SYSTEMATIC INFLUENCES IN A MASS COMPARATOR

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ABSRACT
Systematic influences in a mass comparator can affect their performance with very great importance to ensure the reliability of using instruments and to ensure adequate uncertainty estimations. This work gave experience in the field of high accuracy mass measurements in handling standard level for high accuracy instruments and handling measurement data. Mettler AX64004 and AT1006 are automated mass comparators where measurements with zero loads, 1 kg and 5 kg loads were carried out. Methods for revealing and estimating systematic influences are not sufficiently established which need to be tested and elaborated.

Keywords: Systematic influences, uncertainty, mass comparator, accuracy

1. INTRODUCTION
Measurement is comparison with a reference standard and ultimately with a standard that represents the unit of the measured quantity. Mass measurement usually means measuring the amount of material contained in an object. The mass unit is a kilogram. Among the seven base units of the International System of Units (SI), the kilogram is realized by a material object-the international prototype of the kilogram, which is kept at the International Bureau of Weights and Measures (BIPM) in Sevres near Paris since 1889 [1]. The prototype is a cylinder made of a platinum–iridium alloy with a diameter and a height both of 39 mm. The kilogram as the unit of mass was introduced during the French Revolution as the first prototype artifact equal to the mass of 1L of water at temperature 4^{o}C. From comparisons between the international prototype and its copies maintained at the BIPM and owned by the

countries signatories of the Metre Convention starting from 1875, it turned out that over about 100 years there is a significant drift between the international prototype and more than 40 identical copies; thus initially expected stability of the international prototype has been found doubtful [2]. For this reason, but also because several physical constants, such as Planck's constant and the atomic mass constant, are closely related to the kilogram, for re-definition of the kilogram different experiments have been started since the 70s of the 20th century aimed at linking the kilogram to a fundamental physical constant with suitably small uncertainty. The rise in accuracy for carrying out of such comparisons over the last centuries is considerable. Technical advances in the construction of weighing instruments have made possible increasingly accurate comparisons of mass. Weighing techniques based on the comparison of weight forces by using balances are applied in the range between 10 ng and 1000 t. Nowadays, accuracy of the mass measurements are required in various fields. The accuracy of mass standards used in practice requires considerably higher accuracy of mass standards kept in National Metrology Institutes because at any link of the calibration chain going through calibration laboratories or verification offices until the final user measurement uncertainty is increasing by a factor of up to three. For accurate mass measurement dedicated equipment has been required such as mass comparators specialized for comparing mass standards of the same nominal values with very high repeatability, mass standards of small uncertainty and good long-term stability made of non-magnetic material, suitable rooms for the accommodation and use of the equipment and accurate instruments for measurement of temperature, pressure, humidity and CO_2 content in air for evaluating influence quantities like the air density, temperature [4]. This work gave experience in the field of high accuracy mass measurements in handling standard level with high accuracy instruments and handling measurement data. In this paper we were focused on the systematic influences at automated mass comparator.

2. MEASUREMENT PROCEDURE

Measurements in different conditions with zero loads, 1 kg loads and 5 kg loads by using Mettler AX64004 and AT1006 comparator were carried out for our purpose. Altogether 16 mass comparison were made during this time about 12 hour of each experiments. The relative humidity and temperature during the measurements were (44 – 55) % and (19.5 – 20.0) °C. Specifications for both comparators are shown in the table 1.

Table 1. Manufacturer's specification of the comparators used for experiment.

Type	Manufactor	Capacity	Resolution	Repeatability
AT1006	Mettler-Toledo	0…1011 g	1 µg	5 µg
AX64004	Mettler-Toledo	0…64270 g	0,1 mg	0,4 mg

The Figure 1 show the layout of AX64004 automated mass comparator for calibration of the weights from 1 kg up to 5 kg with high resolution and repeatability mentioned in Table 1.

Figure 1. Picture of the AX64004 comparator

The AX64004 Comparator weighing system comprises:

- The balance with the weight handler
- The balance controller
- The handler controller
- 4 temperature sensors
- Connecting cables to connect the weighing unit, the balance controller and computer
- The process controller with installed Windows program "AX64004-control" software that is provided by Mettler Toledo for fully automatic performance and reporting of comparative weightings
- 4 Glass cylinders (individual draft shields).

Before starting the measurement is needed the centering of the weights. Centering of the weights is realized semi-automatically by built-in self-centering device "Levelmatic". The steps that have been used for centering are:

a. Lowering the turntable,
b. curvature of the weighing pan automatically moves the weights toward the center of the load receiverand
c. raising turntable.

This procedure is repeated until the position of the weight is no longer visibly changes. The good pre-positioning should be after about three repetitions operations. To reduce the number of centering operation to the weights on the turntable is needed placement as centrally as possible on the respective grid. Afterward the weighing process consist on the series of 4 groups of 6 A-B-B-A comparisons weighing scheme.

3. MEASUREMENT RESULTS

The measurements are realized in Estonian National mass laboratory and the results are calculated on the base of A-B-B-A comparator scheme. The uncertainty calculations are based on the Guide to the expression of uncertainty in measurement 1993(E), precision mass measurement and from the International recommendation R 111 of OIML [3,4,5,6]. During the experiments we have seen that systematic influences that affecting the performance of a mass comparator may be of very great importance for the reliable use of the instrument and for providing adequate uncertainty estimates. For this reason relevant characteristics of the mass comparators were determined such as repeatability, sensitivity, asymmetry of local positions and systematic influences in the case of each independent difference of the four load positions [7]. Repeatability of measurement results is shown in the Table 2.

Table 2. Summary of the measurement results based on repeatability.

Nr	Comparator	Loads	Measurment Scheme	Special remarks	Repeatability [mg]
1	AX64004	4 x 5 kg	6 diff. x 3 series	With illumination	0.21
2	AX64004	4 x 5 kg	6 diff. x 3 series	In dark	0.18
3	AX64004	4 x 5 kg	6 diff. x 3 series	With illumination	0.20
4	AX64004	4 x 5 kg	6 diff. x 3 series	With illumination	0.29
5	AX64004	4 x 5 kg	6 diff. x 3 series	In dark	0.27
6	AX64004	0	6 diff. x 3 series	With illumination	0.14
7	AX64004	0	6 diff. x 3 series	In dark	0.20
8	AX64004	4 x 1 kg	6 diff. x 3 series	With illumination	0.22
9	AT1006	4 x 1 kg	6 diff. x 3 series	With illumination	0.0009
10	AX64004	4 x 1 kg	6 diff. x 3 series	In dark	0.21
11	AX64004	4 x 1 kg	6 diff. x 3 series	With illumination	0.21
12	AX64004	4 x 1 kg	6 diff. x 3 series	In dark	0.21
13	AX64004	4 x 1 kg	6 diff. x 3 series	With illumination	0.23
14	AX64004	4 x 1 kg	6 diff. x 3 series	In dark	0.23
15	AX64004	4 x 1 kg	6 diff. x 3 series	With illumination	0.21
16	AX64004	4 x 1 kg	6 diff. x 3 series	In dark	0.16

In the results mentioned above we can see that repeatability is always less than 0.4 mg which means that indispensable environmental conditions are present for this instrument. The AT1006 comparator was used for obtaining reference values of the mass differences of 1 kg standards which was used afterward for testing the performance of AX64004 comparator [7]. Furthermore, figure 2 show the results for sensitivity and linearity of the comparator, asymmetry of the local position and in the end systematic influences as the function of loads position compared in different measurement conditions.

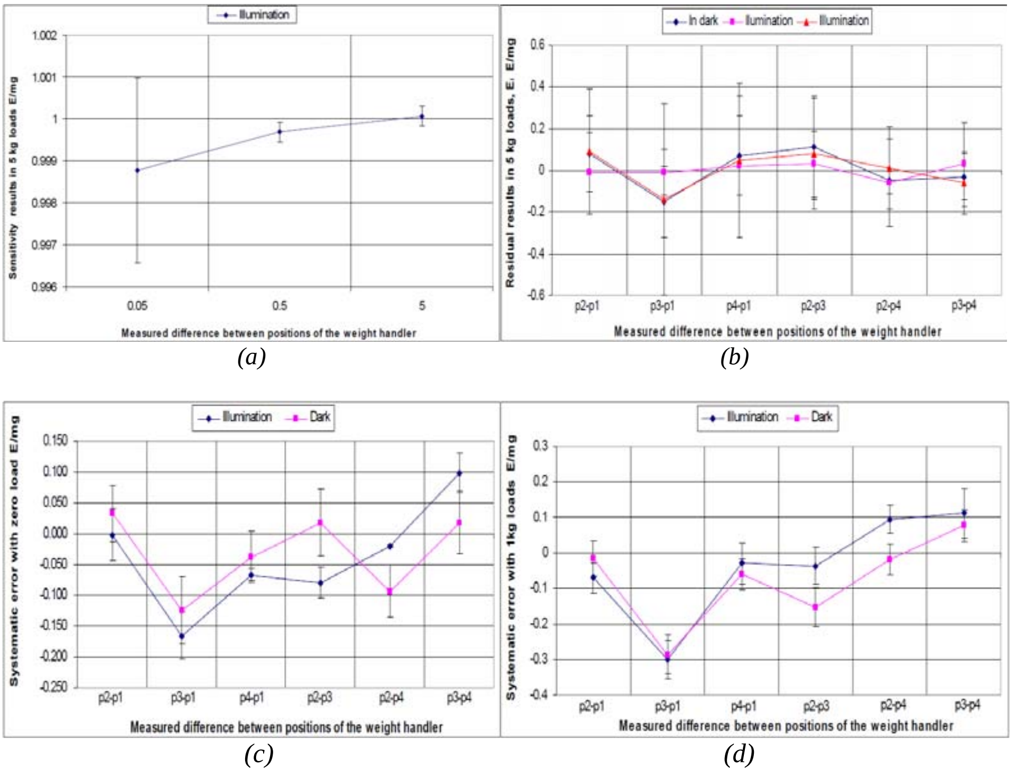

Figure 2. a) Sensitivity and linearity of the AX64004 comparator, b) Asymmetry of local position of the AX64004 comparator, c) Systematic sources of the AX64004 comparator with 0 kg loads as a function of loads position, d) Systematic sources of the AX64004 comparator with 1kg loads as a function of loads position

The measured differences between positions of the weight handler is inserted in x-axis. Six differences are considered started from p2-p1,...p4-p1 and in the y-axis is inserted the numerical value of the measured differences which can characterize the statistical variability of measured differences and in our experiments results is presented systematic influences. Nevertheless, except repeatability the temperature gradients or temperature changes always present may affect the measurement results if loads with different shape or composition are used, and for the loads with relatively small nominal value the contribution of systematic effects is often factor significantly disturbing the outcome.

4. CONCLUSIONS

In the end of our research work we can conclude that systematic influences depend strongly from:

- location of loads on the turntable of comparator,
- the nominal value of the loads and
- environmental conditions during measurements.

Repeatability of both comparators meets well the specification of manufacturer. This demonstrates that environmental conditions are satisfactory. Furthermore in case of AX64004 systematic effects are evident for all the loads. In comparison with the expanded uncertainty of OIML E1 class weights (0,16…0,8 mg) recorded systematic influences up to 0,3 mg are significant in many cases. One most likely reason for the influences revealed is convection due to temperature differences of the comparator. Therefore system for monitoring temperature under the draft shields of all loads was set up and first temperature measurements with standing comparator made.

5. REFERENCES

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