

OPTIMIZATION OF MASS STANDARDS AND WEIGHTS CALIBRATION (1 mg - 1 kg) USING ROTATIONAL AUTOMATIC MASS COMPARATOR

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Abstract: The article presents the influence of automation of mass standards comparison on repeatability during mass determination of mass standards and weights. The analysis comprises test results of selected types of manual and automatic comparators of the same or similar metrological characteristics carried out for the same loads. Standard deviation, which is comparators repeatability measure, was determined for individual loads. The measurements were carried out under the same ambient conditions, characteristic for calibration of mass standards and weights of the highest accuracy classes (E_1 and E_2).

Keywords: mass comparator, standard deviation, repeatability, automation.

1. INTRODUCTION

Automation of measurement processes in laboratories is growing in popularity and, from metrological point of view, is becoming crucial. Analysis of the obtained results of measurements carried out in RADWAG Laboratories proves that repeatability expressed by standard deviation is significantly smaller for automatic mass comparators than for manual ones. It is due to a fact that automatic mass comparators have properly optimized design and suitable algorithm of the measuring system. It is possible to use the same parameters for manual mass comparators, however the results and observations prove that the decrease of repeatability parameter value is caused by human factor. In automatic mass comparators, measurements between successive loadings take practically the same amount of time and it is due to elimination of eccentricity error and vibrations which both are present when performing measurements manually. The tests were carried out in RADWAG Metrology Centre. In the everyday work of a laboratory, which calibrates mass standards and/or weights, the possibility of error caused by human factor is high. Due to that, the automation of calibration process is the best solution to minimise this factor.

2. METROLOGICAL PARAMETERS OF MASS COMPARATORS

Mass comparators are intended to determine difference between mass of a test weight (B) and known mass of reference standard (A). Generally, mass comparators are

used in calibration laboratories to calibrate mass standards, weights and various types of supplementary weights. Comparator's measurement accuracy is affected by: ambient conditions, such as air temperature and relative humidity, and their changes over time, all types of air drafts and vibrations caused by external sources, and very important human factor.

While determining metrological parameters of a mass comparator, OIML R-76-1 (scale interval and maximum capacity) and ISO/IEC Guide 99:2010 (repeatability) were referred to:

Reading unit d , definition of which is to be found in point T.3.2.2 OIML R-76-1, is a value expressed in mass units:

- the difference between the values corresponding to two consecutive scale marks, for analogue indication, or
- the difference between two consecutive indicated values, for digital indication.

Maximum capacity Max (p. T.3.1.1 T.3.2.2 OIML R-76-1) is a maximum weighing capacity, not taking into account the additive tare capacity.

In case of mass comparator, it is the maximum mass that can be calibrated.

Repeatability in accordance with the International Vocabulary of Metrology (VIM) is a measurement precision under a set of repeatability conditions of measurement. Repeatability expressed by standard deviation is the most important metrological parameter of mass comparator.

Standard deviation of mass comparator is expressed for (r) differences between mass of a test weight (B) and reference mass standard (A) for specified n quantity of $ABBA$ or ABA series. Used weighing cycles enable to eliminate the linear drift. Both cycles are recommended for calibrating mass standards of E and F classes. Quantity of n cycles during calibration should be based on required uncertainty and repeatability of the measurements. Minimum quantity of weighing cycles that have to be carried out for specified accuracy class, from E_1 to M_3 , is specified in Table C.3 of OIML R-100.

Standard deviation of mass comparator can be determined using the following formula (1):

$$s = \sqrt{\frac{\sum_{i=1}^n (r_i - \bar{r})^2}{n-1}} \quad (1)$$

where- r_i - $B - A$ means difference of i^{th} measurement
 \bar{r} - arithmetic mean of the differences for n measurements results, formula (3)

$$r_i = \frac{(B_i^{AB} - A_i^{AB}) + (B_i^{BA} - A_i^{BA})}{2} \quad (2),$$

where $(B_i^{AB} - A_i^{AB})$ - difference of masses in AB subsequence, and $(B_i^{BA} - A_i^{BA})$ - difference of masses in BA subsequence

Mean value of r differences can be determined using the following formula (3):

$$\bar{r} = \frac{1}{n} \times \sum_{i=1}^n r_i \quad (3)$$

where: n - measurement quantity (of $ABBA$ or ABA series).

Standard deviation is the most common acceptance criterion of mass comparator during calibration and/or verification. Standard deviation is specified in datasheets provided by manufacturers of mass comparators.

Electrical weighing range is the range of comparator operation within which the measurement process (weighing range) is carried out. Typical electrical weighing range of mass comparator differs from electrical weighing range of balance or scale. The difference is presented on figure 1.

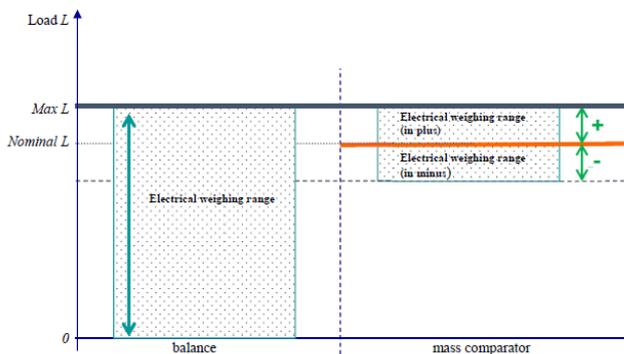


Fig. 1 Electrical weighing range of mass comparator and balance or scale

3. DETERMINATION OF MASS COMPARATORS REPEATABILITY DURING MANUAL AND AUTOMATIC OPERATION

In Laboratory of RADWAG Metrology Centre repeatability of mass comparators was tested by determining standard deviation for specified n quantity of $ABBA$ and ABA cycles. The tests were carried out on similar objects, in both manual and automatic modes, with use of a new line of RADWAG-manufactured automatic mass comparators of UMA and $AK-4$ series and manual mass comparators of $WAY 4Y.KO$ series. Each mass comparator is equipped with 5.7" touch screen connected with mechanical part via flexible cable. The touch screen features dedicated software for comparing masses with database of mass standards and

procedures. Mechanical system of mass comparator contains magnetolectric converter of high resolution. Comparators used for manual mass comparison are equipped with an anti-draft chamber made of glass. During automatic mass comparison process, the comparing mechanism is installed inside of the loader equipped with draft shield made of glass.

Characteristics of tested objects are to be found in Table 1:

	Automatic Mass Comparators	Manual Mass Comparators
Pair 1	UMA 5 Max 5 g $d = 0.0001$ mg Electrical Weighing Range: (0 ÷ 5) g	UYA 5.4Y.KO Max 5 g $d = 0.0001$ mg Electrical Weighing Range: (0 ÷ 5.1) g
Pair 2	UMA 100 Max 100 g $d = 0.001$ mg Electrical Weighing Range: (- 1 ÷ + 10) g	WAY 100.4Y.KO Max 100 g $d = 0.001$ mg Electrical Weighing Range: (- 1 ÷ + 10) g
Pair 3	AK-4/1001 Max 1000 g $d = 0.001$ mg Electrical Weighing Range: (0 ÷ 5) g	WAY 1001.4Y.KO *) Max 1001 g $d = 0.001$ mg Electrical Weighing Range: (0 ÷ 5) g

*) Model purposely prepared for testing

Table 1 Metrological parameters of tested objects

3.1 Measuring Procedure

The procedure consisted in determination of repeatability of mass comparators for different quantities of ABA and $ABBA$ cycles. Mean difference r_i for $ABBA$ cycle for each i^{th} series of measurements has been determined with use of the formula (2). Based on the obtained differences, standard deviation for r differences was determined in accordance with the formula (1).

In $ABBA$ method, measurements for 6 cycles were determined and in ABA method - for 10 cycles. Each measurement was carried out 3 times for each test weight. Next, the mean of 3 obtained standard deviations was determined.

3.2 Testing Workstations:

The tests were carried out in Laboratory of RADWAG Metrology Centre. During testing, the ambient conditions ranged as follows:

- temperature $21.3 \text{ }^\circ\text{C} \div 21.6 \text{ }^\circ\text{C}$
- humidity $46 \% \div 49 \%$

The pace of temperature and humidity changes was accordant to values specified and contained within R-111 OIML for E_1 class. All rooms in which the measurements were carried out feature automatic temperature and humidity regulation with an on-line registration option.

Laboratory in which the measurements were carried out is located on „-1” floor. The base of testing console is separated from the building foundation. The console is made of concrete 3000 kg block. The workstation is presented in figure 2:



Fig. 2 Mass comparators during tests

4. TESTS RESULTS

As a result of measurements carried out in accordance with the procedure described above, repeatability was determined manually and automatically for individual comparators and different types of test loads (weights). The results are presented in tables and graphs below.

Test Load	Standard Deviation SD			Average SD
1 mg	0.00017 mg	0.00021 mg	0.00015 mg	0.00018 mg
100 mg	0.00021 mg	0.00015 mg	0.00020 mg	0.00020 mg
1 g	0.00024 mg	0.00023 mg	0.00024 mg	0.00024 mg
2 g	0.00021 mg	0.00019 mg	0.00020 mg	0.00020 mg
5 g	0.00029 mg	0.00022 mg	0.00026 mg	0.00026 mg

Table 2 The results of UMA 5 measurements, ABBA method

Test Load	Standard Deviation SD			Average SD
1 mg	0.00029 mg	0.00031 mg	0.00032 mg	0.00031 mg
100 mg	0.00033 mg	0.00028 mg	0.00031 mg	0.00031 mg
1 g	0.00033 mg	0.00030 mg	0.00034 mg	0.00032 mg
2 g	0.00044 mg	0.00041 mg	0.00038 mg	0.00041 mg
5 g	0.00046 mg	0.00042 mg	0.00045 mg	0.00044 mg

Table 3 The results of UYA 5.4Y.KO measurements, ABBA method

Test Load	Standard Deviation SD			Average SD
1 mg	0.00016 mg	0.00020 mg	0.00019 mg	0.00018 mg
100 mg	0.00022 mg	0.00017 mg	0.00024 mg	0.00021 mg
1 g	0.00023 mg	0.00024 mg	0.00024 mg	0.00024 mg
2 g	0.00020 mg	0.00022 mg	0.00023 mg	0.00022 mg
5 g	0.00027 mg	0.00022 mg	0.00028 mg	0.00026 mg

Table 4 The results of UMA 5 measurements, ABBA method

Test Load	Standard Deviation SD			Average SD
1 mg	0.00028 mg	0.00029 mg	0.00027 mg	0.00028 mg
100 mg	0.00031 mg	0.00031 mg	0.00033 mg	0.00032 mg
1 g	0.00032 mg	0.00032 mg	0.00036 mg	0.00033 mg
2 g	0.00042 mg	0.00043 mg	0.00037 mg	0.00041 mg
5 g	0.00045 mg	0.00043 mg	0.00047 mg	0.00045 mg

Table 5 The results of UYA 5.4Y.KO measurements, ABA method

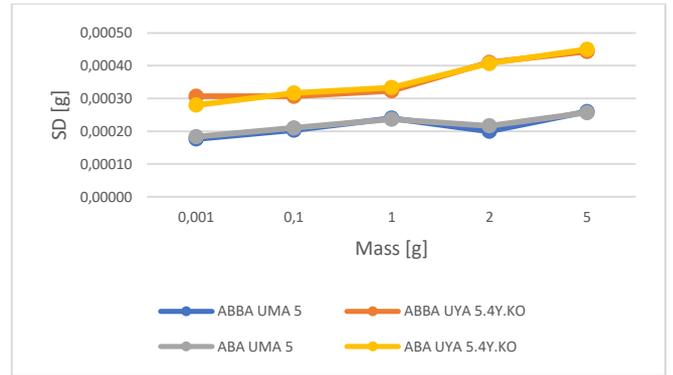


Figure 3 Graph of standard deviation value depending on the load for UMA 5 and UYA 5.4Y.KO mass comparators and for 6 ABBA and 10 ABA cycles

Test Load	Standard Deviation SD			Average SD
10 g	0.0011 mg	0.0008 mg	0.0012 mg	0.0010 mg
50 g	0.0017 mg	0.0011 mg	0.0010 mg	0.0013 mg
100 g	0.0012 mg	0.0013 mg	0.0014 mg	0.0013 mg

Table 6 The results of UMA 100 measurements, ABBA method

Test Load	Standard Deviation SD			Average SD
10 g	0.0029 mg	0.0032 mg	0.0027 mg	0.0029 mg
50 g	0.0028 mg	0.0029 mg	0.0029 mg	0.0029 mg
100 g	0.0032 mg	0.0031 mg	0.0028 mg	0.0030 mg

Table 7 The results of WAY 100.4Y.KO measurements, ABBA method

Test Load	Standard Deviation SD			Average SD
10 g	0.0010 mg	0.0009 mg	0.0013 mg	0.0011 mg
50 g	0.0016 mg	0.0012 mg	0.0011 mg	0.0013 mg
100 g	0.0014 mg	0.0015 mg	0.0013 mg	0.0014 mg

Table 8 The results of UMA 100 measurements, ABA method

Test Load	Standard Deviation SD			Average SD
10 g	0.0031 mg	0.0032 mg	0.0030 mg	0.0031 mg
50 g	0.0029 mg	0.0030 mg	0.0031 mg	0.0030 mg
100 g	0.0030 mg	0.0031 mg	0.0029 mg	0.0030 mg

Table 9 The results of WAY 100.4Y.KO measurements, ABA method

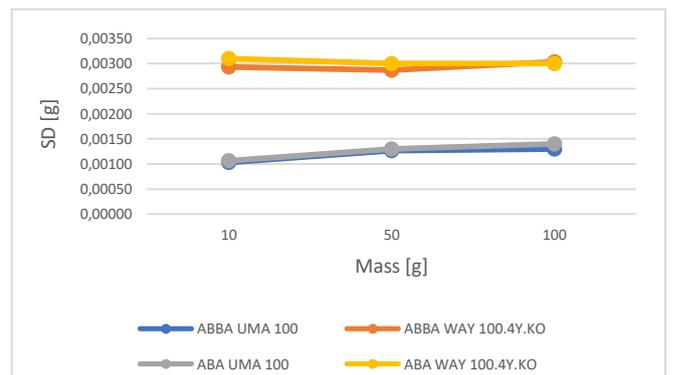


Figure 4 Graph of standard deviation value depending on the load for UMA 100 and WAY 100.4Y.KO mass comparators and for 6 ABBA and 10 ABA cycles

Test Load	Standard Deviation SD			Average SD
1000 g	0.00000 mg	0.00000 mg	0.00000 mg	0.00000 mg

Table 10 The results of AK-4/1001 measurements, ABBA method

Test Load	Standard Deviation SD			Average SD
1000 g	0.00000 mg	0.00000 mg	0.00000 mg	0.00000 mg

Table 11 The results of WAY 1010.4Y.KO measurements, ABBA method

Test Load	Standard Deviation <i>SD</i>			Average <i>SD</i>
1000 g	0.00000 mg	0.00000 mg	0.00000 mg	0.00000 mg

Table 12 The results of AK-4/1001 measurements, ABA method

Test Load	Standard Deviation <i>SD</i>			Average <i>SD</i>
1000 g	0.00000 mg	0.00000 mg	0.00000 mg	0.00000 mg

Table 13 The results of WAY 1001.4Y.KO measurements, ABBA method

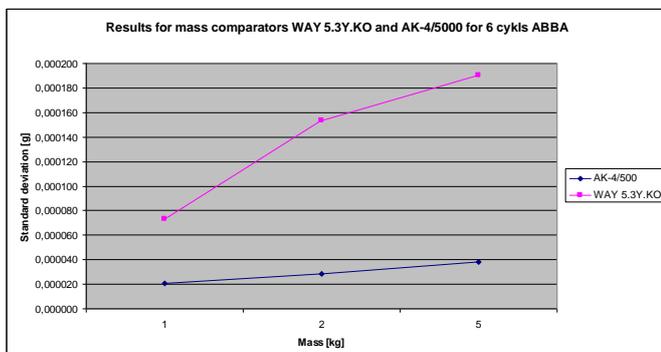


Figure 5 Graph of standard deviation value depending on the load for AK-4/1001 and WAY 1001.4Y.KO mass comparators and for 6 ABBA and 10 ABA cycles

5. CONCLUSIONS

Analysis of obtained results of measurements and repeatability (standard deviation) calculation, which are presented on the graphs (figures 3-5), proves that repeatability, expressed by standard deviation for both ABA and ABBA methods, of automatic mass comparators is 4 times smaller than repeatability of manual mass comparators.

Knowing that the component of calibration uncertainty connected with the repeatability of ABA and/or ABBA method significantly contributes to the whole measurement uncertainty budget, it may be concluded that automation of mass standards and/or weights calibration process makes the calibration uncertainty smaller.

Therefore, it should be noted, that automation of calibration process is a must when achieving higher repeatability (smaller standard deviation) is required.

It also proves that automatic mass comparators have properly optimized design and suitable algorithm of the measuring system. High resolutions that are characteristic for automatic mass comparators can also be used for manual comparators, however this does not result with decrease of repeatability parameter value, which parameter, according to tests, is distorted mainly by human factor. It is because in automatic comparators measurement between successive loadings takes practically the same amount of time and it is due to elimination of eccentricity error and vibrations which both are present when performing measurements manually.

6. REFERENCES

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