IMPROVEMENTS ON DISSEMINATION OF THE UNIT OF MASS IN BEV

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Abstract: The Austrian Federal Office of Metrology and Surveying (BEV) has developed and realized in cooperation with Sartorius AG (Göttingen) and the Vienna University of Technology, three handling systems for automatic calibration of weights on high-precision mass comparators [1]. The metrological performance of these systems has been studied [2].

Recent developments in BEV, like the new laboratories, improved techniques for the dissemination of mass unit required an update and further development of the previous study.

Keywords: mass determination, sub-division, weighing schemes.

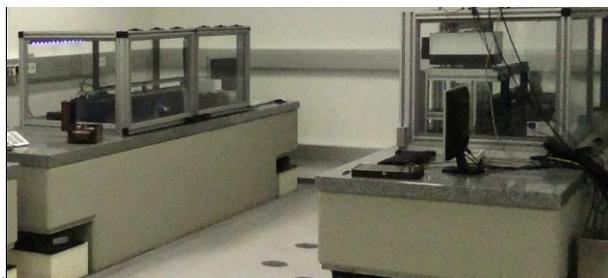## 1. INTRODUCTION AND LATEST DEVELOPMENTS

Fig. 1. 10 g and 1 kg robotic systems in the new laboratory

Key developments:
- New laboratory building opened in 2011 in BEV.
- New balance tables (systems are placed on 4 m long granite plates supported by concrete tables with a mass of approximately 15 t. The concrete tables are mounted on passive air springs. Fig. 1.)
- Better environmental conditions in the new laboratory. Fig 2a and 2b show the temperature and humidity change in the weighing chamber.
- Double housing of the 1 kg mass comparator (type: CC 1000 S-L) also reduced the temperature change in the weighing chamber. The carbon dioxide sensor is situated in the external case but outside of the weighing chamber.
- Alternative solutions for subdivision using the 1 kg comparator:
    - o use of auxiliary device: support plates (the only previously existing solution in BEV, see fig 4),
    - o use of disk weights, see fig 5 and 6,
    - o new 1 kg mass comparator that needs no additional objects performing the sub-division (fig. 7).
- Application of Monte Carlo method.
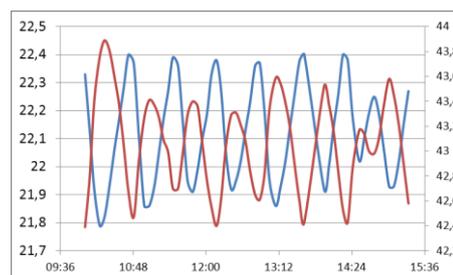- Development of the new primary balance (fig. 7).

Fig. 2a. Temperature and humidity stability in the weighing chamber in the old laboratory. Blue – temperature, red – humidity.
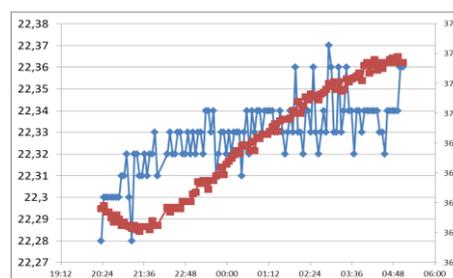

Fig. 2b. Temperature and humidity stability in the weighing chamber in the new laboratory. Blue – temperature, red – humidity. The first 10-15 measurements usually reflect the warming up period of the balance enclosure.

The previously obtained periodical change of the temperature and the humidity caused a higher standard deviation of measurement. In the new laboratory by the isolated case this effect has been eliminated.

Fig. 3. The CC 1000 SL balance has an isolated external case.

To replace the support plates in the decade of 100 g – 1 kg, BEV ordered two special disks with the nominal values of 100 g and 500 g made of the same material and with the same properties as the weights of class E_1. Both disks are about 56 mm in diameter providing enough surface area to hold the combinations of weights. A third disk weight in nominal value of 50 g is used by the subdivision of the next decade.
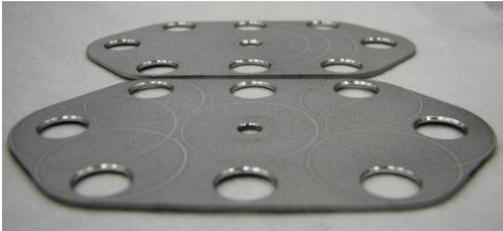

Fig. 4. Support plates designed for subdivision using CC 1000 S-L mass comparator

Fig. 5. The set of new disk weights for the subdivision using CC 1000 S-L mass comparator

Fig. 6. Disk weight with 500 g nominal value is holding a combination of another 500 g weighs to be compared against 1 kg standards

Fig. 7. The 1 kg new primary balance of BEV allows measuring combinations without additional devices

2. EVALUATION SOFTWARE AND ITS VALIDATION USING MONTE CARLO SIMULATION

The BEV developed three steps for evaluation of the measurement data using separate programs. First the measuring systems are collecting the weighing and environmental data with the very necessary basic filtering and integration. The second step is the evaluation of the single weighing using the collected data. This evaluation software is based on a spread sheet program. The third step is the implementation of the subdivision method.

For the validation of the calculations using sub-division technique among others the following method was used:

step 1. A set of input quantities were generated so that the mass of the weights were set.

step 2. The mass differences of the comparisons of the weights or weigh combinations were calculated using this set of the generated input quantities.

step 3. The standard deviations related to the mass differences were chosen close to the real ones.

step 4. The masses of the weights were calculated from mass differences using the software. These values were compared to the original masses (step 1).

The good matching values validate the calculation of the masses.

- step 5. Monte Carlo simulation used for the validation of the calculation of the uncertainties. The input quantities for the simulation were the calculated mass differences (step 2) and the related standard deviations (step 3).
- step 6. The uncertainties generated by the simulation and the uncertainties calculated by the software were compared.

The following charts are showing the differences between the conventional mass values and the related uncertainties calculated by the software and the Monte Carlo simulation in the case of the weighing design described in [3].
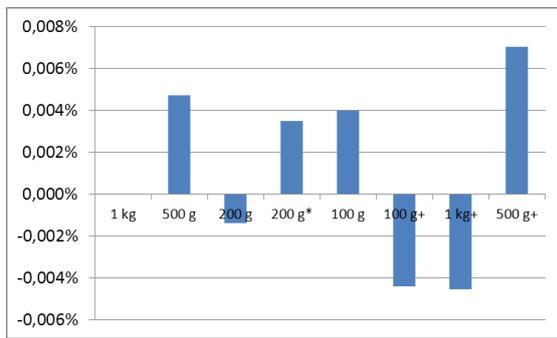

Fig. 8. Difference between the mass values calculated by the analytical method and the results of the Monte Carlo simulation (10.000 runs) relative to the maximum permissible error of the class E_1
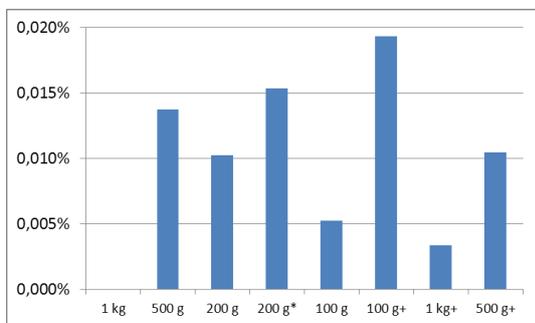

Fig. 9. Difference between the uncertainties of the mass values calculated by the analytical method and the results of the Monte Carlo simulation (10.000 runs) relative to the maximum permissible error of the class E_1

The graphs show good agreement of the two methods. The uncertainties are always slightly larger by the Monte Carlo simulation due to the fact that the analytical results are obtained using perfectly matching equations, which is not the case during the simulation.

3. ANALYSIS OF WEIGHING SCHEMES

Using the mathematical model described above, the following 5 weighing schemes were studied in the first decade taking into account the properties of the 1 kg mass comparator:

- ws-1. Using support plates carrying out the measurements according to table 1 repeating the marked (yellow) measurements after changing the position of the weights. (Referred as plate all).
- ws-2. Using support plates according to table 2 without repeating measurements [2]. This method handles the pair of support plates as a weight. This technique reduces the number of measurements by three in comparison with ws-1. (Referred as plate).
- ws-3. Using the special support disks weights. The 100 g+ and 500 g+ weighs are special disk weights that support the other weights in the combination. Scheme as written in [3] with the only change that by the fifth measurement instead of the 100 g weight the disk weight (100 g+) is used to support the two 200 g weights (referred as [3]).
- ws-4. The scheme is the same as ws-3, but two measurements were added (referred as [3]+).
- ws-5. The weighing scheme described in OIML R 111 [4] to complete the analysis. This scheme cannot be used with the disks. Another disadvantage is that all the recommended 12 measurements need support plate using the CC 1000 S-L comparator. This scheme is not used in BEV, but was analysed for the sake of completeness (referred as OIML).

No	1 kg	500 g	200 g	200 g*	100 g	100 g+	1 kg+	500 g+
1	-1						1	
2	-1	1						1
3		1					-1	1
4		1						-1
5		-1	1	1	1			
6			1	1		1		-1
7			-1	1				
8			-1		1	1		
9				-1	1	1		
10							-1	1

Table 1. Basic weighing scheme

No	1 kg	500 g	200 g	200 g*	100 g	100 g+	1 kg+	500 g+	Plate
1	-1				1				
2	-1	1					1		-1
3		1				-1	1		-1
4		1				-1			
5		-1	1	1	1				-1
6		1	1				-1	1	-1
7			-1	1					
8			-1		1		1		-1
9				-1	1		1		-1
10					-1		1		
11	-1		1	1	1		1		-1
12		1	1			-1	1	1	-1
13					-1			1	-1

Table 2. Weighing scheme used with support plates

No	1 kg	500 g	200 g	200 g*	100 g	100 g+	1 kg+	500 g+
11	-1		1	1	1			1
12			1	1			1	-1	1

Table 3. Additional measurements to table 1.

The result of this analysis is summarised in table 4 and in fig 10.

The schemes using support plates have additional problems caused by the material and design of the support plates (small density, large surface area). Taking into account the number of measurements and the uncertainty the method [3]+ can be a good choice.

Weights/Schemes	Plate all	Plate	[3]	[3]+	OIML
500 g	0,70%	0,80%	0,91%	0,79%	0,78%
200 g	0,86%	0,92%	1,16%	0,90%	0,84%
200 g*	0,86%	0,92%	1,16%	0,90%	0,84%
100 g	1,00%	1,16%	1,35%	1,09%	1,13%
No. Measurements	16	13	10	12	12

Table 4. Number of measurements and the standard uncertainties of the different schemes (without buoyance and uncertainty of standard) relative to the maximum permissible error of the class E_1
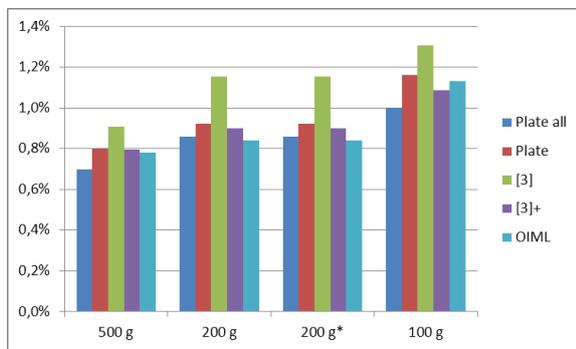

Fig. 10. Standard uncertainties of the different schemes (without uncertainty of the buoyance and the standard) relative to the maximum permissible error of the class E_1

Let's assume that the 1 kg standard has a standard uncertainty of 15-25 µg, which produces about 3%-5% uncertainty component for the weight in this decade. Therefore the analysis of the whole uncertainty budget shows that the differences among the various weighing schemes are negligible.

4. VALIDATION AND CHANGES DUE TO THE NEW ENVIRONMENT

Due to the reinstallation of the balances and robotic systems in the new laboratory all the instruments needed validation. Serious changes were not expected, but slightly smaller uncertainties due to the better mechanical, temperature and humidity stability in the new laboratory (see Fig. 2a and 2b).

During the validation the position errors of the balances were also investigated. This error occurs when using balances with an automatic weight exchange mechanism and the indication difference between two weights are different when the positions are interchanged [4].

The effect was previously demonstrated by the smallest robotic system of the BEV (see Fig. 11)
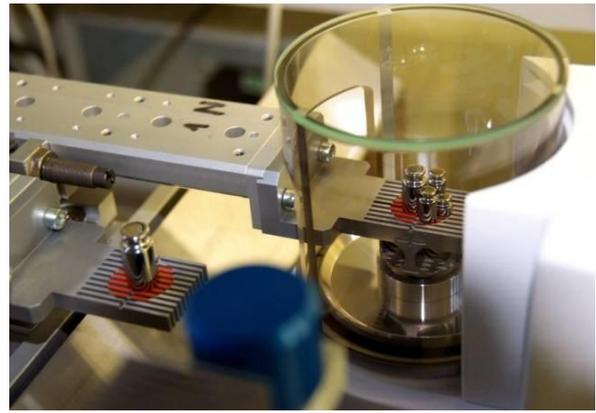

Fig. 11. The 10 g robotic system is comparing a weight (10 g) to a combination of weights.

As it was previous published [2], the corrections can be calculated during the subdivision method and what is more important they remain stable during a fixed setup. Due to the new environment, probably to the more rigid weighing tables (see fig. 1), the corrections became smaller see fig. 12.
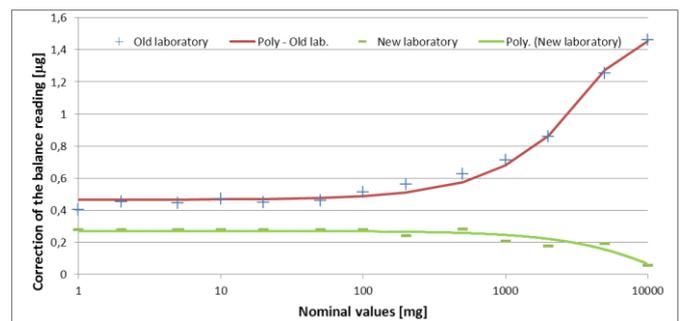

Fig. 12. Balance corrections (with parabolic regression)

5. CONCLUSION

The new laboratory conditions made worthwhile to introduce new techniques in the mass laboratory of BEV to reduce further the measurement uncertainties.

Besides the better environmental conditions, the new constructions (e.g. double housing), the replacement of the support plates by the special disks weights, the improved weighing schemes and the new evaluation software allow reaching approximately 30%-50% smaller measurement uncertainties of the mass standards in BEV.

ACKNOWLEDGMENTS

6. REFERENCES

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