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Analysis of Change of Mass Difference between Weight Support Plates during Subdivision of 1 kg

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Abstract

In the research a possibility was studied how to reduce a number of repetitions of measurements when performing dissemination of 1 kg mass standard and at the same time maintain the level of confidence of the measurement results.

The method considered is designed for weighing schemes where a pair of support plates for weights is required to carry out comparisons of combinations of weights on comparators with automatic weight handler and the same pair of support plates is used for many of the compared weight combinations.

The results of analysis indicate to minor relation between the changes in mass differences of the compared weights and the changes in mass differences of the support plates. It can be seen that there is no influence on the mass of compared weights due to improper handling of the weights. The main reason for the deviations of the measurement results when using the support plates might be the performance of the comparator.

Keywords: *calibration, comparator balance, weights, support plates, quality assurance*

Introduction

A method for quality assurance of the measurement results during a subdivision of 1 kg mass standard is considered. The method is designed for weighing schemes where a pair of support plates for weights is required to carry out comparisons of combinations of weights on comparators with automatic weight exchange mechanism.

During a calibration of weights on the OIML R111-1 [1] E1 accuracy class level with the subdivision of 1 kg, not negligible differences between results of measurements, which were performed within few days time interval, were noticed when comparing the same combination of weights and using the same support plates. These deviations were up to several times larger than the standard deviation of a single measurement. There can be three main reasons for the deviations: poor performance of a comparator, unstable mass of compared mass standards or unstable mass of the support plates. Until now this problem was solved by multiple repetition of the same measurement and averaging of these results. The new idea is based on the fact that the same support plates are involved in all comparisons of combinations of weights on the same comparator and is aimed to identify eventual relation between inconsistency of measuring results and changes in mass difference of the support plates. If such relation exists, the amount of repetitions can be reduced.

Realisation of mass scale

The mass scale is realised trough dissemination of the mass value of the 1 kg weight [2,3]. The weighing scheme in Table 1 presents possible combinations of weights which must be compared in the scope of one decade (an example of decade from 1 kg to 100 g). In Table 1 all the weights used in *j* – th comparison and marked with **1** are considered as reference weights and all the weights marked with **-1** as test weights.

		Weight							
		1 kg	1 kg*	500 g	500 g*	200 g	200 g*	100 g	100 g*
Comparison No. *j*	1	**1**	**-1**	0	0	0	0	0	0
	2	**1**	0	**-1**	**-1**	0	0	0	0
	3	0	**1**	**-1**	**-1**	0	0	0	0
	4	0	0	**1**	**-1**	0	0	0	0
	5	0	0	**1**	0	**-1**	**-1**	**-1**	0
	6	0	0	0	**1**	**-1**	**-1**	0	**-1**
	7	0	0	0	0	**1**	**-1**	0	0
	8	0	0	0	0	**1**	0	**-1**	**-1**
	9	0	0	0	0	0	**1**	**-1**	**-1**
	10	0	0	0	0	0	0	**1**	**-1**

Table 1: Combinations of weights in scope of one decade (from 1 kg to 100 g)

It can be seen from Table 1 that for the comparisons numbered 2, 3, 5, 6, 8 and 9 a group of weights (denoted as -1) is compared to a single weight (denoted as 1). The construction of the automatic load alternator of the comparator requires use of a pair of special support plates on which the weights are put on.

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. That is achieved with a procedure in which two comparisons of the same combination of weights and with a different position of the support plates are performed. Comparisons where the support plate number 1 is under reference weight and support plate number 2 is under group of test weights are additionally marked with latter “a”. With “b” are marked all the comparisons with opposite position of support plates.

For “a“ series of measurements the following equality (1) is valid:

$$m_R - \rho_a V_R + m_{P1} - \rho_a V_{P1} = m_T - \rho_a V_T + m_{P2} - \rho_a V_{P2} + \Delta_a \qquad (1)$$

and for "b" series of measurements an equation:

$$m_R - \rho_b V_R + m_{P2} - \rho_b V_{P2} = m_T - \rho_b V_T + m_{P1} - \rho_b V_{P1} + \Delta_b \qquad (2)$$

where m_R and V_R are actual mass and volume of the weights on position R, m_T and V_T actual mass and volume of the weights on position T, m_{P1} and V_{P1} actual mass and volume of support plate 1, m_{P2} and V_{P2} actual mass and volume of support plate 2, Δ_a and Δ_b mass differences established based on relevant "a" and "b" series of measurements, ρ_a and ρ_b air density at "a" and "b" series of measurements.

The only difference between equations (1) and (2) is caused by different positions of the support plates. The mass difference of the compared weights, which is the primer result of the measurements, can be expressed based on equations (1) and (2) when the mass difference of the support plates is eliminated.

$$m_R - m_T = \frac{(V_R - V_T)(\rho_{a_1} + \rho_{a_2})}{2} + \frac{(V_{P1} - V_{P2})(\rho_{a_1} - \rho_{a_2})}{2} + \frac{\Delta_1 + \Delta_2}{2} \qquad (3)$$

Fundamentals for analysis performance and measuring equipment used

The fact that during calibration procedure a large number of comparisons of the same support plates are performed enables the analysis of the changes in mass differences between support plates.

Measurements in our laboratory are performed on Sartorius comparator balances C50S, CC1000S-L and C10000S. All of them are equipped with the automatic load alternators and require use of the support plates for the comparisons of groups of weights.

For comparisons on C50S a pair of support plates made of stainless steel is used and for comparisons on CC1000S-L a pair made of duraluminium. Depending on the nominal mass of the compared weights different laboratory made support plates of our own production are used on C10000S. In Figure 1 the support plates used on comparator balance C50S and C1000 are shown.

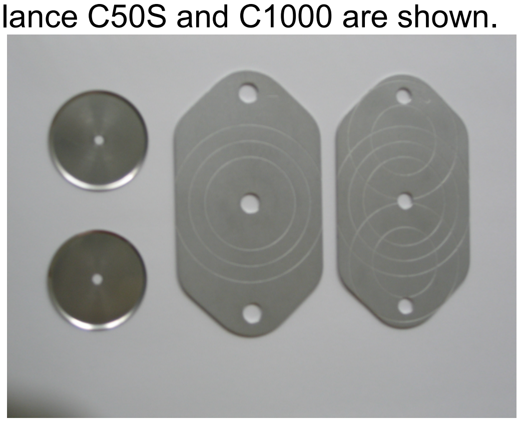

Figure 1: The support plates for comparator C50S and CC1000S-L.

For all the comparisons stainless steel weights were used. The weights also fulfilled the requirements of the international recommendation OIML R 111 for E1 accuracy class. Based on mentioned fact and fact that all the weights were used in controlled environment we presumed that the mass of weights was not changed during performance of "a" and "b" measurements.

Realization of the analysis on changes of the support plates mass differences

For the purpose of the analysis, unknown mass difference between compared combinations of weights needed to be excluded from the weighing equation in order to enable monitoring the mass difference of the support plates. Every comparison had to be performed twice: positions of the support plates on the exchanger were switched while weights remained in the same positions.

The analysis was carried out in two steps. At first we considered the long-term stability of the difference between masses of the support plates. We observed all the measurements performed in four years where the same pair of support plates was used. In the second stage we observed the relation between the changes in differences between masses of the compared E1 weights and the changes in differences between masses of the support plates.

Changes in mass difference of support plates

The idea for the first part of the analysis was to treat the special support plates as two weights and the standard weights that were compared as two dead loads needed only to reach the appropriate measuring range of the comparator balance. In this case the mass difference between the support plates can be expressed based on equations (1) and (2) when the mass difference of compared weights is eliminated.

$$m_{P1} - m_{P2} = \frac{(V_{P1} - V_{P2})(\rho_b + \rho_a)}{2} + \frac{(V_T - V_R)(\rho_b - \rho_a)}{2} + \frac{\Delta_b - \Delta_a}{2} \qquad (4)$$

where V_R is the actual volume of the weights on position R, V_T actual volume of the weights on position T, m_{P1} and V_{P1} actual mass and volume of the support plate 1, m_{P2} and V_{P2} actual mass and volume of the support plate 2, Δ_a and Δ_b mass differences established based on relevant “a” and “b” series of measurements, ρ_a and ρ_b air density at “a” and “b” series of measurements.

Since the ambient conditions in calibration room are very stable the correction due to air buoyancy influence on weights was not necessary for two successive “a” and “b” measurements. The influence of different height of gravity centres between single weight and group of weights was eliminated by the method where “a” and “b” measurements are repeated.

Since support plates are made of the same piece of material their density of both support plates is the same. The mass difference between the support plates is relatively small therefore the difference in their volumes is small and the correction due to the air buoyancy influence on mass difference can be neglected. The correction due to different height of the centre of gravity of the support plates is not necessary because the shape of pair of the support plates is the same [4].

Presentation of the results for the first step of the analysis for all the measurements performed on C50S comparator balance in years from 2004 to 2007 where the same support plates were used is shown in Figure 2. The analysis was conducted on C50S comparator balance because the results of measurements were the most problematic for this comparator.

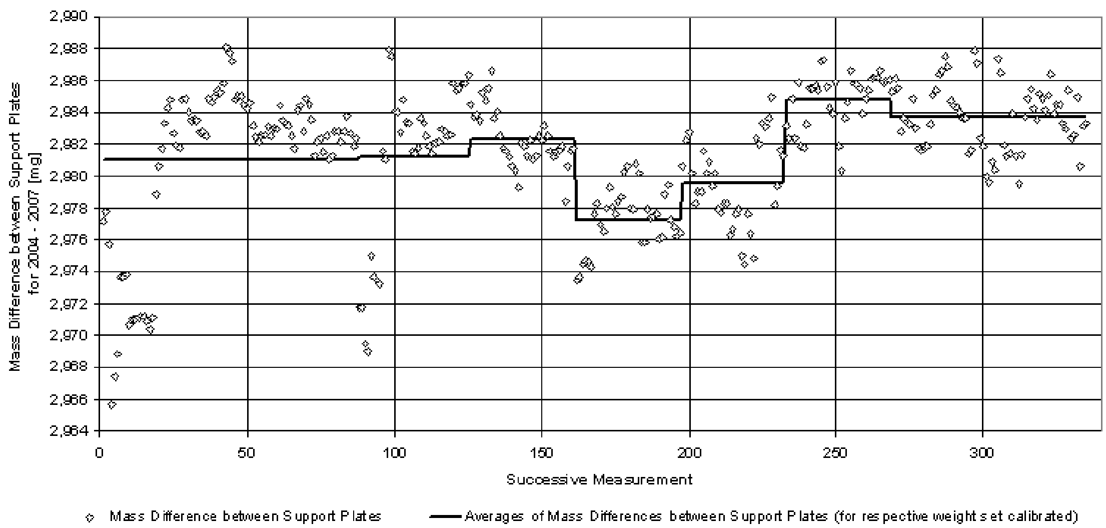

Figure 2: Diagram of changes of mass difference between support plates

In Figure 2 the trend of changes in mass difference between support plates for period of four years is shown. Also the trend of changes in mass difference between support plates during the period of calibration of one set of weights is shown. The review of the mentioned trends indicates that the changes are random and that the mass difference between support plates is relatively stable.

Relation between changes in mass difference of support plates and changes in mass differences of weights

During the second step of the analysis we searched for the relation between the changes in mass difference of the support plates and the changes in mass differences of weights. We successively compared all the above mentioned measurements performed on C50S comparator balance.

To be able to compare the mass differences of weights we had to apply the correction according to equation (5) to all the measuring results.

$$I_{corr} = I - \Delta_{buoy} - \Delta_{grav} \qquad (5)$$

where I and I_{corr} are the results of measurement before and after correction, Δ_{buoy} a correction due to air buoyancy influence calculated according to equation (6) and Δ_{grav} correction due to influence of different centre of gravity calculated according equation to (7).

$$\Delta_{buoy} = \varphi \cdot (V_T - V_R) \qquad (6)$$

where φ is the air density during weighing, V_T and V_R the volumes of the compared weights

$$\Delta_{grav} = \frac{m_N}{9{,}8062012016} \cdot (-3{,}085 \cdot 10^{-9}) \cdot (a_T - a_R) \qquad (7)$$

where m_N is the nominal mass of referent weight, a_T and a_R the levels of the centre of gravity for test and reference weight, respectively.

In order to compare different measurements, the deviations of the differences between the support plates and the deviations of the differences between the compared weights from their averages, are drawn in the diagram in Figure 3 (the middle diagram) relatively to their average values.

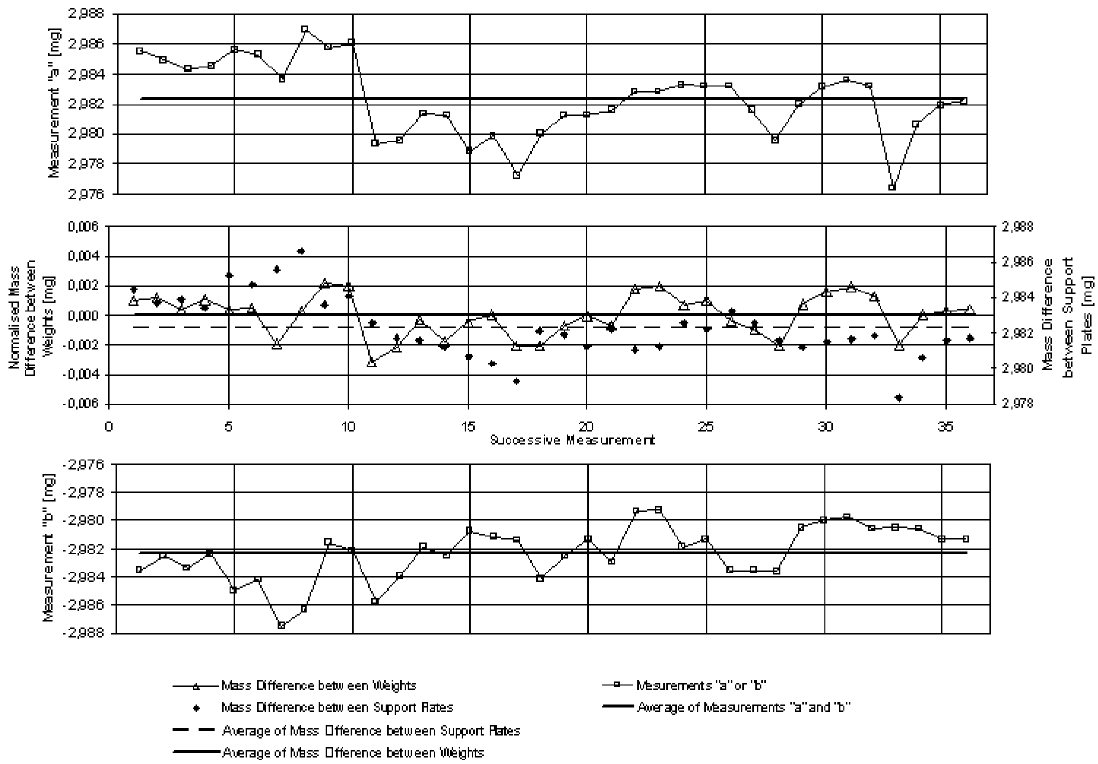

Figure 3: Diagram of relations between weights' mass difference and support plates' mass difference together with respective "a" and "b" measurements

It can be noticed from Figure 3 that there is no particular relation between changes in the difference between the weights and corresponding changes in the difference between the support plates.

In the further analysis it was examined which measurement from the "ab"-pair influenced the changes in the difference between the weights. We compared "a" and "b" measuring results corrected according equation (5) and normalised relatively to the respective averages with the results for the mass differences between the weights. In Figure 3 (upper and lower diagrams) the "a" and "b" measuring results are drawn respectively.

A pattern can be noticed that when measurement "a" or measurement "b" deviates significantly form the appertained normalised average also the deviation of difference between the weights from normalised average is significant. In rare cases both "a" and "b" measurements deviate significantly from the appertained average. This phenomenon is obviously not in a direct relation with the changes of difference between weights because in these cases the difference between the weights sometimes deviate from the normalised average and sometimes not.

Conclusion

From the presented analysis of relation between the mass difference of the support plates and the mass difference of the weights it can be concluded that there is no direct relation between them. The performance of the comparator balance is therefore assumed as the main reason for changes in the mass difference between the weights. From the results it could also be anticipated that some dust particles deposited on the weights or the support plates are the cause of the problems. A lot of attention still needs to be paid on the performance of the comparator balance used and a further investigation of correct handling of weights and support plates must be done in the future and supported with a suitable statistical analysis.

It seems that comparison of "a" and "b" normalised measurements with the long term average of difference between support plates could be a useful tool for quality assurance when performing mass dissemination of 1 kg with help of the support plates.

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