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Mass Comparison: 5 kg laboratory balance

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MITTATEKNIIKAN KESKUS
CENTRE FOR METROLOGY AND ACCREDITATION

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ABSTRACT

A comparison M4 of a 5 kg balance was carried out in June 2003 by the Centre for Metrology and Accreditation (MIKES). Six participants from four accredited calibration laboratories from Finland participated in the comparison. The reference laboratory was MIKES.

The comparison was made with a high resolution (d = 1 mg) laboratory balance. The measurements were made at MIKES. The participants calibrated the balance according to their own measurement procedures using their own weights. Measurement results of the laboratories were taken from calibration certificates.

All results were in agreement with the results of MIKES.

TIIVISTELMÄ

Mittatekniikan keskus (MIKES) järjesti kesäkuussa 2003 massan vertailumittauksen M4. Vertailu tehtiin 5 kg tarkkuusvaa'alla. Vertailumittaukseen osallistui kuusi kalibroijaa neljästä akkreditoidusta kalibrointilaboratoriosta Suomesta. Vertailun referenssilaboratoriona oli MIKES.

Vertailuun käytetyn vaa'an resoluutio oli 1 mg. Mittaukset tehtiin MIKESissä. Vertailuun osallistuneet laboratoriot tekivät mittaukset omien mittausmenetelmiensä mukaisesti käyttäen omia punnuksiaan. Mittaustulokset on otettu laboratorioiden antamista kalibrointitodistuksista.

Kaikki mittaustulokset olivat mittausepävarmuuksien sisällä samoja kuin MIKESin tulokset.

CONTENTS

MASS COMPARISON: 5 kg LABORATORY BALANCE

1. INTRODUCTION

A mass comparison M4 was arranged in June 2003 by the Centre for Metrology and Accreditation (MIKES). The comparison was made with a 5 kg laboratory balance.

The aim of the comparison was not only to compare measurement results but also to compare measurement methods, uncertainties analysis and contents of calibration certificates. No detailed calibration instructions were given to the laboratories.

Six persons from four accredited mass calibration laboratories from Finland participated in the comparison.

2. BALANCE

The comparison was made with a high resolution laboratory balance: Sartorius LC5100-00VAA n/o 30702842. The capacity of the balance is 5100 g and its resolution is 1 mg. The weighing range is 0-5100 g. The balance does not have any centring device. At MIKES the balance is used as a mass comparator. The balance is adjusted with an external 5 kg weight.

3. REFERENCE LABORATORY

The mass laboratory of MIKES is the national standard laboratory for mass in FINLAND. The traceability of mass comes from BIPM. In the calibration of the balance the following weights sets were used:

SET	OIML CLass	Uncertainty (k=2)	Calibrated
P110 1 kg, 2 x 2 kg, 5kg	F_1	0,1 – 1,5 mg	2002
P112 100g, 200 g, 500 g	F_1	0,05 – 0,1 mg	2003
P7 500 g	E_2	0,05 mg	2002
P13 500 g	E_2	0,05 mg	2000
P111 500 g	F_1	0,05 mg	2003
P107 500 g, 1 kg	F_1	0,15 – 0,2 mg	2001

Table 1, Reference weights used by MIKES

4. PARTICIPANTS

The following laboratories participated in the comparison:

Oy G.W. Berg & Co Ab, K029, Vantaa ,
Inspecta Oy, K004, Helsinki,
Raute Precision OY, K019, Lahti,
Teopal Oy, K037, Espoo,

The measurements were made on 6.6, 9.6, 10.6 and 17.6.2003.

5. MEASUREMENTS BY MIKES

5.1 Measurement methods

The balance was preloaded with a 5 kg weight for at least one hour before measurements. After this period the balance was adjusted with a 5 kg weight. The maximum change in adjustment was about 10 mg. The load was removed just before the measurements started. The balance was on a stone table in a temperature controlled laboratory. The humidity was constant during the calibrations.

MIKES calibrated the balance with two different methods. Both methods have been included in the EA draft on the calibration of a weighing instrument. Method 2 has also been described also in MIKES publication Julkaisu J6/1998.

In Method 1 each load was applied separately in the following way:

a) load was removed
b) the balance reading was recorded
c) the load was applied
d) the balance reading was recorded

This was repeated at least 3 times for each load. The loads were 0 g, 100 g, 200 g, 500 g, 1000 g, 1500 g, 2000 g, 2500 g, 3000 g, 3500 g, 4000 g, 4500 g, 5000 g. The loading was centric. The measurements with this method took about 1 hour.

In Method 2 the balance was loaded continuously in the following way:

a) zero load reading was recorded
b) first load was applied and the reading was recorded
c) next load was added without removing the previous load, the reading was recorded

This procedure was applied up to the largest load. After that the loads were removed in the reverse order.

The following loading points were applied: 0 g, 500 g, 1000 g, 2000 g, 3000 g, 4000 g, 4500 g and 5000 g. It was not possible to avoid eccentric errors. The loading was repeated three times. Eccentric errors at 2 kg and repeatability at 5 kg and 2 kg were measured.

The balance was calibrated with method 1 on three days before the comparison and on each day during the comparison. Method 2 was applied at the end of the comparison.

5.2 Measurement results

The measurement results were calculated by the formula:

$$E = I - m,$$

where E is the error of indication of the balance, I is the indication of the balance and m is the conventional mass of the weights.

The air buoyancy correction was not applied. The following aspects reduce the air buoyancy correction:

- the balance was adjusted before measurements,
- the density of weights is close to 8000 kg/m^3 (7960 – 8000 kg/m^3),
- air density was close to 1,2 kg/m^3 (1,182 – 1,208 kg/m^3).

The largest contribution comes from the density of weights.

Figure 1 shows measurement results with Method 1. Only measurements made during the comparison days (6.6 – 17.6) were used in the analysis of the results. The average results in Fig. 1 is the average of these four measurements. The results on 3.6 and 4.6 deviate significantly from the other results. Possible reasons for the deviation are adjustment error or loading history. A polynomial fit to the measurement results was calculated. Because the fit did not seem to add any new information to the results a linear interpolation between the measured points (lines in Fig. 1) was considered sufficient for the reference value.

Figure 2 shows measurement results with Method 2. Measurements were made on 23.6.2003. The average values in Fig. 2 is the average of results with increasing loads. Also here a linear interpolation lines are given.

5.3 Measurement uncertainty

The measurement uncertainties in Figures 1 and 2 are standard uncertainties. In Fig. 1 the average curve has the following uncertainty components:

- weights (u = 0,01 – 0,75 mg)
- repeatability (u = 0,5 – 1,5 mg)
- resolution (u = 0,41 mg)
- variation of results on different days (u = 0,2 – 2,1 mg)
- air buoyancy correction (u = 0,05 – 2,2 mg).

In Fig. 1 also the uncertainty of the measurement on 3.6 is given. In this case the uncertainty does not include the component due to day to day variation. The uncertainties of the other curves are similar.
In Fig. 2 only the uncertainty of the average is given. It has the following components:

- weights (u = 0,1 – 0,4 mg)
- repeatability (u = 0,5 – 2 mg)
- eccentricity (u = 1 – 1,8 mg)
- resolution (u = 0,41 mg)
- variation of results on different loading (u = 0,5 – 5 mg)

Uncertainty component due to temperature change during calibration was not taken into account. It may be significant for the balance.

The result of Method 1 (average values) were taken as reference values.

6. MEASUREMENT INSTRUCTIONS

The following information was given to the participants in advance:
Balance model Sartorius LC5100S, MAX 5100 g, d = 1 mg, Nro 30702842. The range to be calibrated: 0 - 5100 g, no adjustment. It was allowed to bring weights to MIKES in advance. For each laboratory the measurement time was four hours. No instructions for the measurement method or loading points were given. The participants were asked to send their results as calibration certificates to MIKES within few weeks after the measurements.

7. RESULTS

All laboratories presented their results as calibration certificates. The uncertainties were estimated using the document EA-4/02.

Following the EA intercomparison practice all laboratories were given letter codes (A-D). If two persons come from the same laboratory they are identified by a number after the letter code. In the case of MIKES the number refers to the measurement method.

Results are given in Figure 3 and in Table 2. The error of indication is denoted by *E*. The uncertainties *U* are expanded uncertainties corresponding to a coverage probability of 95 %. In all cases the coverage factor is two ($k = 2$).

A tool often used in analysing the results from interlaboratory comparisons is the normalised error E_n, which takes into account both the result and its uncertainty. The normalised error E_n is given as:

$$E_n = \frac{E_{lab} - E_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \quad .$$

here the subscript *lab* refers to the calibration laboratory and *ref* refers to MIKES. For the reference values the results of MIKES [1] were used.

LAB	**A[1]**		**A[2]**		**B[1]**		**B[2]**		**C**		**D**		**MIKES [1]**		**MIKES [2]**	
Load	*E* mg	*U* mg	*E* mg	*U* mg	*E* mg	*U* mg	*E* mg	*U* mg	*E* mg	*U* mg	*E* mg	*U* mg	*E* mg	*U* mg	*E* mg	*U* mg
0 g	0	10	0	6	0	15	0	8	0	3	0	7,8	0.0	1,7	0,0	2,4
1 g	0	10	-1	6					-1	3						
10 g	-1	10	-1	6	0	15	0	8	0	3	0	7,8				
50 g	-2	9	-1	6							0	7,8				
60 g					0	15	1	8								
100 g	-2	9	0	6					1	3	1	7,8	0,9	1,7		
200 g													1,8	1,7		
260 g					1	15	2	8								
300 g											2	7,8				
500 g	1	9	3	7					5	3	1	7,8	3,4	1,8	4,8	2,6
760 g					4	15	4	8								
1000 g	3	10	5	8					8	4	3	7,9	6,1	1,9	8,3	2,6
1260 g					6	15	6	8								
1500 g													7,8	1,8		
2000 g	4	11	7	13					12	4			9,5	2,3	11,8	3,5
2460 g					6	15	9	9								
2500 g													10,0	3,2		
3000 g	1	14	8	18					11	7	6	9,3	9,1	3,7	11,2	8,8
3500 g													7,8	4,5		
3660 g					6	15	7	9								
4000 g	-1	14	10	19					11	7			7,2	4,5	10,4	6,3
4500 g													7,5	4,4	12,5	10,9
4660 g					10	16	10	10								
5000 g	4	15	19	19					14	8	12	11,7	5,3	6,1	17,0	7,4
5060 g					14	16	15	10								

Table 2, Results of the comparison, *E* = error of indication of the balance, *U* = expanded uncertainty

Load (g)	A[1]	A[2]	B[1]	B[2]	C	D	MIKES [2]
1	0,00	-0,17			-0,33		
10	-0,10	-0,17	0,00	0,00	0,00	0,00	
50	-0,22	-0,17				0,00	
60			0,00	0,13			
100	-0,32	-0,15			0,02	0,01	
260			-0,07	-0,01			
300						-0,04	
500	-0,26	-0,05			0,46	-0,30	0,45
760			-0,05	-0,10			
1000	-0,30	-0,13			0,44	-0,38	0,70
1260			-0,06	-0,12			
2000	-0,49	-0,19			0,53		0,55
2460			-0,26	-0,11			
3000	-0,56	-0,06			0,24	-0,31	0,22
3660			-0,11	-0,07			
4000	-0,56	0,14			0,46		0,42
4660			0,20	0,32			
5000	-0,08	0,68			0,86	0,50	1,21
5060			0,54	0,97			

Table 3, E_n values for the comparison

Calculated E_n-values of all the results are shown in Table 3.

A summary of the E_n-values and expanded uncertainties are given in Table 4. Also the E_n values for MIKES[2] were calculated.

Laboratory	E_n-values	Uncertainties
A 1	-0,56 … 0	9 – 15 mg
A 2	-0,19 ... 0,68	6 – 19 mg
B 1	-0,26 …0,54	15 – 16 mg
B 2	-0,12 …0,97	8 – 10 mg
C	-0,33 … 0,86	3 – 8 mg
D	-0,38 … 0,50	8 – 12 mg
MIKES [2]	0,22 … 1,21	3 – 8 mg
MIKES [1]		2 – 7 mg

Table 4, Summary of E_n values and expanded uncertainties

The result in an interlaboratory comparison is regarded acceptable if the absolute value of the normalised error E_n is less than 1. In this case all the results of the laboratories are acceptable.

There seems to be a problem with this balance at the maximum load (5 kg). The balance is behaving differently depending on the load history. If the balance is loaded many times at 5 kg the value tends to decrease.

8. MEASUREMENT PROCEDURES AND CONTENTS OF CERTIFICATES

All laboratories calibrated the balance by first loading it to the maximum load and then unloading it. Some laboratories did not remove weights during loading (at least lab A and lab C). All laboratories determined also eccentric loading error and repeatability. The repeatability was determined at 5 kg by all laboratories and at 2 kg by lab D. The methods used by the laboratories are in accordance with publication J6/1998. The publication is not however very specific and leaves much freedom for the calibration procedure.

LAB	weights	hysteresis	resolution	repeatability	eccentric loading
A [1]	x	x	x	x	x
A [2]	x	x	x	x	x
B [1]	x	x	x	x	x
B [2]	x	x	x	x	x
C	x		x	x	
D	x		x	x	

Tab 5, Uncertainty components included in uncertainty calculations.

Table 5 gives uncertainty components which were included in the combined uncertainty. Laboratories C and D did not include hysteresis or eccentric loading in the uncertainty of the loading curve. In the calibration certificate Lab D also gives an overall uncertainty which includes these components.

In Table 6 magnitudes of uncertainty components for different laboratories are given. There is a relatively large variation in the repeatability mainly due to loading history. At best repeatability values below 1 mg can be obtained.

LAB	resolution (mg)	eccentric loading (mg)	hysteresis (mg)	repeatability (mg)	weight class
A [1]	1	0-5	0-3,5	3-4	F_1
A [2]	1	0-7	2	2,5-4	F_1
B [1]	0,4	4,6	4,9	2,1	E_2/F_1
B [2]	0,4	2,9	1,2	2,2	E_2/F_1
C	0,4	2	5	0,7	F_1
D	0,4	4	2	1,1/3,9	F_1

Table 6, Uncertainty components in standard uncertainties.

The OIML class of weights used in the calibration are given in Table 6. All laboratories used F_1 weights at large loads. All laboratories except Lab A included the number of the calibration certificate and the place of calibration for the weights in their own calibration certificate.

As a rule the certificates of all participating laboratories were in accordance with the requirements of ISO/IEC 17025.

9. CONCLUSIONS

Four accredited mass calibration laboratories participated in an comparison of a 5 kg laboratory balance. The calibrations were made at MIKES in June 2003.

All results from the participating laboratories were in agreement with the reference values of MIKES.

The balance Sartorius LC5100S was found to be relatively stable and its resolution was sufficient for this comparison.

10. REFERENCES

EA-4/02: Expression of the Uncertainty of Measurement in Calibration

ISO/IEC 17025: General requirements for the testing and calibration laboratories.

“Vaakojen kalibrointiohje”, Julkaisu J6/1998, MIKES 1998

Weights of Classes E_1, E_2, F_1, F_2, M_1, $M_{1\text{-}2}$, M_2, $M_{2\text{-}3}$, M_3 , OIML R111, draft 2002

“EA guidelines on the calibration of non-automatic weighing instruments, EA-10/NN draft, 2002

KR 7.10.2003

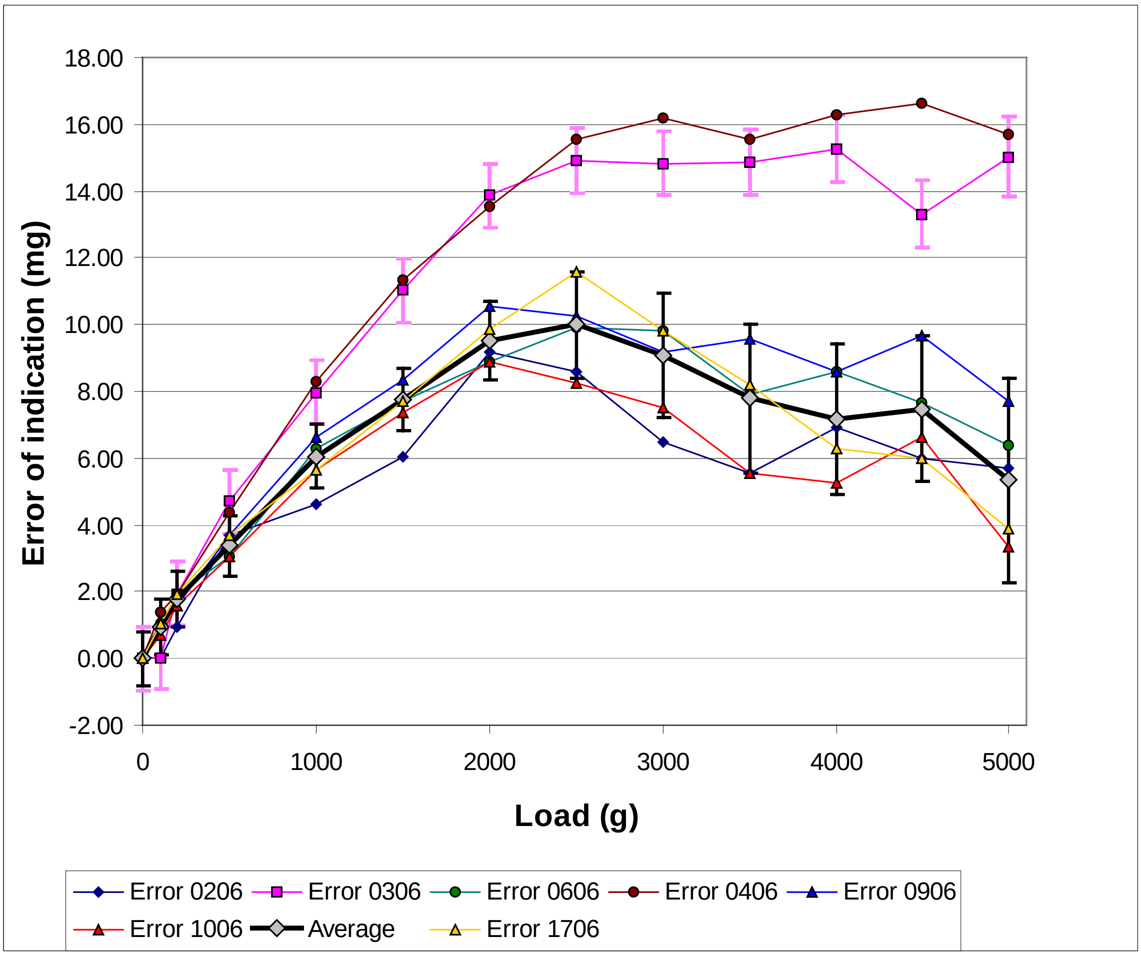

Fig. 1, Results of MIKES using method 1. The uncertainty bars are standard uncertainties.

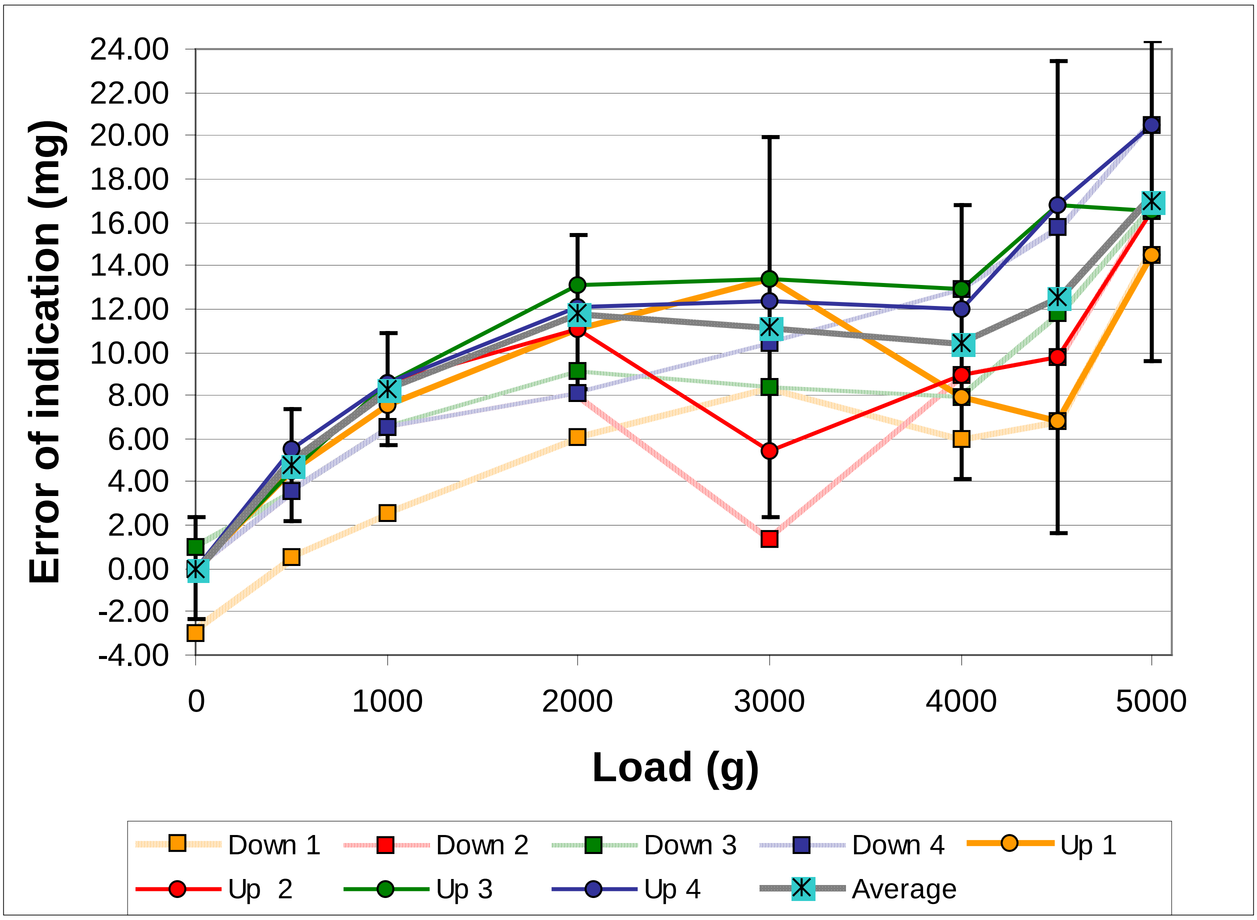

Fig. 2, Results of MIKES using Method 2 . The uncertainties are standard uncertainties.

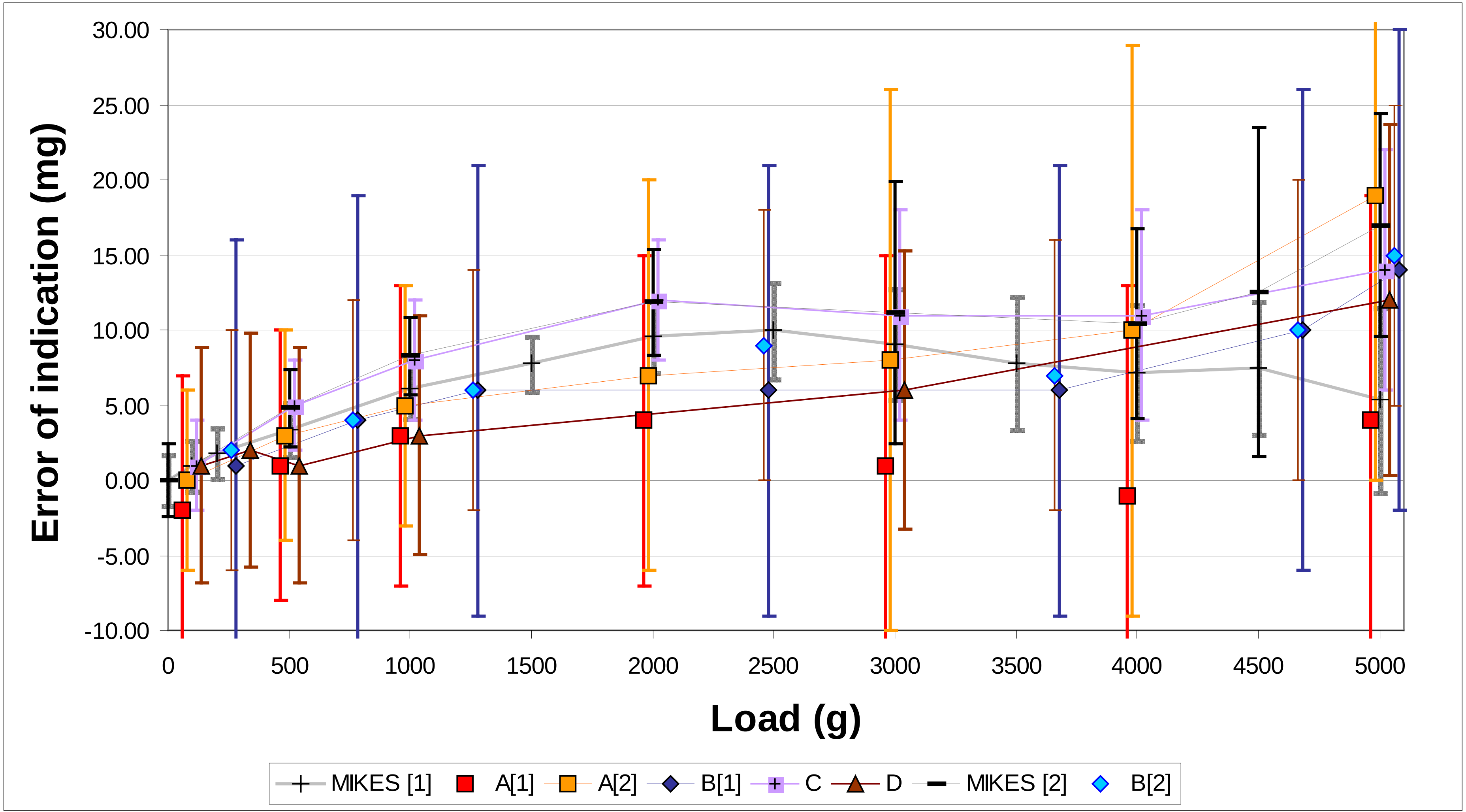

Fig. 3, Measurement results of the comparison. The uncertainties are expanded uncertainties.

Recent publications

J7/1999 T. Weckström, *Lämpötilan vertailumittaus L10, S-tyypin termoelementin kalibrointi*

J8/1999 S. Nevalainen, *Mekaanisten värähtelyiden mittausten kartoitus*

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