IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference
11 – 13 October 2022, Cavtat-Dubrovnik, Croatia

CONSTRUCTION OF A HYBRID ROBOT INTENDED FOR MASS STANDARD COMPARISON, EQUIPPED WITH A SUSPENDED SELF-CENTRING WEIGHING PAN

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Abstract:

The subject of this article is the development of innovative construction solutions as well as the determination of metrological parameters of the robotic mass comparator with 1 µg resolution. The instrument is intended for mass standards from 10 g up to 200 g.

The described construction, being an innovation when compared to other robotic mass comparators, has enabled the use of a suspended self-centring weighing pan, eliminating eccentricity errors.

Keywords: robotic; mass comparator; self-centring pan; uncertainty repeatability

1. INTRODUCTION

Automation of weighing processes in laboratories is becoming more popular and, therefore, more indispensable from a metrological standpoint. Analysis of the results of tests performed in RADWAG Laboratories [1] allows us to observe that the repeatability parameter for mass comparators, expressed as standard deviation, is significantly lower for automatic mass comparators. This is because automatic mass comparators have an optimised construction and a proper measuring system algorithm. It is possible to use the same parameters for manual mass comparators, but the test results and observations made during the use prove that worse accuracy (worsening of the repeatability parameter) is caused by the influence of human factor.

The introduction of robots (Figure 1) into the process of mass standard comparison has resulted in a high increase in throughput and a decrease in mass standard uncertainty. A great asset of such a measuring system is the possibility to perform 100 % automated dissemination, e.g. transition from the national 1 kg mass standard to lower masses at insignificant measurement uncertainty. The high resolution of robotic mass comparators complicates the setup of weighing mechanism eccentricity, whereas continuous weighing chamber opening causes a change in ambient conditions during the measurement, resulting in greater errors.

2. CONCEPT AND DESIGN OF THE NEW COMPARATOR

Mass comparator construction (Figure 2), in comparison to available market solutions, has been designed unconventionally. The reason for that was a desire to implement the advantages of automatic mass comparators into the robotic ones. The main advantages of such a solution are:

- no need to open the weighing chamber during the comparison process, which significantly reduces changes in ambient conditions in the course of the measurements (temperature, humidity),
- compensation of the pressure difference between the weighing module interior and the weighing chamber, which eliminates the so-called upward air current (the transfer of air between the weighing module inside and the weighing chamber after the chamber door is opened),
- no runs of robot during the measurement, which may cause extra air draughts as well as vibrations influencing the measurements.

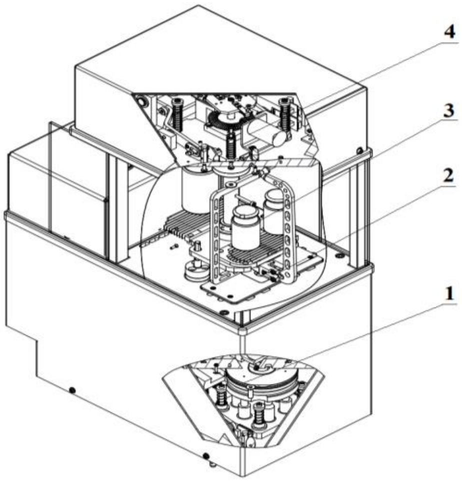

Figure 1: Construction of the robot of a mass comparator featuring an air-suspended weighing pan: 1 – weighing module; 2 – air-suspended weighing pan; 3 – mass standard magazine; 4 – lift-up and rotate mechanism

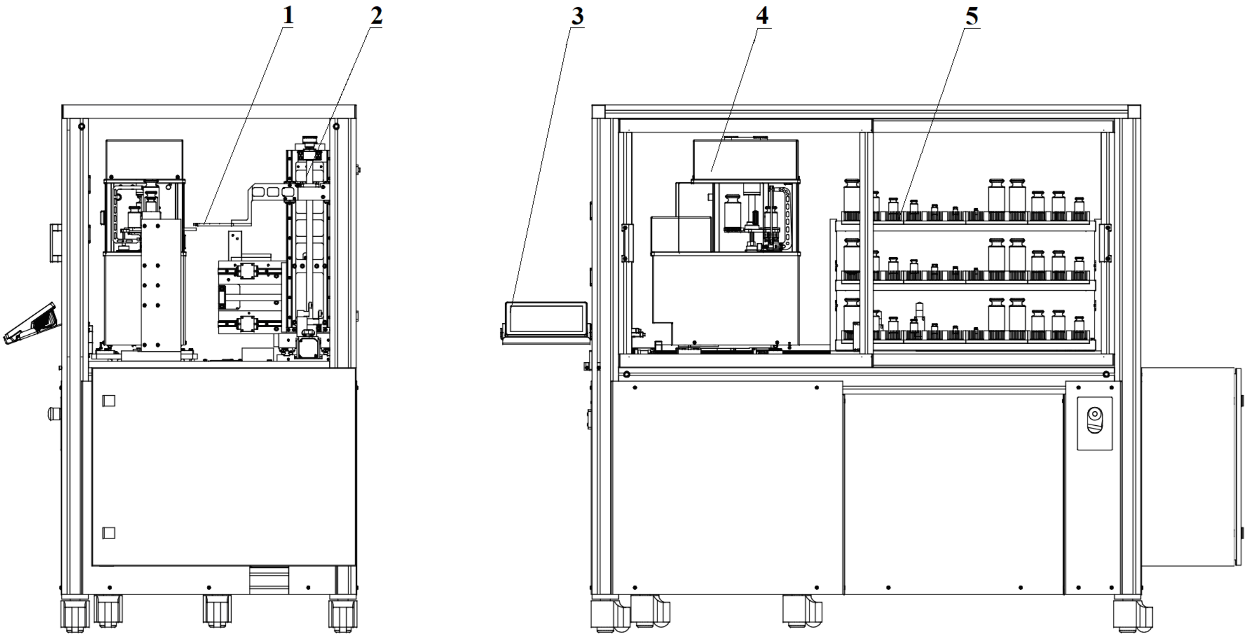

Figure 2: Construction of a hybrid robotic mass comparator: 1 – loading arm; 2 – robot; 3 – control unit; 4 – mechanism with a weighing module; 5 – mass standard magazine

3. UNCERTAINTY ESTIMATION

Uncertainty was estimated according to the commonly accepted procedures [2], adapted to the particular measurement task.

3.1. Procedures

The experimental test procedure was based on the typical work cycle of the comparator. It included six repetitions, each of them consisting of 6 *ABBA* cycles. The number of cycles and repetitions was limited due to the required short time intervals to keep repeatability conditions [3]. The single *ABBA* sequence provided a difference r_i between the mass of a test weight (B) and a reference mass standard (A), according to equation (1) [1].

$$r_i = \frac{\left(B_i^{AB} - A_i^{AB}\right) + \left(B_i^{BA} - A_i^{BA}\right)}{2} \tag{1}$$

where i denotes the number of the cycle from i = 1 to 6, $\left(B_i^{AB} - A_i^{AB}\right)$ is the mass difference obtained in subsequence *AB*, and $B_i^{BA} - A_i^{BA}(\mathrm{B}_\mathrm{i}^{\mathrm{BA}}\text{-}\mathrm{A}_\mathrm{i}^{\mathrm{BA}})$ is the mass difference in subsequence *BA*.

Assuming a normal distribution of random variations in each *ABBA* sequence, the standard deviation was calculated for each 6-cycle repetition. The obtained standard deviations can be considered Type A standard uncertainties, as follows:

$$u_j\,(r_i) = s_d = \sqrt{\frac{\sum_{i=1}^{n}\left(r_i - \overline{r_j}\right)^2}{n-1}} \tag{2}$$

where j denotes the number of repetitions from j = 1 to 10, n = 6 is the number of *ABBA* cycles in one repetition, $\overline{r_j}\overline{r}j$ is the average for six cycles of a repetition. The procedure was repeated six times for each of the weights of 10 g, 50 g, and 200 g, with the readability d = 1 µg.

Having respective experimental values, it was possible to estimate Type A standard uncertainty and expanded uncertainty of both a single measurement and of an average [2], as well as the equipment variation *EV* [4].

3.2. Laboratory Conditions

The experiments were performed in the Measuring Laboratory of RADWAG, Poland. Figure 3 presents the overall view of the RMC 1000.1.5Y comparator during the tests.

Figure 3: The new RMC 1000.1.5Y comparator during repeatability tests

The controlled and registered temperature and humidity of ambient air were kept in strict ranges, as follows:

- temperature between 21.93 °C and 22.16 °C (±0.08 °C)
- relative humidity between 52.3 %RH and 54.1 %RH (±1 %RH)

The changes in ambient conditions were much smaller than the ranges recommended for calibration of weights class E_1, namely, ±0.3 °C per hour and ±5 %RH per 4 hours, respectively. The laboratory is situated on "level -1".

3.3. Results

According to the Type A uncertainty methodology, uncertainty is mainly reflected by the standard deviation sd . Figure 4 presents the example of the standard deviations obtained during six repetitions of 6-cycle measurement as it was described in section 3.1.

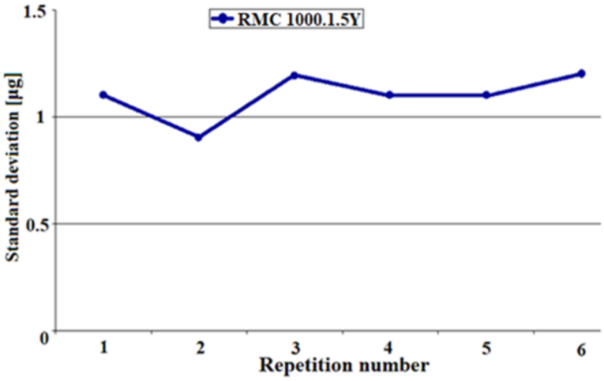

Figure 4: Example of the standard deviations obtained during six repetitions of 6-cycle measurement

To calculate the expanded uncertainty, the level of confidence was assumed to be p = 99 %, typical for precise laboratory measurement. The respective coverage factor recommended by [5] is k_p = 2.576. The values of uncertainties are shown in Table 1.

Table 1: Uncertainty estimation for the measurements of 10 g, 50 g, and 200 g for the RMC 1000.1.5Y comparator

Device	RMC 1000.1.5Y		
Readability d / µg	1		
Measured weight m / g	10	50	200
Standard uncertainty $u(r_{i\,\mathrm{sr}})$ / µg	0.9	1.1	1.5
Expanded uncertainty $U_{0.99}$ / µg	2.32	2.83	3.86

However, it was found necessary to assess the repeatability of the device, applying typical industrial procedure for Equipment Variation EV to the particular case of the mass measurement system [5].

Repeatability describes the variation of the results obtained from the measurement system in the measurement process. In the case of a mass comparator, in order to assess the repeatability of the comparator, the tests were performed for weights ranging from 10 g to 200 g. Thus, it was assumed that:

$X_{i\bullet}$ – average r (µg) obtained from six subsequent repetitions (six cycles each),

i – number of the subsequent repetition, from 1 to n; in that case n = 6,

j – number of measured weights, from 1 to k; in that case k = 3

These values were put into equation (3).

$$\sum E = \sum_{i=1}^{n} \sum_{j=1}^{k} \left(X_{ij} - X_{i*}\right)^2 \tag{3}$$

The obtained value of $\sum E$ was entered into equation (4).

$$s_E^2 = \frac{1}{n(k-1)} \sum E \tag{4}$$

and finally, EV for the level of confidence of 99 % was calculated from equation (5).

$$EV = 5.15 s_E \tag{5}$$

In this procedure, however, the standard uncertainty can be calculated for $X_{i\bullet}$, which is the average value of six obtained $r_{i\,\mathrm{sr}}$, as it is shown in Table 2.

Table 2: Results for the measurements of 10 g, 50 g, and 200 g

RMC 1000.1.5Y			
Readability d / µg	1		
Measured weight m / g	10	50	200
$X_{i\bullet}$ / mg	-0.018 1	-0.041 8	0.391 8
Standard deviation sd / mg	0.000 67	0.000 71	0.001 21
Expanded uncertainty $U_{0.99}$ / mg	0.001 7	0.001 8	0.003 1
Repeatability EV / mg	0.005 16		

4. TEST OF THE INFLUENCE OF WEIGHING MODULE ECCENTRICITY DURING THE PROCESS OF MASS STANDARD DISSEMINATION

The test consisted in checking the influence of the eccentricity of the weighing module of the automatic mass comparator applied in the robotic mass comparator to the obtained result, which result was a difference in mass between the reference and the test weight.

The test was performed using one and the same weighing module. However, first the mass comparator was equipped with a fixed weighing pan; next, an air-suspended self-centring weighing pan was installed. In both cases, two tests were performed, wherein six measurements consisting of six ABBA cycles were carried out, and an average of the difference in mass between the test and the reference weight was calculated:

- for the first test, three mass standards, 200 g + 100 g + 200 g, were used as the reference weights, whereas the test weight was one 500 g weight,
- for the second test, a reverse rule was applied, as a reference weight one 500 g mass standard was used, whereas for the test weights, three mass standards, 200 g + 100 g + 200 g, were taken.

The obtained results are given in Table 3.

Table 3: Differences in mass between the reference weights and the test weights during the dissemination process

RMC 1000.1.5Y			
Reference weight A / g		200 + 100 + 200	500
Test weight B / g		500	200 + 100 + 200
Fixed pan	r_i / mg	0.645 6	0.662 3
	sd / mg	0.001 41	0.001 53
Air-suspended pan	r_i / mg	0.657 6	0.655 1
	sd / mg	0.001 76	0.001 72

The analysis of the obtained results, presented in Table 3, leads to the conclusion that the air-suspended weighing pan significantly reduces errors resulting from the weighing module eccentricity. For the fixed weighing pan, the error caused by the eccentricity takes the level of 16.7 µg, whereas for a weighing module with an air-suspended weighing pan, the same error is 2.5 µg. This value is slightly greater than the average standard deviation obtained during the measurements.

5. CONCLUSIONS

1. Estimation of measurement uncertainty gave the values of a maximum of 3.1 µg at a readability of 1 µg. This value of expanded uncertainty corresponded to 200 g of the measured weight for the level of confidence p = 99 % typical for precise laboratory measurement. The respective coverage factor is k_p = 2.576.
2. The repeatability parameter checked for three different masses, 10 g, 50 g, and 200 g, remained as low as EV = 5.1 µg. Such a high level of repeatability places the new comparator among the best ones available on the market. As such, it may be successfully employed for the calibration of standards of the E_1 class in the full range described in OIML R111 [6].
3. Much of the improvement in characteristics can be attributed to the innovative design of the suspended self-centring weighing pan. Compared to other robotic mass comparators with standard constructions, non-centricity error was reduced by 85 %, from 16.7 µg down to 2.5 µg.

4. For a mass comparator with a fixed weighing pan, eccentricity error is a major source of difficulty in adjusting the geometry of the weighing module due to the ‘device resolution’:‘maximum capacity’ ratio.

6. REFERENCES

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