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Automated weight calibration with robotic mass comparators

Mark Kliebenschaedel [1]

[1] Mettler-Toledo AG, Greifensee, Switzerland

E-Mail (Presenter): javier.levitt@mt.com

Abstract – A robotic mass comparator is a very productive, reliable and accurate piece of equipment which is used for the calibration of weights by national institutes, calibration laboratories and weights producers to calibrate all weight classes. Performance and reliability on the one hand, productivity on the other, are of concern to metrologists. To meet their requirements, many factors have to be considered from the operator side as well as from the manufacturer of equipment side. This paper gives an overview of robotic systems, the ideal operation and the relevant factors which have to be taken into consideration when calibrating weights.

Keywords: Mass Calibration, Robotic Mass Comparators, Mass Metrology, Productivity in Mass Calibration.

1. INTRODUCTION

If a weight (unknown in its mass) has to be determined / calibrated, it will be compared to a reference mass where the mass value is known. This procedure can be either carried out manually by loading a weight on the weighing pan of a comparator balance or it can be achieved automatically, e.g. with a robotic system.

The first commercially available robotic system for weights calibration was introduced in 1999. The development and design was carried out by the company called METROTEC in collaboration with Mettler-Toledo GmbH. The balance used for this robotic system was a METTLER TOLEDO comparator balance. A robotic system capable of determining weights from 1 mg up 5 g was first installed at a regional calibration facility in the UK. The customer required an instrument with improved accuracy for smaller weights and capable of calibrating a large number of weights without human interaction.

To meet the markets demand, the robots have been continuously improved and systems with higher weight and magazine capacity have been developed.

The market has grown substantially: worldwide more than 80 units have been installed so far (as per March 2017).

Productivity and accuracy on the one hand and security and reliability on the other hand is the reason for this growing market in robotic weighing. The decision to invest in a robotic comparator depends on the requirements and processes. Calibration laboratories generally have a large throughput and therefore time efficiency is a relevant factor without any compromise in accuracy. Offering their customers a competitive price for the calibrated weights and having short lead times is also a main target of a calibration service. The main factors for a National Institute however are generally accuracy, security and shortage of personnel.

2. PRINCIPLES

The system consists of a cabinet containing a weight magazine, a comparator balance, and a 3-axis robotic system. The robot is controlled by a control software which executes the process, collects the measured data and calculates relevant parameters for mass determination.

The 3-axis robot moves to the magazine where the weights are located, picks up a weight carrier or the weight directly and moves it towards the balance. The balance door opens and the robot slowly and accurately deposits the weight onto the weighing pan. The robot will process the weights according to a programmed setting and weighing scheme (figures 1 and 2).

In order to achieve a high level of accuracy, environmental data such as temperature, humidity and pressure has to be measured for the air density which is mandatory to calculate the air buoyancy correction.

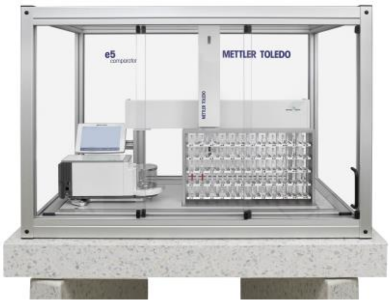

Figure 1. e5 robotic comparator (1 mg to 5 g).

Figure 2. a1006XL robotic comparator (10 g to 1000 g).

Depending on the type and accuracy of the robot, a full range or a window range comparator is used. Window range comparators are equipped with a counter weight which is in equilibrium with the maximum load capacity of the comparator. If smaller weights are measured, dial weights have to be switched. A robotic comparator is able to actuate these weights automatically. Whatever weight is located on the magazine, these dial weights will be switched prior to the start of the measurement. This allows the calibration of a weight set with different nominal values without interference (figure 3).

If using a comparator balance with an automatic handler (4-position turntable), however, only the same nominal weights can be measured at the same time, due to the fact that the dial weights cannot be switched automatically.

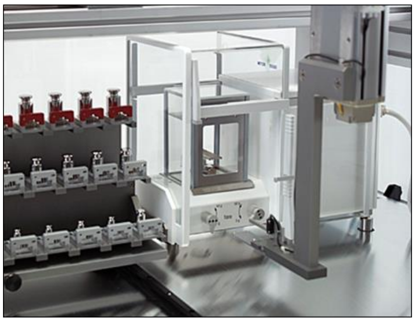

Figure 3. Switching dial weights of a107 comparator.

3. SECURITY

Security is an important factor when carrying out weights calibration. The risk of losing a weight, writing down an incorrect value, reading wrong numbers from the balance indication, interrupting the measurement process, etc. are of concern to metrologists and calibration managers.

Due to the fact that mostly a repetitive measurement has to be performed, there is a potentially higher risk of "mixing up" or losing a weight.

Calibrating mass with robotic mass comparators has proved that there is far less risk involved, especially when using smaller sized weights (wire weights and sheet weights).

To minimize risks, many features are implemented into a METTLER TOLEDO robotic system:

- "Balance Position Sensor" – if the balance moves during a measurement caused by an incident, such as an earthquake, the process will stop to avoid a crash with the weighing pan
- "Optimized Robot Arm Speed" – the robot moves with a very slow acceleration to prevent the weight from moving or falling from the carriers.
- "Safety Doors" – measurement process is stopped if doors of robot housing are opened.
- "Emergency Stop" – at any time within the process the robot can be stopped immediately by the operator.
- "Carrier Detection" – an optical sensor detects whether there is a weight carrier in the magazine and if the right type of carrier was loaded.
- "Secure Data Management" – all weighing values are recorded without transcription error and stored automatically on the hard drive.

A tendency of using microgram weights can be seen in the market. On a manual mass comparator it is very challenging to measure these special weights produced by METTLER TOLEDO (figure 4).

Figure 4. Wire weight with the nominal value of 0.05 mg loaded on the hook of an a10XL weight carrier.

A robotic system, however, such as the a10XL is able to measure those weights to a very high level of accuracy. They provide the ideal solution to carry out this type of measurement.

4. ACCURACY AND PERFORMANCE

In mass metrology the determination of unknown masses and the dissemination of weight sets can demand a great deal of time, skill and expertise. The manual handling of weights also requires a lot of patience, attention and precision. If the measurement of the mass is carried out with a robotic system, accuracy and performance is improved.

Negative human influences, such as: imprecise placement of the weight, inconsistent stabilization time until reading is taken; body heat, etc. can be neglected.

Thanks to the automation, overnight measurements can be performed reducing the influence of random pressure changes (door movement), vibrations coming from external sources (e.g. automobiles, trains, and machinery), temperature fluctuation, etc. In addition, the possibility of setting a start delay for the measurement enables the possibility to acclimatize weights prior to the measurement which improves the accuracy and the quality of the results.

The balance stands separate from the robot housing to avoid any vibration coming from the robotic system (figure 5).

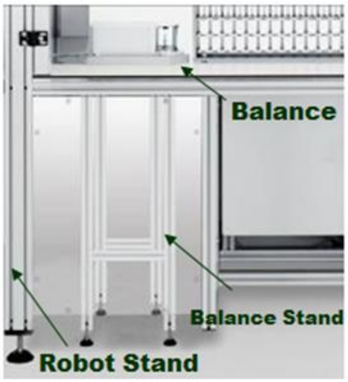

Figure 5. Separate stand of ultra-microbalance.

Mass comparators have very high resolutions and a drift of the balance reading must be taken into consideration. The controller software will however eliminate the drift by using the ABA or ABBA methods recommended by the OIML R111. Moreover, a big advantage is that reference weights experience less abrasion if handled by a robotic system instead of doing it manually. Therefore reference weights will remain longer within the tolerance of their class.

All in all, a better performance and accuracy can be achieved with a robotic system compared to a manual comparator.

5. INFLUENCE OF CORNERLOAD ON A ROBOTIC SYSTEM

The eccentric load is the deviation in the measurement value caused by eccentric loading, in other words asymmetrical placement of center of gravity. The eccentric load increases with increasing load and distance from the center of the load receptor. [1] Robotic systems with a fixed (static) weighing pan or with a so-called LevelMatic™ [1] are available. A weight which is lowered and lifted repeatedly by the robot arm onto a LevelMatic™ will center itself and move towards the center of gravity (figure 6). Therefore the eccentricity error is negligible. With a fixed weighing pan however, the weight has to be centered/positioned on the weighing pan accurately. The higher the weight in mass, the more important is an accurate placement.

Figure 6. LevelMatic™ weighing pan of AX32004-M10.

METTLER TOLEDO has developed the so called “weight carrier principle”. These carriers have different recesses with different diameters, or are adjustable to the right size of the weights diameter. Selecting the best suitable carrier will prevent a minimum of eccentricity effect – this is especially important for the calibration of the highest class of weights (figure 7).

Figure 7. Weight carrier of e5 / a10XL robotic comparator (1 mg to 10 g).

If weights of a low class are determined, METTLER TOLEDO can provide a sheet which calculates what type of carriers, respectively which recessed diameter should be used depending on the class and the nominal weight also taking the eccentricity error of the balance into consideration.

Robot systems are able to measure the eccentricity error of balance individually for each nominal weight. This is relevant if a weights combination is measured and the balance weighing pan is unequally loaded e.g. 5 g vs. 3 g + 2 g (explained in section 6 “Dissemination”).

6. DISSEMINATION

A calibration of a set of weights is mainly carried out using two established methods. One is to compare the weights with a reference set using the one vs. one method, which requires a full reference weight set with all required standard weights. The other method is to calibrate the unknown masses by using only one reference weight and working down- or upwards, also called dissemination or subdivision.

Table 1. Design matrix used for the decade 1 g - 100 mg on e5 comparator.

Design Matrix for Dissemination – 5 g Robotic Comparator								
	1g T	1g REF	500 mg T	500 mg Ch	200 mg T	200 mg Ch	100 mg T	100 mg Ch
1	B	A	-	-	-	-	-	-
2	B	-	A	A	-	-	-	-
3	-	B	A	A	-	-	-	-
4	-	-	B	A	-	-	-	-
5	-	-	B	-	A	A	A	-
6				B	A	A	-	A
7	-	-	-	-	B	A	-	-
8	-	-	-	-	B	-	A	A
9	-	-	-	-	-	B	A	A
10	-	-	-	-	-	-	B	A

This can be very time-consuming and difficult to achieve with a manual or automatic comparator. Often weights have to be stacked and specially designed weighing schemes have to be employed if using automatic or manual comparators. For instance: the placement of several weights onto a hanging weighing pan of a manual balance can be very challenging.

Finding the center of gravity of a group of weights with different nominal values is nearly impossible.

On the other hand with the robotic system a flexible design of a weights dissemination scheme can be applied, where up to 3 weights can be loaded simultaneously onto the weighing pan. The weights are automatically loaded symmetrically to avoid eccentric load errors. For example: 50 g vs. 20 g + 10 g + 20 g (figure 8).

If an asymmetrical weighing scheme is chosen, for instance 5 g vs. 3 g + 2 g, an automatic correction to the measured value is made according to the determined value of the eccentricity error. A paper on this particular topic was issued for the IMEKO in 2001 by Arthur Reichmuth, “A new Mass Comparator Generation for the Automatic Calibration of weights sets” [3].

Figure 8. Three weights loaded symmetrically on the weighing pan of the a107 robotic comparator for dissemination.

7. PRODUCTIVITY

Productivity is a relevant factor if calibrating a large number of masses. The robotic systems have been continuously improved over the last few years to perform more efficiently and productively.

This section explains which relevant settings and parameters have to be considered to work efficiently and still fulfil the accuracy needed to calibrate according to the required tolerances.

7.1. Set-up of the ideal weighing process

Pre – run: With this parameter the system will carry out an initial check of the loaded weight prior to the measurement start.

History specific pause (this applies only for weights larger than 100 g): This measure eliminates the drift affecting the weight difference between two weights when one of them has reached a higher temperature than the other because of a longer exposure to the environment of the balance weighing chamber which is slightly warmer than the environment of the weight magazine, as an example when the reference weight is compared with several equal nominal test weights (500 g ref vs. 500 g test1, 500 g ref vs. 500 g test2, 500 g ref vs. 500 g test3, etc.), the reference weights 500 g ref will rise in temperature. A recommended time of 15 min. should be set.

Start delay (acclimatization of weights): Within the robot housing the temperature may be higher than within the mass lab itself. This can vary from 0.1 °C to 0.5 °C. The reference weights usually stay permanently on the magazine. Therefore the standard and the test weights are not equally acclimatized.

Depending on the weight class and nominal value, one has to wait a certain time before the weights can be measured. For instance, if a 1 kg weight with class E2 is calibrated, and the difference in temperature between the inside of the robotic system and the mass lab is 0.5 °C, the weight has to be acclimatized for at least one hour before the measurement can be started (figure 9).

Thermal stabilization in hours

ΔT^*	Nominal value	Class E1	Class E2
± 0.5 °C	1 000, 2 000, 5 000 kg	-	-
	100, 200, 500 kg	-	1
	10, 20, 50 kg	11	1
	1, 2, 5 kg	7	1
	100, 200, 500 g	3	1
	< 100 g	1	0.5

ΔT^*= Initial difference between weight temperature and laboratory temperature.

Figure 9. Section B.4.3 of OIML R111- Thermal stabilization in hours [2].

Attaching an acclimatization chamber to the robotic system allows the weight to acclimatize to the temperature within the robot resulting in a more efficient and productive process.

Number of non-reported pre-weighings per group: In order to reduce the "first weighing effect" (drift) noticeable in particular after a change of nominal value, it is recommended to carry out one pre-weighing without reporting this set of data.

Number of reported comparisons per group: Depending on the class calibrated and the comparison scheme used, a recommended number of comparisons should be chosen (figure 10).

Class	E_1	E_2	F_1	F_2	M_1, M_2, M_3
Minimum number of ABBA	3	2	1	1	1
Minimum number of ABA	5	3	2	1	1
Minimum number of $AB_1...B_nA$	5	3	2	1	1

Figure 10. Section C.4.3 in OIML R111, – Number of weighings [2].

Stabilization time: Ideal stabilization is evaluated by the technical expert who installs the robotic system.

Integration time: time, in seconds, which runs after the stabilization time has elapsed and during which the system records one measurement value every second; the average of the recorded values is stated as result in the measurement report – a minimum of 5 seconds should be chosen.

7.2. Built-in productivity improvements

7.2.1. If several weights with different nominal values are located on the magazine, those with the same nominal values will be processed consecutively, as switching the dial weights is time consuming.

7.2.2. The software “Efficiency Pac” allows the placement of several customer weight sets. Each of the weights will be measured individually and a measurement report for each set will be created.

7.2.3. The software enables the import of an existing measurement setting while the robot is still in progress. This import job can be either created locally or by a host system.

7.2.4. Optimization of the magazine location allows a faster loading of the weights.

7.2.5. Reduction of pre-run / centering time using ‘Standard’s centering history’: Standard weights included in the process are re-used for multiple measurements. The centering / pre-run of these standard weights can be skipped and valuable time can be saved.

7.2.6. The controller software is able to send emails to inform the operator of measurement starts, successful measurement completions as well as measurement abortions.

8. CONCLUSION

The installation of a robotic comparator brings many benefits to the metrologist, the calibration manager, and the calibration laboratory as a whole.

Robotic systems can handle a large number of weights (throughput), maximizing security in many ways and delivering highest accuracy in mass calibration.

Since their introduction, robotic mass calibration systems have been continuously improved and optimized to meet the expectations of all users.

More than 80 METTLER TOLEDO robotic systems installed worldwide prove the tendency towards automation and productivity in the field of mass calibration.

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