9**	**-31.1**	**2.9**	**-61.1**	**27.9**
En (95%)	**-0.88**	**0.44**	**0.46**	**0.35**	**-0.33**	**0.14**	**-0.38**	**0.03**	**-0.12**	**0.58**
									C	**103.7**
									Wt mean	**71.1**

Table 35 - analysis of results for 40 mm carbide gauge block

75 mm carbide	NPL	MSA	METROSERT	MIRS	UZ	SMD	NML	JV	LNMC	INM
d_1	-51	-19	-42	-10	-20	-35	-120	-30	-170	20
$u(d_1)$	27	50	59	68	114	23	71	77	414	32
w_i	0.245	0.072	0.051	0.039	0.014	0.338	0.035	0.030	0.001	0.175
x_i-Wt mean	**-20.6**	**11.4**	**-11.6**	**20.4**	**10.4**	**-4.6**	**-89.6**	**0.4**	**-139.6**	**50.4**
En (95%)	**-0.44**	**0.12**	**-0.10**	**0.15**	**0.05**	**-0.12**	**-0.64**	**0.00**	**-0.17**	**0.87**
									C	**178.8**
									Wt mean	**-30.4**

Table 36 - analysis of results for 75 mm carbide gauge block

8.4 Result revision or withdrawal

SMD asked to revise some results for the steel gauge blocks, as did METROSERT. Neither labs had been informed of the results of the comparison and the Draft A report had not been circulated, so this was not an issue. Both labs revised their results because subsequent re-calibration of their master gauge blocks had revealed drift, which would have affected the comparison results.

Only the revised results are reported in this document.

8.5 Analysis of results

The analysis is quite straightforward since all of the results have an E_n value of magnitude less than 1.0, at the 95% (k = 2) confidence level. This means that the results are all in agreement with the relevant weighted mean, and there are therefore no outliers and no further processing is required.

8.6 Variation in length results

As well as the deviation from nominal length measured at the centre, d_1, participants were also asked to measure the deviation from nominal length at the four corners, d_2 to d_5. From these 5 measurements on each gauge block, the variation in length, v, is calculated as max-min[d_1, … d_5].

These values are also reported in Tables 4 through 19. For the standard uncertainty of the measurement of v, the individual uncertainty at each point, u(di) has been multiplied by 1.414, since the two results which are used to calculate v are two independent measurements of deviation from central length.

The results, shown in Tables 4 through 19, are also plotted in Figures 20 through 35.

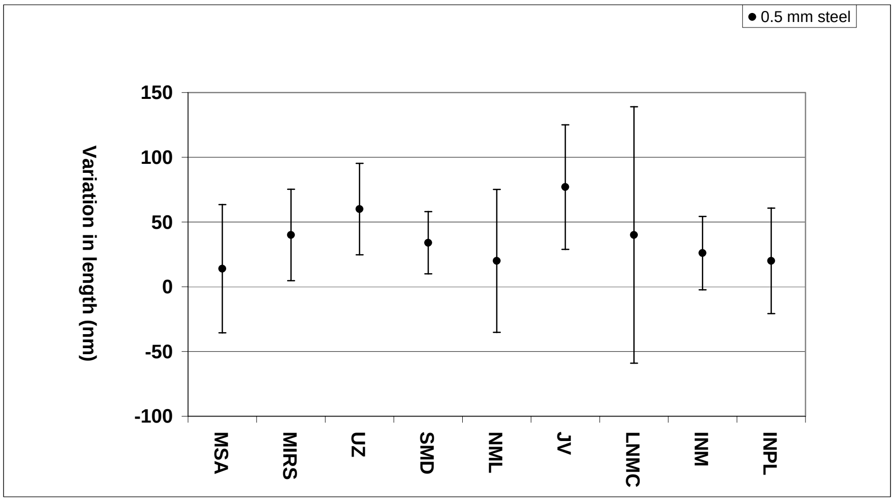


Figure 20 - variation in length, 0.5 mm steel gauge (k=1)

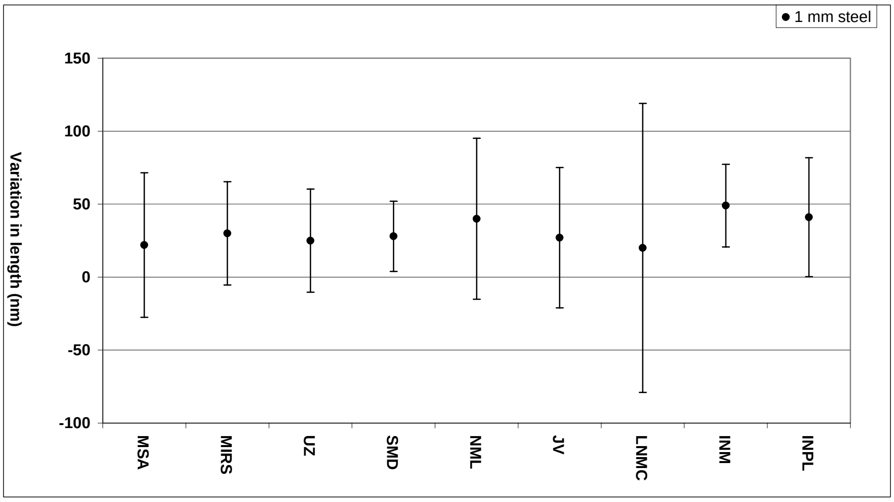


Figure 21 - variation in length, 1 mm steel gauge (k=1)

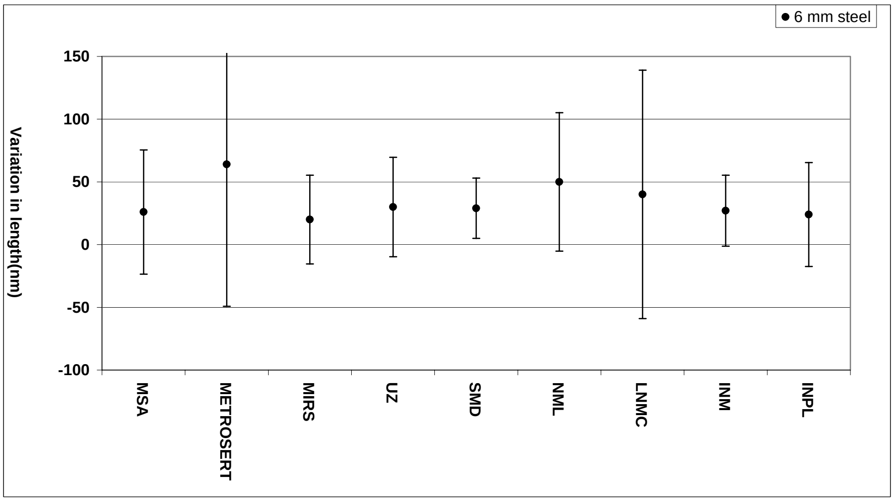


Figure 22 - variation in length, 6 mm steel gauge (k=1)

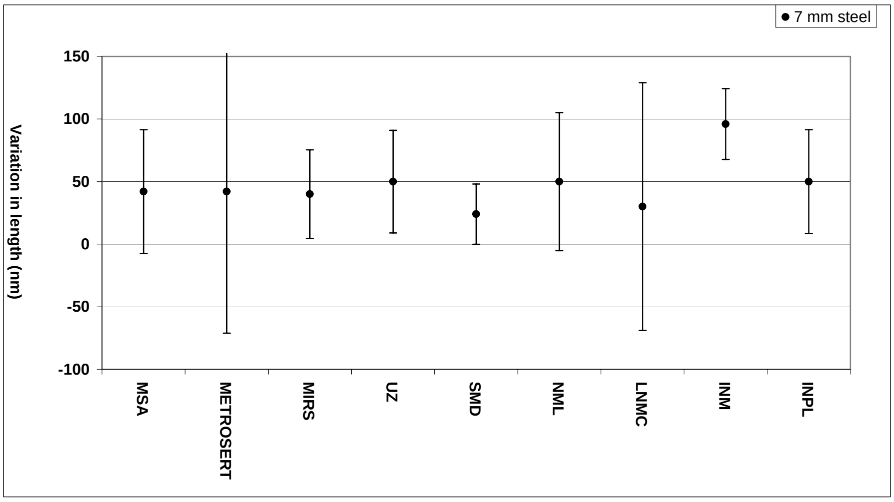


Figure 23 - variation in length, 7 mm steel gauge (k=1)

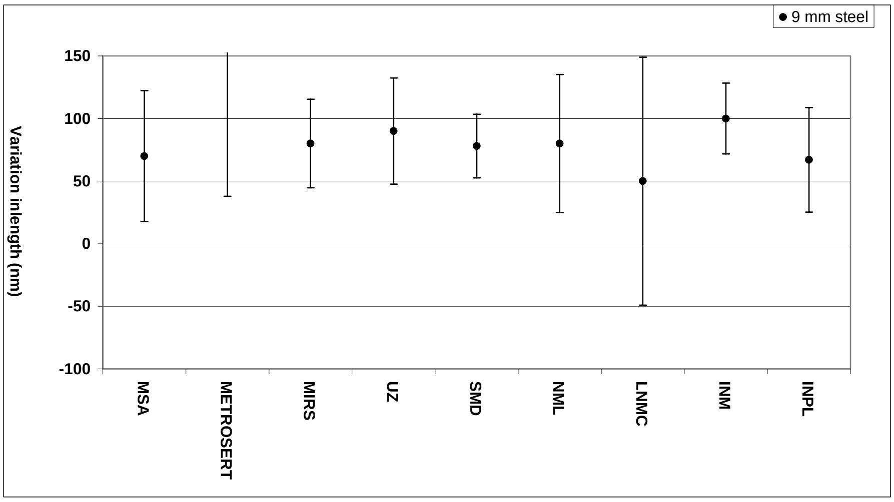


Figure 24 - variation in length, 9 mm steel gauge (k=1)

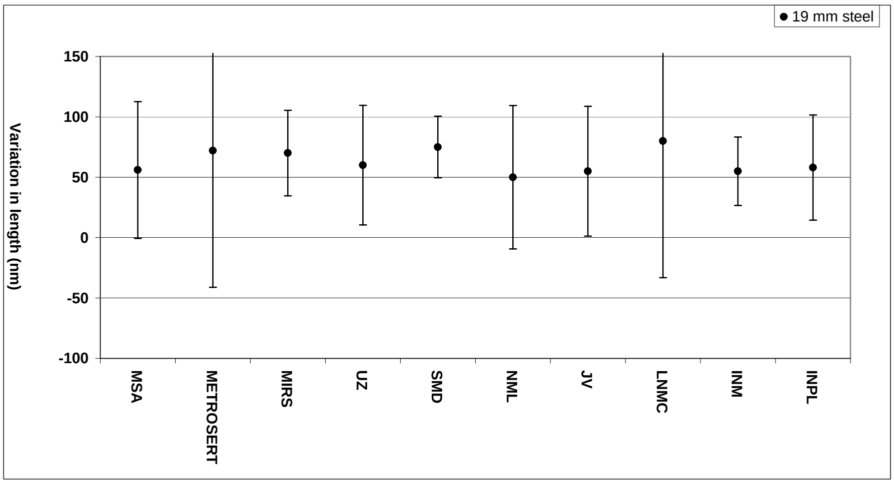


Figure 25 - variation in length, 19 mm steel gauge (k=1)

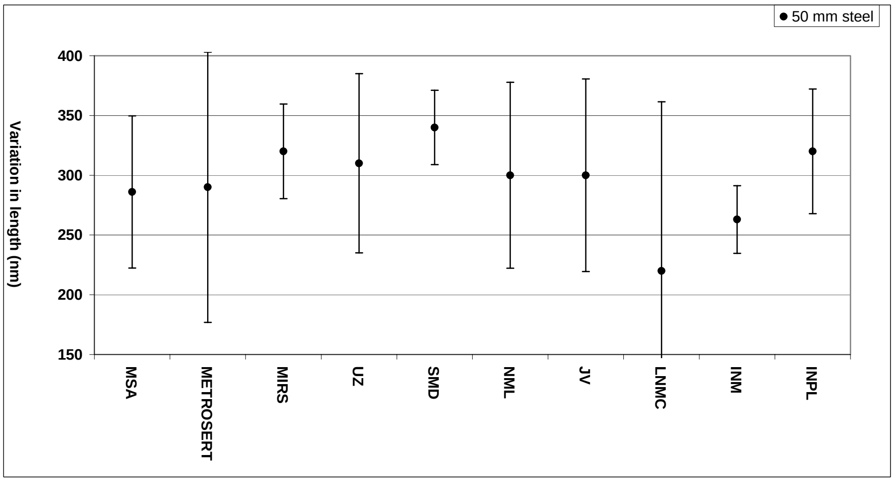


Figure 26 - variation in length, 50 mm steel gauge (k=1)

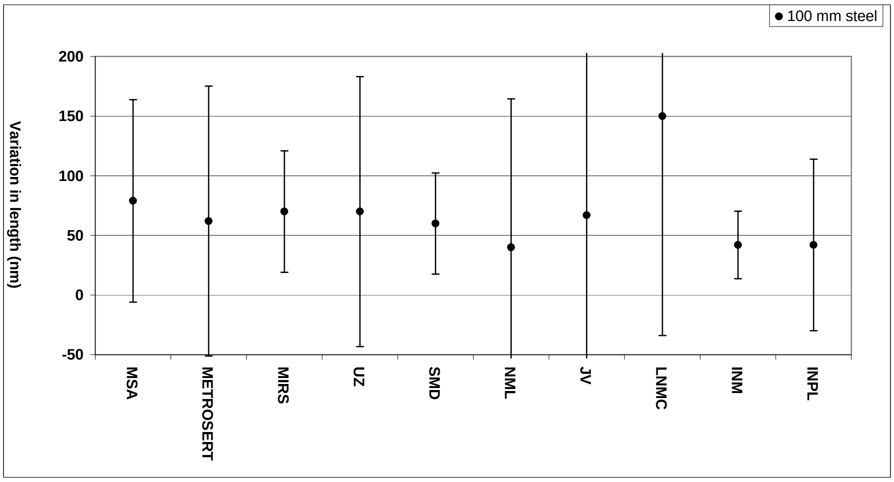


Figure 27 - variation in length, 100 mm steel gauge (k=1)

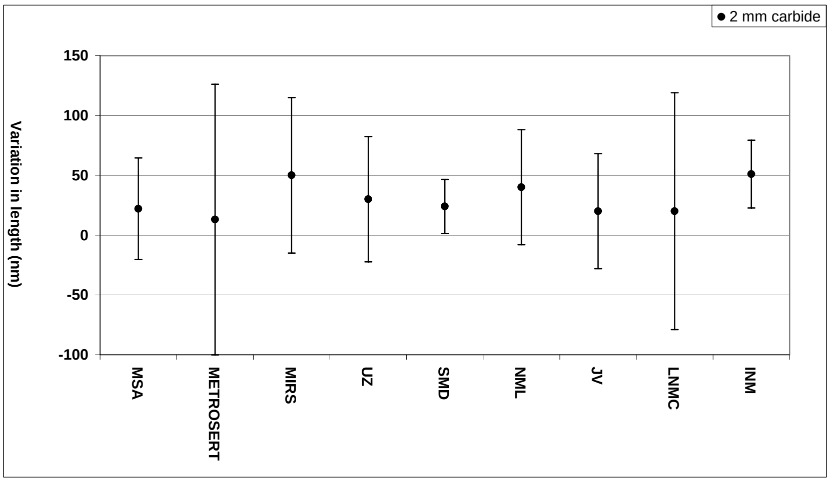


Figure 28 - variation in length, 2 mm carbide gauge (k=1)

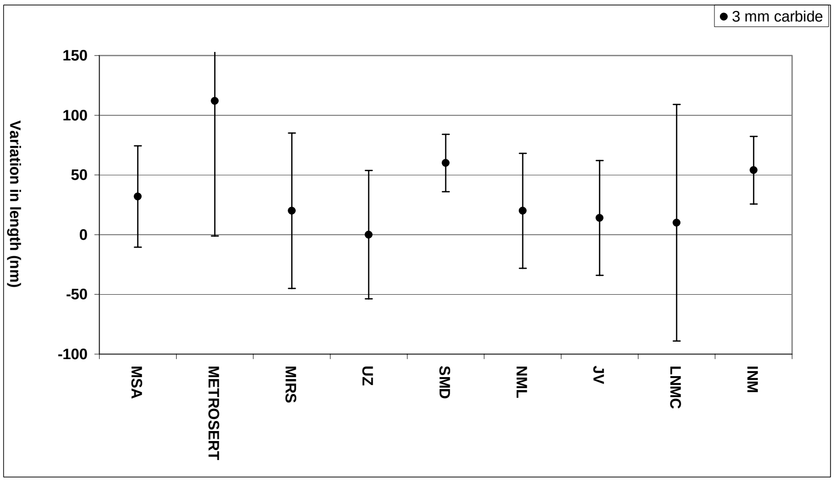


Figure 29 - variation in length, 3 mm carbide gauge (k=1)

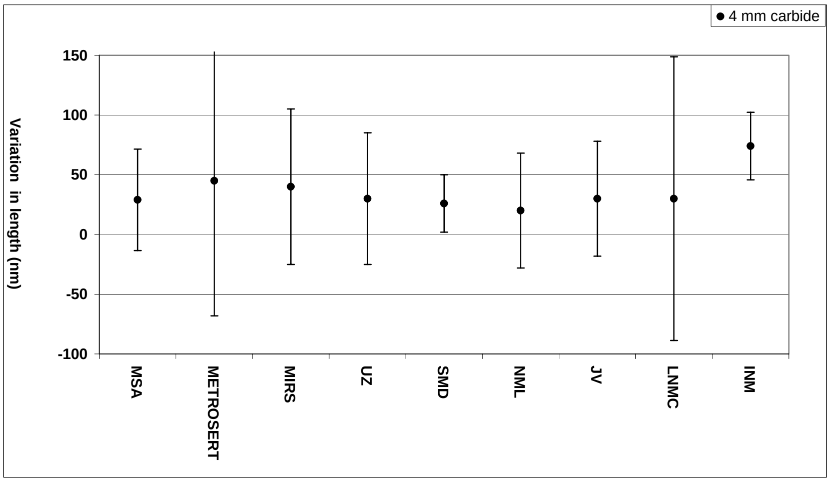


Figure 30 - variation in length, 4 mm carbide gauge (k=1)

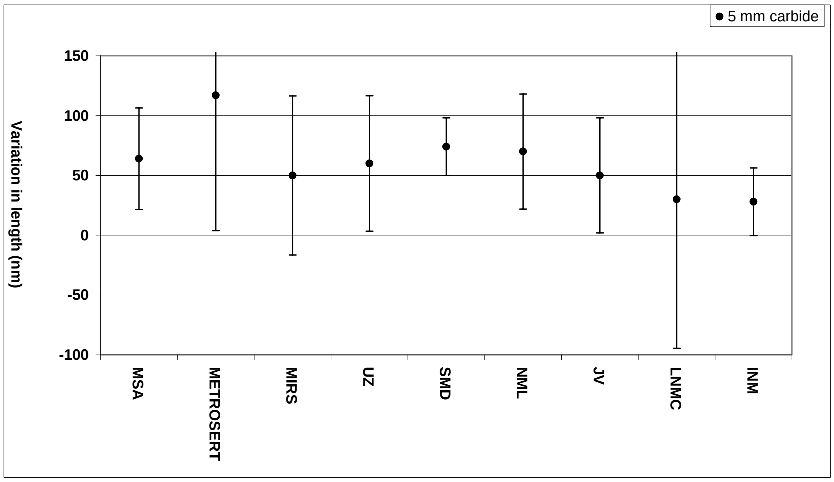


Figure 31 - variation in length, 5 mm carbide gauge (k=1)

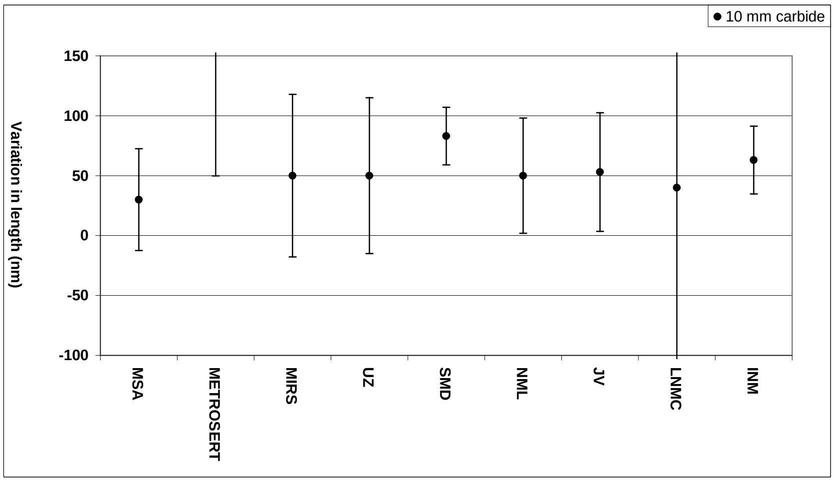


Figure 32 - variation in length, 10 mm carbide gauge (k=1)

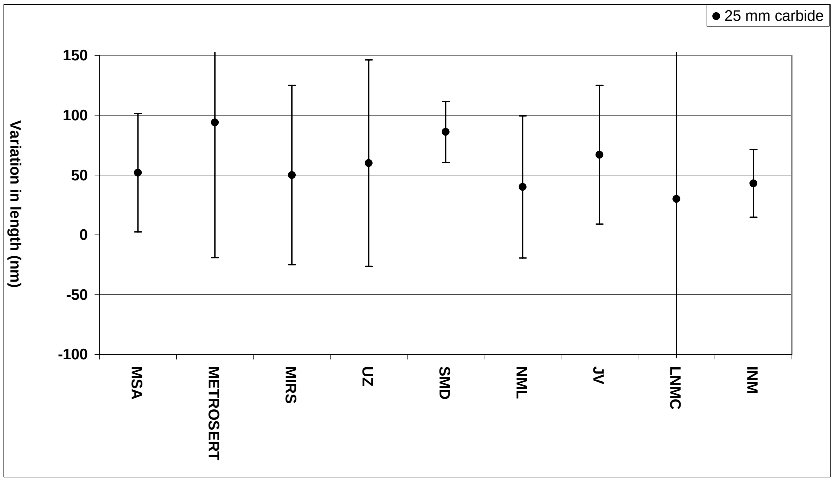


Figure 33 - variation in length, 25 mm carbide gauge (k=1)

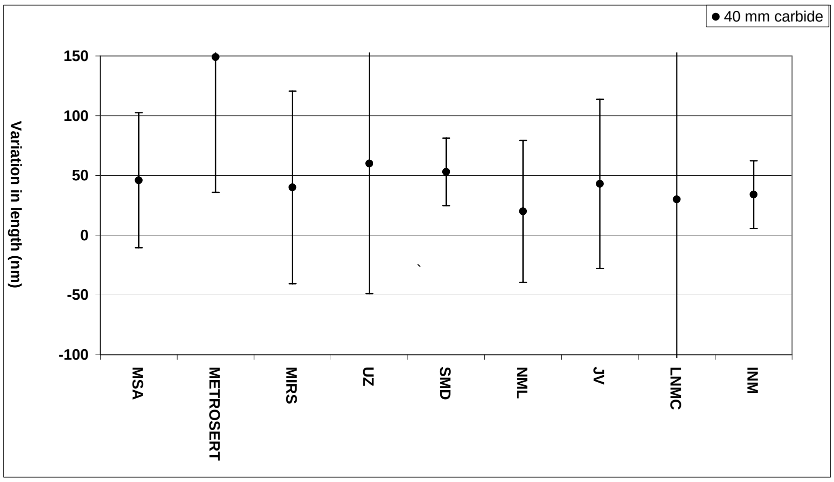


Figure 34 - variation in length, 40 mm carbide gauge (k=1)

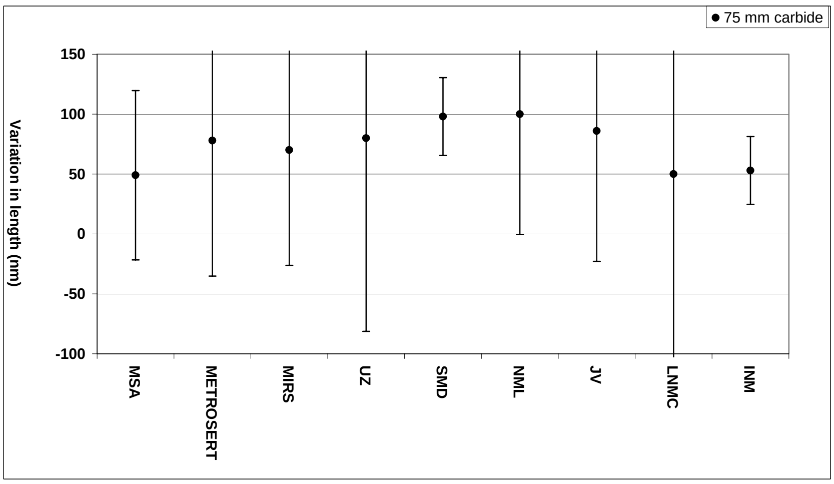


Figure 35 - variation in length, 75 mm carbide gauge (k=1)

The analysis of the variation in length results is, again, quite straightforward since all of the results have an E_n value of magnitude less than 1.0, at the 95% (k = 2) confidence level. This means that the results are all in agreement with the relevant weighted mean, and there are therefore no outliers and no further processing is required.

9 Conclusions

From the EUROMET.L-S16 gauge block supplementary comparison, the following conclusions can be drawn:

- From the start of the comparison, the time taken to perform all the measurements, including transportation, was slightly longer than originally planned, namely 18 months. This was not too long and did not cause undue problems.

- One gauge block, the 5 mm tungsten carbide gauge, was damaged during the circulation. A nick was added to one edge, causing wringing problems. Fortunately, this comparison did not require wringing of the gauges.

- Overall, the comparison has been very successful. No results are considered as outliers and all results are in agreement with the weighted means within their $k = 2$ uncertainties.

- One participant did not measure the tungsten carbide gauges, as they do not offer this service routinely to customers.

- Another participant had difficulty fitting some gauges into their equipment due to the gauges being slightly over-sized. These gauges were from old NPL stock and the dimensions were not checked against the latest specification standard ISO 3650. The gauges pre-dated this standard,

- The CMC claims for al the participants for gauge block measurement by mechanical comparison are supported by the results of this comparison.

10 Acknowledgements

The NPL co-pilot laboratory work on the comparison was funded by the DTI NMSPU Programme for Length Metrology 2002 – 2005 and the DIUS NMSPU Programme for Engineering Measurement 2005 – 2008.

11 References

[1] CIPM, Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes, 1999, BIPM.

[2] BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML *Guide to the expression of uncertainty in measurement* (1995).

Appendix 1 - Equipment and techniques used by the participants

			SMD	METROSERT	NPL	HMI	NML	INPL	LNMC	MSA	JV	INM	MIRS
MEASURING STSTEM	COMPARATOR	Type	Mechanical	Mechanical	Mechanical	Mechanical	Mechanical	Mechanical	Interferential	Mechanical	Mechanical	Mechanical	Mechanical
		Model	IVC 153	UPC	IVC 153	826	UPC	UPC	IKPV	UPC	UPC	UPC	826
		Make	Cary	Tesa	Cary	Mahr	Tesa	Tesa	Kalibr	Tesa	Tesa	Tesa	Mahr
	DISPLAY UNIT	Model	Carylabor	Tesamodul	Carylabor	—	Tesamodul	Tesamodul	—	Tesamodul	Tesamodul	Tesamodul	—
		Make	Cary	Tesa	Cary	—	Tesa	Tesa	—	Tesa	Tesa	Tesa	—
		Resolution	10 nm	10 nm	10 nm	10 nm	10 nm	10 nm	50 nm	10 nm	10 nm	10 nm	10 nm
STANDARDS	FOR STEEL BLOCKS	Material	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel
		Make	Cary	Mitutoyo	Pitter	Mahr	—	Pitter	Kalibr	Cary	—	Carl-Zeiss	Karl-Frank
		Grade	K	K	K	K	K	1/20	1	K	K	0	00
		Traceability	in-house	MIKES	in-house	PTB	—	—	in-house	NPL	—	—	—
	FOR TC BLOCKS	Material	TC	TC	TC	Steel	—	TC	—	TC	TC	TC	Steel
		Make	Select	Cary	Select	Mahr	—	CE Johanson	—	Select	—	—	Karl-Frank
		Grade	K	K	K	K	—	00	—	K	K	0	00
		Traceability	in-house	in-house	in-house	PTB	—	—	—	METAS	—	—	—
DATA ACQUISITION			via RS32	—	Manual	—	—	—	—	via RS 232	—	—	—
CALCULATION			Software	—	Excel	—	—	—	—	Excel	—	—	—
TEMPERATURE [°C]	DEVIATION FROM 20°C	Steel	19.83 - 20.14	20.0 ± 0.5	19.8 - 20.2	19.9 - 20.4	0.14	19.7 - 20.5	20.6 - 20.9	< ± 0.50	< ± 1	20.39 - 20.74	19.93 - 20.05
		TC	19.83 - 20.14	20.0 ± 0.5	19.8 - 20.2	19.9 - 20.4	0.12	—	20.4 - 20.6	< ± 0.50	< ± 1	20.39 - 20.74	19.93 - 20.05
	DIFF BETWEEN BLOCKS	Steel	—	—	—	—	—	—	—	< ± 0.04	< ± 0.085	—	—
		TC	—	—	—	—	—	—	—	< ± 0.04	< ± 0.085	—	—