XIX IMEKO World Congress
Fundamental and Applied Metrology
September 6–11, 2009, Lisbon, Portugal

DISSEMINATION OF THE UNIT OF MASS IN A FULLY AUTOMATIC MASS LABORATORY USING SUBDIVISION

Zoltan Zelenka

Affiliation: BEV- Bundesamt für Eich- und Vermessungswesen
(Federal Office of Metrology and Surveying), Vienna, Austria
zoltan.zelenka@bev.gv.at

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 operation of these systems has an unusual aspect.

The robot covering the measuring range from 1 milligram up to 10 gram is a flexible tool to calibrate the majority of the weights. An analysis of this system shows that it has excellent repeatability, but also a systematic error. A modified weighing design is helpful to handle this property.

Keywords: mass calibration, subdivision

1. INTRODUCTION

The objective of the BEV was to develop and realize handling systems for loading and alternating weights on high-precision mass comparators (from 1 milligram up to 20 kilogram). The dissemination of the unit of mass is rather effective by using these comparators, especially the 10 gram.

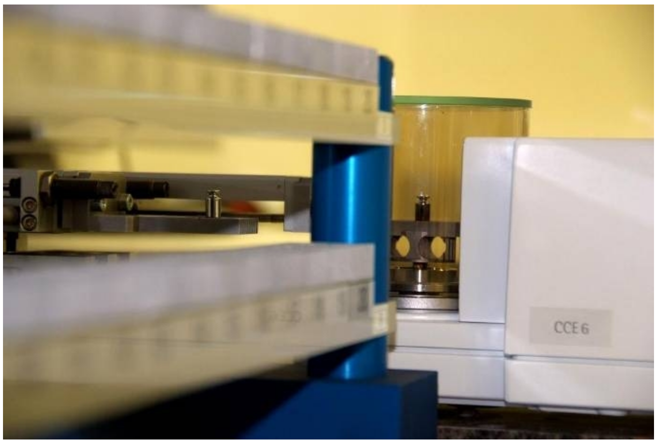

Fig. 1. The Robot in action

This robot is very versatile with its 80 slots loaded with reference and test weights. Combinations of weights can be used as well as single ones.

All robotic systems were completed with an Excel application to evaluate the measurement data. Weights (and its combinations up to 11 pieces) can be chosen from its databank. It contains flexible weighing designs to realize the subdivision.

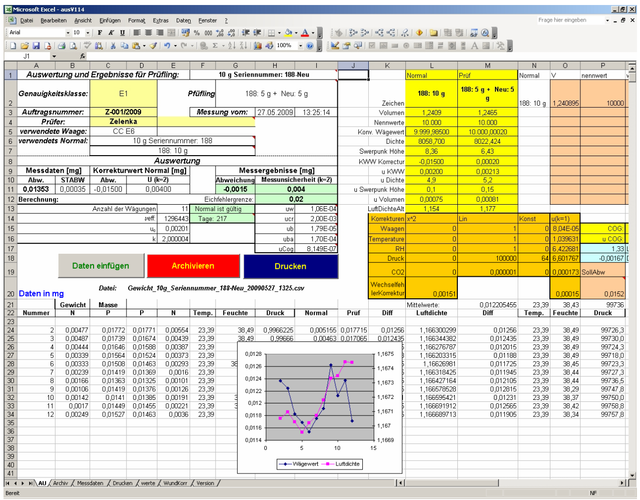

Fig. 2. Part of the main screen of the application

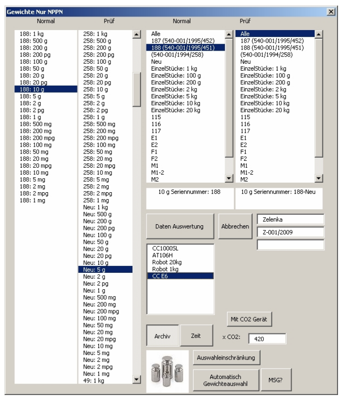

Fig. 3. The control panel selecting a combination

The repeatability of the system is better than 0,2 µg. Investigating the measurement data a systematic error was found, which only depends on the load of the balance, in our case (with a good approximation) only on the nominal values of the weights.

Instead of the classical approach (strictly paired measurements and a typical weighing design [2]), a special weighing scheme was introduced to improve the measurement uncertainty.

2. THE DESIGN

2.1. A basic weighing design

To introduce the method we chose a relatively simple weighing design:

1 kg	500 g	200 g	200 g*	100 g	100 g*
-1	1	1	1	1	0
-1	1	1	1	0	1
0	-1	1	1	1	0
0	-1	1	1	0	1
0	0	-1	1	0	0
0	0	-1	0	1	1
0	0	0	-1	1	1
0	0	0	0	-1	1

Fig. 4. Original weighing design

The set of equations resulting weighted matrixes can be solved by least squares [3].

2.2. The systematic error

The above mentioned weighing design can be used when the mass difference Δm_c between the test weight (m_{ct}) and the reference weight (m_{cr}) is:

$$\Delta m_c = m_{ct} - m_{cr} \qquad (1)$$

By the robot, to compensate the systematic error, an additional balance correction C_{bi} is applied:

$$\Delta m_c = m_{ct} - m_{cr} + C_{b_i} \qquad (1)$$

The correction is constant for each nominal value.

2.3. An analogue example

This is similar to the case of the Sartorius CC1000SL balances [4], where an additional pair of support plates was introduced to hold the combinations of weights.

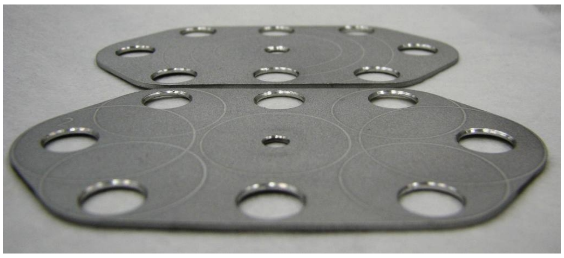

Fig. 5. Support plates

The two support plates are supposed to be made of the same material, and to have similar geometry and mass. In order to calculate the mass difference between the compared weight combinations, the mass difference between the support plates, which is a part of a measurement result, needs to be eliminated. Usually to achieve it two comparisons of the same combination of weights with different positions of the support plates are performed.

Instead of calculating the mass difference from paired measurements, we handle the pair of plates as a weight with the following parameters (weight: the weight difference of the plates; volume: the volume difference of the plates calculated from weight and density: density of aluminium, difference between the centre of gravity: zero). Assuming that the mass difference of the plates during the measurements is constant, it is introduced in the design.

1 kg	500 g	200 g	200 g*	100 g	100 g*	ΔPlate
-1	1	1	1	1	0	1
-1	1	1	1	1	0	-1
-1	1	1	1	0	1	1
-1	1	1	1	0	1	-1
0	-1	1	1	1	0	1
0	-1	1	1	1	0	-1
0	-1	1	1	0	1	1
0	-1	1	1	0	1	-1
0	0	-1	1	0	0	0
0	0	-1	0	1	1	1
0	0	-1	0	1	1	-1
0	0	0	-1	1	1	1
0	0	0	-1	1	1	-1
0	0	0	0	-1	1	0

Fig. 6. Extended weighing design

This arrangement guarantees an estimation of the corrections of the weights that is independent of the mass difference of the plates.

In the original design (fig. 4.) there are five unknowns with eight measurements. The extended design containing all the measurements of the classical approach (fig. 6) has six unknowns, but 14 measurements. This is far more redundant, consequently the number of measurements can be reduced and neither the corrections nor the uncertainties change significantly.

2.4. Subdivision using the robot

The robot with 10 gram maximum load is capable of carrying out the dissemination in four decades. For each decade it performs measurements on four nominal values. It means additional four corrections (C_{bi}) in each decade (due to the balance errors) to the five weights to be measured. The corrections (C_{b10}, C_{b5}, C_{b2}, C_{b1}) are used like weights in the weighing design.

10 g	5 g	2 g	2 g*	1 g	1 g*	C_{b10}	C_{b5}	C_{b2}	C_{b1}
-1	1	1	1	1	0	1	0	0	0
1	-1	-1	-1	-1	0	1	0	0	0
0	-1	1	1	1	0	0	1	0	0
0	1	-1	-1	-1	0	0	1	0	0
0	0	0	0	1	-1	0	1	0	1

Fig. 6. Part of the weighing design

We perform 16 measurements (twice the measurements in fig. 4.) to determine the 9 unknowns (5 weight corrections, 4 balance corrections). The results over the measuring range show, that the corrections have parabolic behaviour.

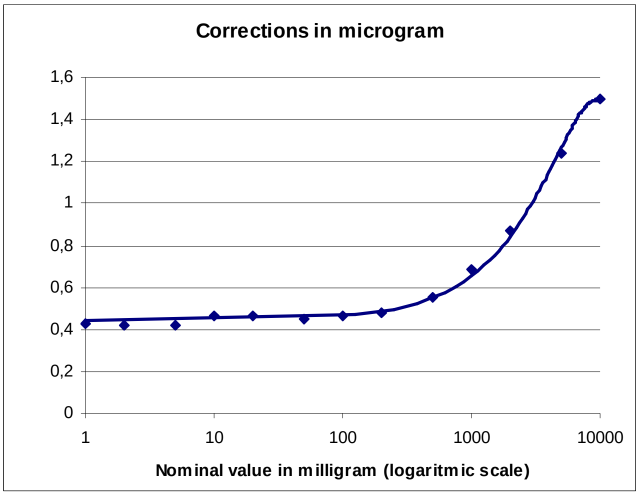

Fig. 7. Balance corrections (with parabolic regression)

Theoretically the number of measurements could be reduced, but further reduction in the number of degrees of freedom of the least squares solution is not recommended.

4. CONCLUSIONS

The modified weighing design is useful to handle systematic errors and to calculate the corrections of weights easily and independently.

The systematic errors of the 10 gram robot at BEV were investigated and eliminated using extended weighing designs.

This technique can also be applied for the support plates for weighing mass combinations, produced by Sartorius AG.

ACKNOWLEDGMENTS

With acknowledgment to all the colleagues at BEV, and special thanks to Christian Buchner.

REFERENCES

[1] C. Buchner: Fully automatic mass laboratory from 1 mg up to 50 kg – Robots perform high precision mass determination IMEKO 20th TC3, 2007. Merida, Mexico.

[2] International Organization of Legal Metrology, International Recommendation 111.1-Weights of classes E1, E2, F1, F2, M1, M1−2, M2, M2−3 and M3 (Part 1: Metrological and technical requirements) Edition 2004(E) OIML, Paris, 2005.

[3] M. Kochsiek, M Gläser: Comprehensive Mass Metrology, WILEY-VCH; Berlin, 2000

[4] M. Grum, M. Terlep: Analysis of Change of Mass Difference between weight support plates during subdivision of 1 kg IMEKO 20th TC3, 3rd TC16 and 1st TC22 International Conference, 2007. Merida, Mexico.