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Evaluation of standard uncertainty of measured mass difference on 10 kg comparator balance

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Abstract

Three pairs of different weight support plates, which are needed in the procedure of multiplication of 1 kg value, were used on Sartorius C10000S comparator balance in order to study their influence to the measurement results. In the study a pair of 2 kg weights was compared with the aid of different support plates. The mean values and the standard deviations of the measurements with the support plates were compared to the results of measurements without the use of the support plates. The analysis confirmed the differences in the means and in the standard deviations of measured results when various support plates were used but in a smaller extent as it had been noted in earlier routine measurements. The analysis showed that the use of a certain pair of the plates assured smaller standard deviations and better agreement with the results of measurements where the plates were not used.

Keywords: calibration, comparator balance, weights, support plates, standard deviation

1. Introduction

A comparator balance is one of the key parts of a measurement system for a calibration of standard weights. In the present article, the analysis of the measurement results and accompanied standard uncertainties of comparator balance Sartorius C10000S, used for the multiplication of 1 kg reference value to the range from 2 kg to 10 kg on OIML R111 [1] E1 accuracy class level, is performed. An attention is paid to the examples where due to the comparison of the combinations of the weights the support plates are used. Such combinations of weights can be 2 kg / 2 x 1 kg; 5 kg / 2 x 2 kg & 1 kg and 10 kg / 2 x 5 kg. The design of the automatic load alternator doesn't allow a simple direct comparison of combinations of weights and a usage of the plates is a possible solution, which enables such comparisons.

Experiences from past measurements showed a significantly larger scattering of measured mass differences for the measurements where the support plates for the weights were used as for the measurements without the plates. It was assumed that the usage of the support plates caused worse centring of the weights on the automatic weight handler. The centring errors are influenced by mechanical properties of the weight handler and integrated centering mechanism. Consequently those lead to the significant dispersion of the measured mass differences between the series of measurements of the same weights.

2. The scatter of the measured mass differences on the comparator balance C10000S

In order to put a light on the problem first the comparator balance C10000S and the support plates will be described, then the calculation of mass difference between compared weights and estimation of standard uncertainty of measured mass difference will be explained and information on comparator's performance will be given that stimulated us to perform the detailed analysis.

2. 1 The comparator balance and the support plates

Basic metrological data of comparator type C10000S with the automatic weight handler type YLA 01 C manufacturer Sartorius, are: weighing range 2 kg, 5 kg, 10 kg with electronic weighing range 55 g. Division is 0,01 mg. Standard deviation of 6 ABBA measurement cycles is according to producer specification 0,1 mg.

The considered balance has the automatic weight handler with two positions. Its construction enables a comparison of two weights of a same nominal mass. Experiences with the comparisons of different combinations of weights (2 kg with two 1 kg weights, 5 kg with two 2 kg weights and one 1 kg weight and 10 kg with two 5 kg weights) showed that only the combination of two 5 kg weights can be placed properly on the exchanger without the help of the support plates, while other combinations can not be placed, centered and weighed satisfactorily.

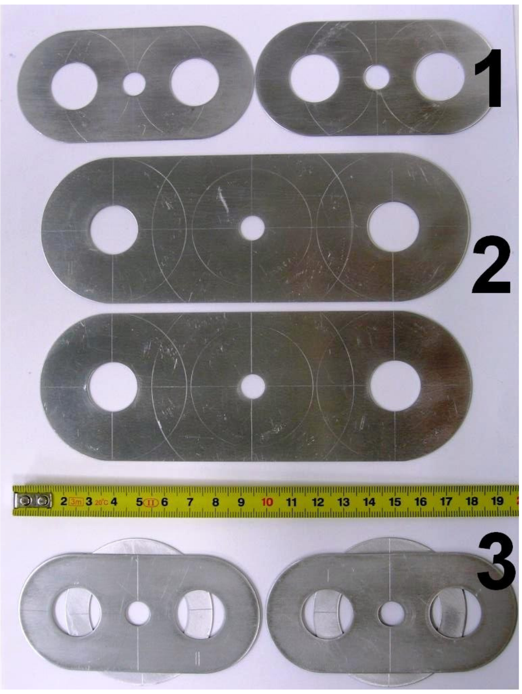

Figure 1: Pairs of the support plates No. 1, No. 2 and No. 3

The support plates are of our own manufacture, made out of 1 mm thick aluminium. The shape and the dimensions can be seen on Figure 1. The support plates pair No. 1 was manufactured in order to compare 2 kg weight with a pair of two 1 kg weights while the pair No. 2 is intended for comparison of 5 kg with 2 x 2 kg and 1 kg.

2. 2 The evaluation of the mass difference of the weights

For the comparisons with the support plates a measurement result of a single series includes also a difference of apparent masses of the support plates. Therefore the unknown masses of support plates needs to be eliminated with repetition of each measurement series. At the second series position of the support plates is exchanged while the weights remain on their positions. The actual mass difference $m_A - m_B$ is estimated following the equation:

$$m_A - m_B = m_N \frac{\partial g}{\partial z} \frac{z_B - z_A}{g} + \frac{\rho_{a,I} + \rho_{a,II}}{2}\left(V_A - V_B\right) - \frac{\Delta_I + \Delta_{II}}{2}, \qquad (1)$$

where the indexes I and II indicate the first and the second series of measurements and A and B position of weights on the load alternator. Δ is the average measured mass difference of compared weights, ρ_a the air density, z the height of weight mass gravity centre, V the volume, g the gravity acceleration and m_N the nominal mass of the weight. Mass difference therefore equals to the average measured mass difference, corrected for the influence of different heights of mass centers and air buoyancy.

For the comparisons where the support plates are not used, series of measurements are not repeated. Equation (1) is simplified to a form:

$$m_A - m_B = m_N \frac{\partial g}{\partial z} \frac{z_B - z_A}{g} - \rho_a\left(V_A - V_B\right) - \Delta. \qquad (2)$$

2. 3 Dispersion of measurement results

According to [2] experimental standard deviation of average measured differences s is established:

$$s = \frac{s(\Delta)}{\sqrt{N}}, \qquad (3)$$

where $s(\Delta)$ is a standard deviation of measured differences and N a number of measurement cycles.

In order to estimate a standard deviation $s(\Delta)$ from equation (3) is not enough to evaluate only a repeatability of weighing instrument during a single measurement series but also data from past must be taken into account. Standard deviation $s(\Delta)$ can be estimated as [3]:

$$s^2(\Delta) = \frac{m(n-1)}{n \cdot m - 1}\bar{s}_n^2 + \frac{n(m-1)}{n \cdot m - 1}s_m^2, \qquad (4)$$

where $\bar{s}_n$ is the average standard deviation of m measurement series (each series including n ABBA measurement cycles), s_m is a standard deviation of mean values of m measurement series. If an air density significantly changed during the measurements a special care must have been paid to preliminary bring into effect the buoyancy correction.

2. 4 Comparator's performance in the past

In order to have a sort of starting-point results, which can give insight in the performance of the comparator and which can be compared to the results presented further in the article some results of the comparator's past performance are given here.

Figure 2 shows the results of the comparison of two 2 kg weights. Measurement series of 6 ABBA cycles were carried out several times. Presented are mean values and standard deviations of the measurement series. Buoyancy effect is corrected. Average standard deviation is $\overline{s}_n$ = 0,114 mg, standard deviation of mean values s_m = 0,084 mg and standard deviation of average s = 0,058 mg (for N = 6).

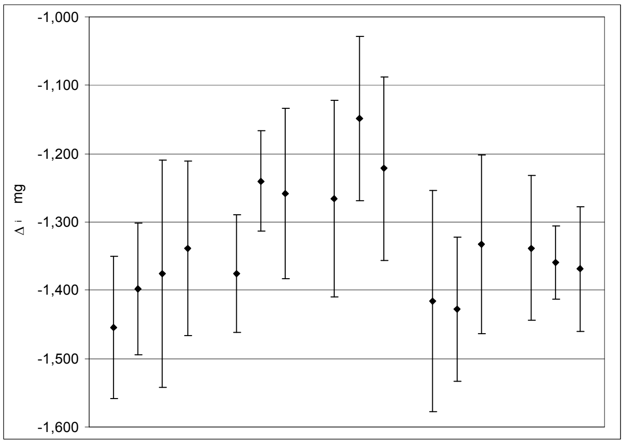

Figure 2: The results of comparison of 2 kg weights without use of support plates

On Figure 3 the results of the comparison of two kilogram weight with the combination of two one kilogram weights and with the help of the support plates are presented. Again 6 ABBA cycles were carried out for several times. On Figure 3 mean values and standard deviations of measurement series after buoyancy correction and correction of difference of weights mass centers heights are shown. In this case average standard deviation is $\overline{s}_n$ = 0,144 mg, standard deviation of mean values s_m = 0,226 mg and standard deviation of average s = 0,101 mg (for N =6).

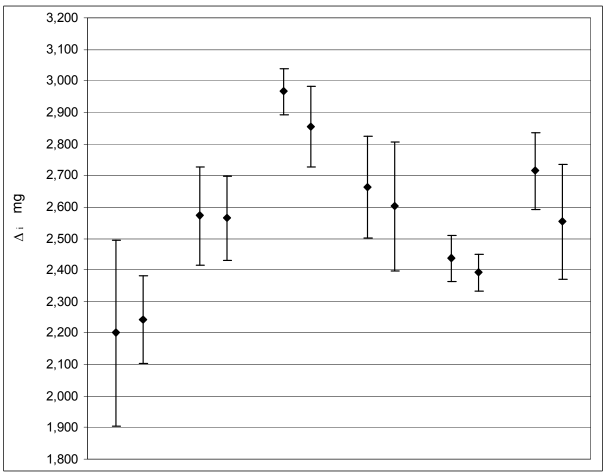

Figure 3: The results of comparison of 2 kg weight with two 1 kg weights with use of the support plates.

The mass difference results on Figures 2 and 3 can not be compared since different weights are used. But a large difference in the values of the standard deviations and dispersion of the mean values can be noticed. Cause could be found in influence of use of support plates on measurement results.

3. Analysis of the influence of different support plates

The results from the previous chapter point out that the standard deviation of average s is larger when the support plates are used. In order to get better insight to this phenomenon and to evaluate the influence of the support plates on measurements' dispersion, several comparisons of the same pair of weights were carried out by the ABBA substitution method. Two 2 kg stainless steel OIML R 111-1 shaped weights were compared without and with the support plates of which three different pairs, as seen in Figure 1, were used.

By comparing the weights of the same characteristics a need to take into account influences of several parameters on the results was avoided. In order to exclude the influence of mass difference between the support plates every comparison was done twice: positions of the support plates were switched while the weights remained on the same positions on the weight handler.

The following comparisons of two 2 kg weights were performed:

- direct comparison without the support plates,
- comparison with the support plates, pair No. 1,
- comparison with the support plates, pair No. 2,
- comparison with the support plates, pair No. 3.

The pairs of the support plates No. 1 and No. 2 were already described. Shape and dimensions can be seen of Figure 1. The pair of the support plates No. 3 was produced as a modification of the pair No. 1 intended to simulate an effect of a single weight while centering.

Two stainless steel Mettler-Toledo weights with nominal mass 2 kg of accuracy class E2 were used in comparison. According to the producer general specifications the density of applied weights is 8000 kg/m^3 with the measurement uncertainty 30 kg/m^3. The actual weights volume difference is therefore so small that the buoyancy correction is not needed. Also the correction of gravity force due to different heights of mass centers of weights is not necessary. All this enables easy comparisons of the measured mass differences of any performed comparison.

The results of the performed comparisons are shown on Figures 4, 5, 6 and 7. The mean values and the standard deviations of the measurement series are presented. Each measurement series was composed of 6 ABBA cycles. When the comparisons were performed using the support plates the results were gained based on two repetitions of measurements with the exchanged support plates positions.

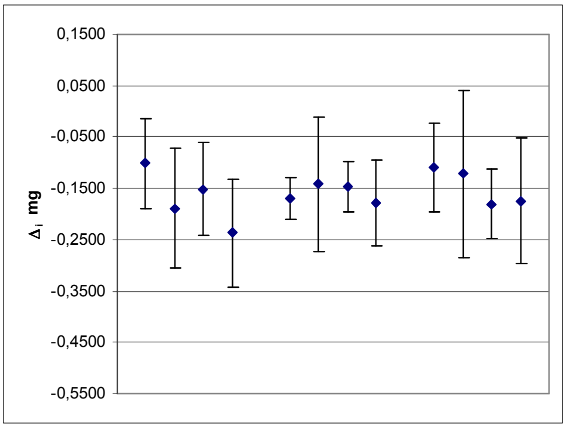

Figure 4: The results of comparison of two 2 kg weights without use of the support plates

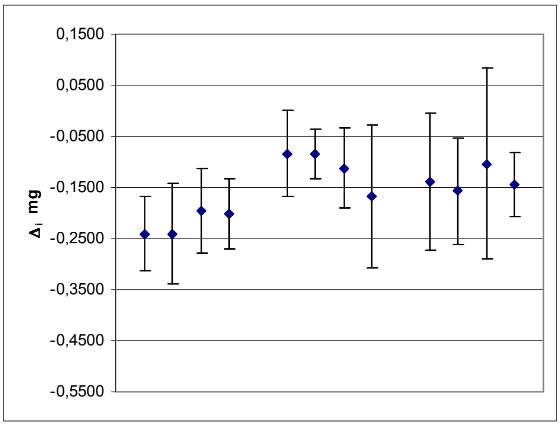

Figure 5: The results of comparison of two 2 kg weights with use of pair of the support plates No. 1

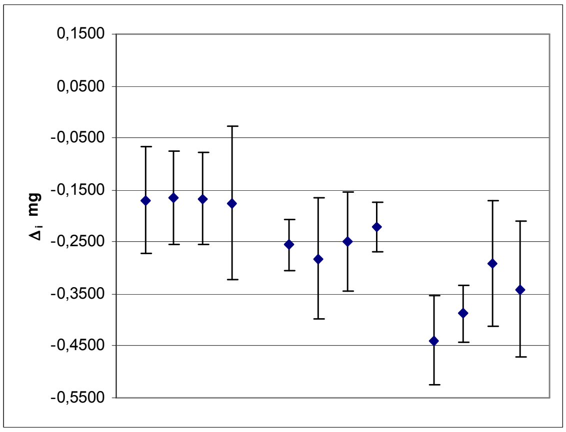

Figure 6: The results of comparison of two 2 kg weights with use of pair of the support plates No. 2

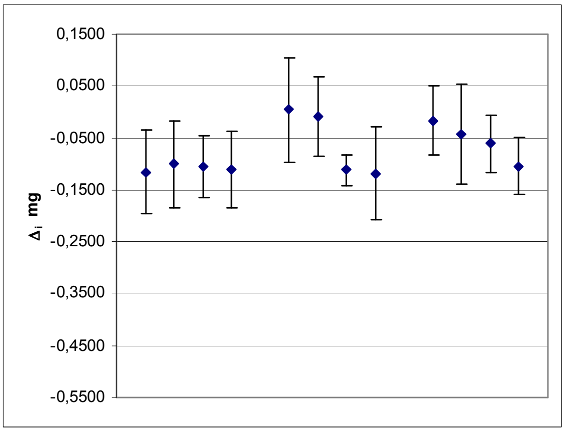

Figure 7: The results of comparison of two 2 kg weights with use of pair of the support plates No. 3

The abstracts of the results from Figures 4, 5, 6 an 7 are given in Table 1 along with the standard deviations $\bar{s}_n$, s_{m}, $s(\Delta)$ and s.

Table 1
Comparison of the results of the measurements of two 2 kg weights without and with the pairs of the support plates No. 1, 2 and 3.

	Mean mg	$\bar{s}_n$ mg	s_{m} mg	$s(\Delta)$ mg	s (N=6) mg
Without the support plates	-0,158	0,095	0,038	0,095	0,039
Pair No. 1	-0,156	0,097	0,055	0,104	0,042
Pair No. 2	-0,262	0,094	0,091	0,123	0,050
Pair No. 3	-0,074	0,081	0,047	0,080	0,033

4. Conclusion

The purpose of the research was to establish the influence of different pairs of the weight support plates on the measurement results of comparison of the standard weights. Two 2 kg stainless steel weights ware compared first directly without the plates and then with a help of three different pairs of the support plates. The results of the four comparisons are comparable since the same pair of weights was used in the research. We were interested in the mean values and the standard deviations of the comparisons.

From the measurement results we can see that there is a good agreement in the mean values of the comparison without the support plates and the comparison with the set of plates No. 1. Other two pairs of plates gave larger differences in the mean values. The standard deviations s_n are comparable between all four trials. If we finally take a look to the standard deviation s_m it can be seen that for three cases the standard deviations are comparable but use of the pair of plates No. 2 gave significantly larger dispersion of the mean values.

From above we can conclude that the use of pair No. 1 is the most favourable and can give reliable results.

References

[1] OIML R 111-1, Weights of classes E_1, E_2, F_1, F_2, M_1, M_{1-2}, M_2, M_{2-3}, M_3, OIML, Paris, 2004.

[2] Guide to the Expression of Uncertainty in Measurement, BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, Geneva, 1995.

[3] M. Glaser, Advices for the calibration of mass standards, PTB-MA-52, Braunschweig, 1997