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THE TEMPERATURE CHANGE DURING MEASUREMENT VIA MASS COMPARATOR WITH AUTOMATIC LOAD ALTERNATOR

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Abstract – We changed a new 10-kg mass comparator with automatic load alternator at CMS (Center for Measurement Standards) last year to replace the older one which was out of function. During installation, the temperature issue comes out to affect the measurement results under the same environment of laboratory as usual. In this paper, we will discuss the abnormal phenomenon caused by the thermal effect.

Keywords: mass comparator, automatic load alternator, thermal effect

1. INTRODUCTION

To obtain good mass measurements, it is necessary to have good laboratory facility, environment, as well as good standards and balances. The sources of uncertainty will come from the instability of the air currents, the temperature gradient, magnetic or electrostatic fields, and so on. It is critical for mass calibrations to have environmental thermal equilibrium. This is why the weights are always asked to be placed in or near the balance for 24 hours prior to a calibration. Convection currents will be generated when an object is on the balance pan and an erroneous reading may result, if thermal equilibrium is not reached.

2. PRINCIPLES

2.1. Buoyancy correction

According to OIML R111 (2004) [1], the conventional mass difference Δm_c between the test weight and the reference weight of a cycle *i* for mass comparison is:

$$\Delta m_{ci} = \Delta I_i + m_{cr} C_i \qquad (1)$$

Where the air buoyancy correction is

$$C_i = \left(\rho_{ai} - \rho_0\right) \times \left(\frac{1}{\rho_t} - \frac{1}{\rho_r}\right) \qquad (2)$$

2.2. Air density

The CIPM formula (1981/91) or an approximate formula used for the calculation of air density can be seen in the annex E of OIML R111 (2004). The approximate formula is:

$$\rho_a = \frac{0.34848\,p - 0.009(hr) \times \exp(0.061t)}{273.15 + t} \qquad (3)$$

Where the density of air ρ_a is obtained in kg m^{-3}; the pressure *p* is given in mbar or hPa; the relative humidity *hr* is expressed as a percentage; and the temperature *t* is given in °C.

3. EXPERIMENT

3.1. Chamber

We have built an independent chamber to isolate the mass comparators from the environment, because the dimension of our laboratory is about 814 cm x 663 cm x 305 cm with temperature controlled actively within the range of (21 ± 1.5) °C. The chamber shown as in Fig. 1 is made mostly from aluminum and polystyrene. The design and construction of the chamber can refer to the paper we introduced in APMF2011 [2].

Figure 1. Exterior of the chamber.

The new 10-kg mass comparator (Sartorius CCE10000U-L) we have bought last year was installed as shown in Fig. 2 at the same location as the replaced Sartorius CC10000U-L at the right side of the chamber and Sartorius CC50000S is at the left side. The control units, display units and transformers for both comparators are moved away from the comparators and located outside the chamber. The motors for the motorized platform movement and weighing cell would be the least inevitable heat source. To observe the difference of the temperature condition between the inside and outside of the chamber, one thermometer with two thermistor probes was used.

3.2. First installation

Figure 2. Location of new installed mass comparator.

As shown in Fig. 3, the mass comparator consists of (a) weighing cell, (b) centermatic pan, (c) automatic load alternator, (d) display unit, (e) control unit and (f) draft shield. The specification for repeatability is not bigger than 50 µg.

After first installation, we had 96 measurements for 4-weight comparison and the percentage of the standard deviation obtained from each measurement to meet with the specifications (< 50 µg) is only about 74% as shown in Fig. 4. It is not acceptable for a new comparator.

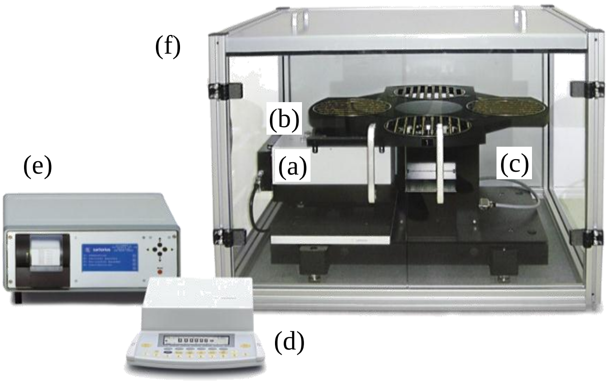


Figure 3. Composition of the mass comparator ((a) weighing cell, (b) centermatic pan, (c) automatic load alternator, (d) display unit, (e) control unit and (f) draft shield).

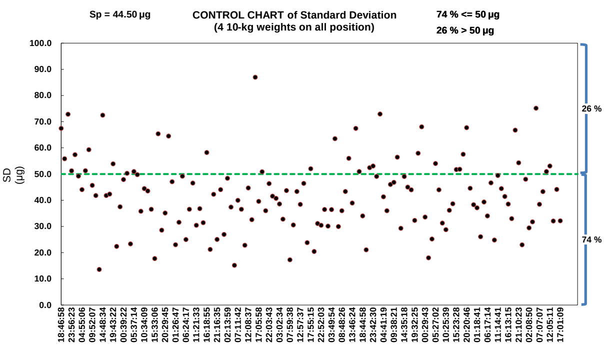


Figure 4. The standard deviation after first installation.

To find out the reason of the instability, we took some further measurements.

3.3. Vibration measurement

First, we took some vibration measurements to see if the environmental vibration causes the instability. We use PCB high sensitivity ICP accelerometer to measure the vibration frequency on the marble table which the mass comparator was installed on it. The accelerometer is shown in Fig. 5 and the results are shown in Fig. 6. In Fig. 6, the original signals are (a), (b), (c), (g), (h), (i) and we select the frequency only under 60 Hz to be (d), (e), (f), (j), (k), (l). All the amplitude variations under 60 Hz are small than 1 µm.

Figure 5. PCB high sensitivity ICP accelerometer.

Even if the phenomenon of vibration is not obviously distinguished, we still changed the marble table to the granite table to have better stability.

3.4. Weighing unit measurement

After then, the comparator was disassemble to observe the stability of the weighing cell. As shown in Fig. 7, we remove the platform away from the load alternator and put 10-kg disc weights on the weighing cell directly without the centermatic pan. The disc weights kept loading on the weighing cell without unloading during measurements.

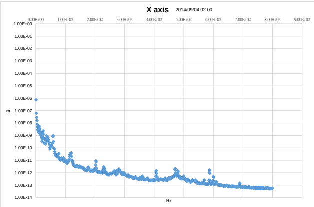
To avoid the air current, we use a small draft shield came from the old Sartorius C10000S to cover on the weighing cell as shown in Fig. 8. The measurement result is standard deviation $\sigma < 6.1$ µg as shown in Fig. 9. It shows that the granite table is good enough for measurements. Because the platform will on the load alternator normally, we remove the small draft shield away as shown in Fig. 10 and took more measurements. Unfortunately, the mean value of standard deviation $\overline{\sigma}$ is 30.7 µg as shown in Fig. 11 but the temperature variation inside the chamber (T_{in}) is smaller than 0.05 °C per 16 hour as shown in Fig. 12.

Is the air current the reason? We sealed the gap of the draft shield with tape as shown in Fig. 13. It was useless because $\overline{\sigma}$ is 40.3 µg as shown in Fig. 14 where the temperature variation inside the chamber (T_{in}) is smaller than 0.05 °C per 12 hour as shown in Fig. 15. Then we use the carton and plastic box as small draft shield separately as shown in Fig. 16 and Fig. 17.

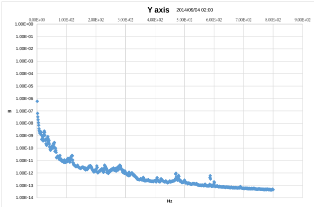
Two good results "$\sigma < 7.0$ µg" and "$\sigma < 6.0$ µg" were obtained respectively as shown in Fig. 18 and 19. The usage of plastic box also told us that it was nothing about static electricity.

We modify the carton to different types to see the results. The types and the results are shown as in Fig. 20 respectively. In (a), the weighing cell is fully covered with small gap left only but the 10-kg disc weights was totally opened to the air;

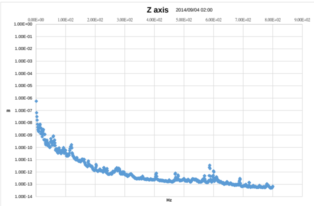
(b) is similar with the carton in Fig. 16 except for the opening top; (c) is similar with (b) except for the shorter cardboard cylinder; (d) ~ (g) are modified according to (h) which is the allocation of the centermatic pan on the weighing cell. These results can be seen from the note below the figure respectively and only type (b) is good enough to be accepted. It is weird.



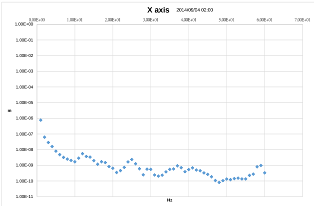
(a) 9/4 02:00 X-axis



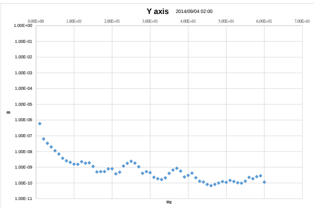
(b) 9/4 02:00 Y-axis



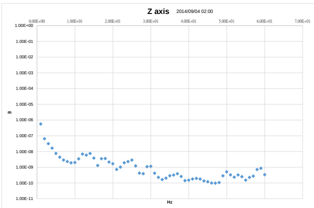
(c) 9/4 02:00 Z-axis



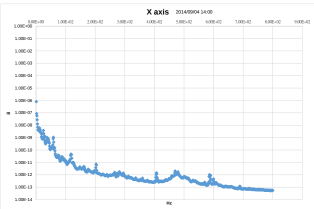
(d) data under 60 Hz in (a)



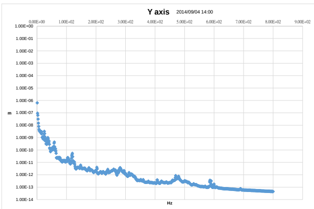
(e) data under 60 Hz in (b)



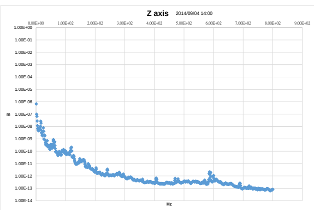
(f) data under 60 Hz in (c)



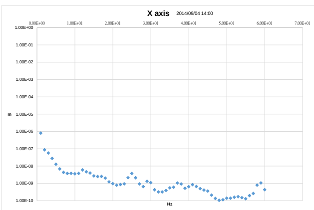
(g) 9/4 14:00 X-axis



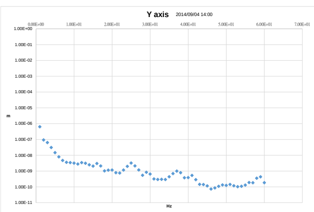
(h) 9/4 14:00 Y-axis



(i) 9/4 14:00 Z-axis



(j) data under 60 Hz in (g)



(k) data under 60 Hz in (h)

(l) data under 60 Hz in (i)

Figure 6. Results of vibration measurements.

3.5. Final installation

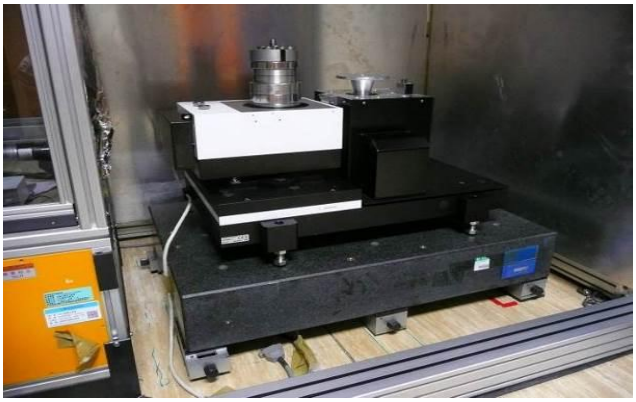


Figure 7. Disc weights on the weighing cell directly without the centermatic pan and the platform on the load alternator.

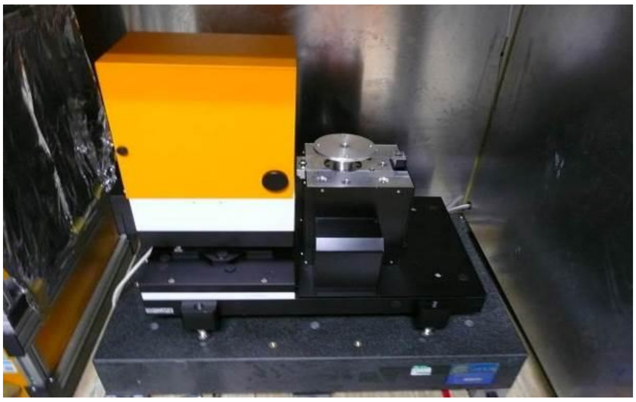


Figure 8. Draft shield on the weighing cell to avoid the air current.

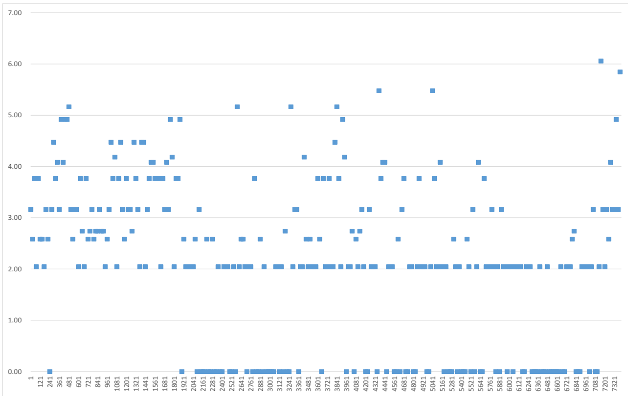


Figure 9. Standard deviation σ < 6.1 μg.

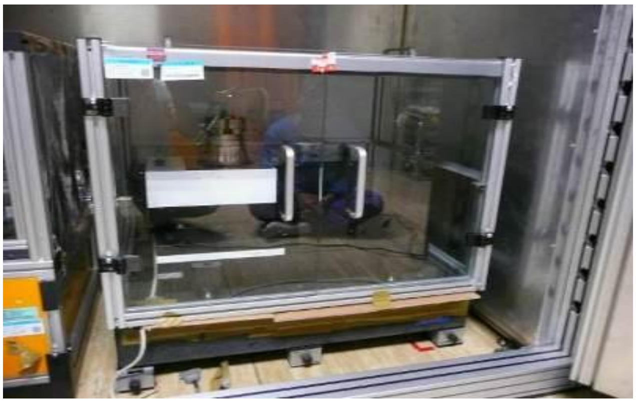


Figure 10. Remove the small draft shield away.

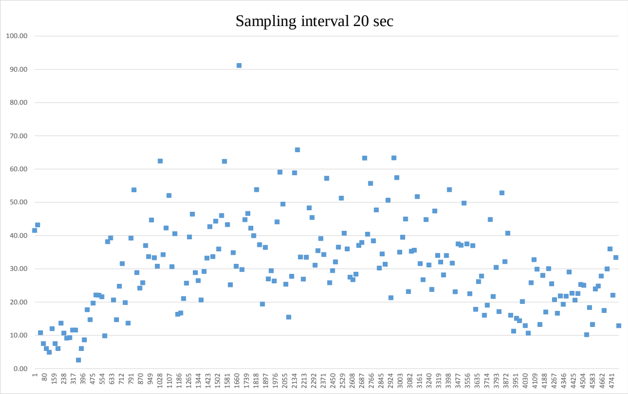


Figure 11. The mean value of standard deviation $\bar{\sigma}$ is 30.7 μg.

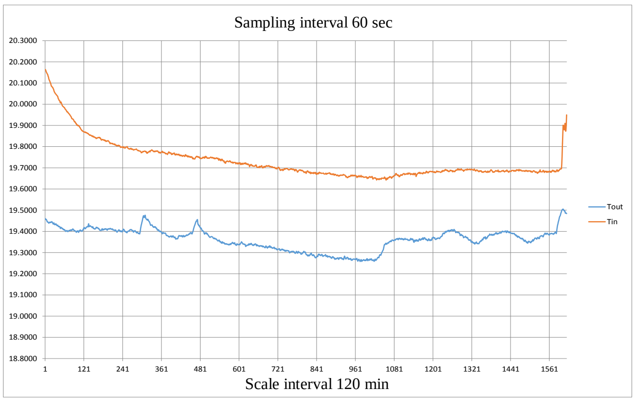


Figure 12. Temperature variation $< 0.05\ ^{o}C/16$ hr (for Tin).

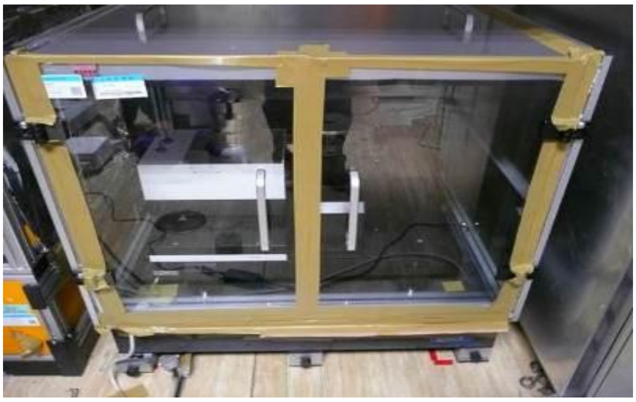


Figure 13. The gap of the draft shield was sealed with tape.

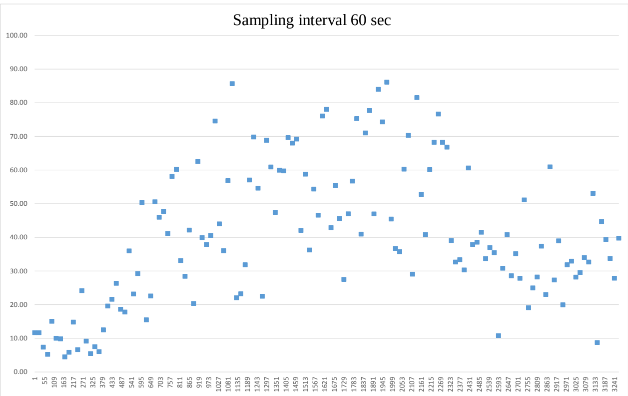


Figure 14. The mean value of standard deviation $\bar{\sigma}$ is 40.3 μg.

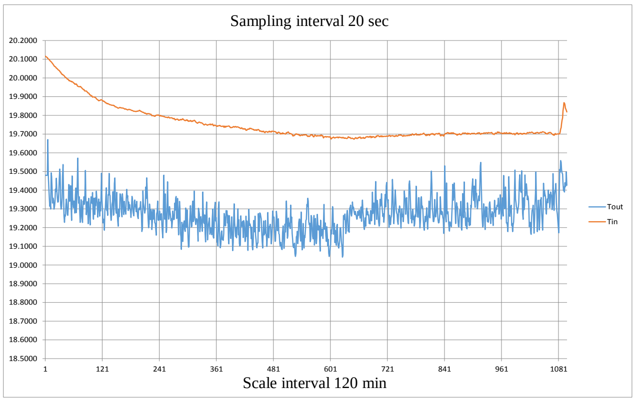


Figure 15. Temperature variation $< 0.05\ ^{o}C/12$ hr (for Tin).

Figure 16. Use carton box as small draft shield.

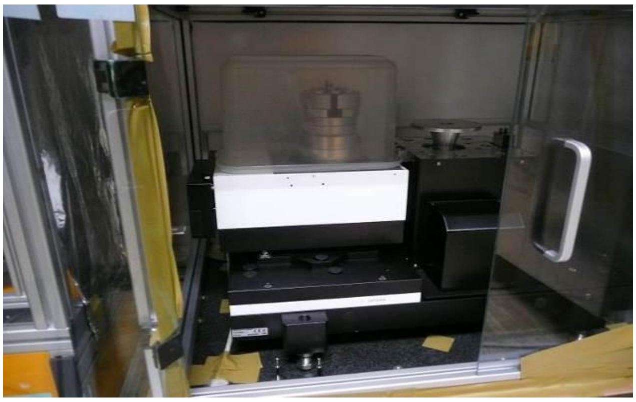


Figure 17. Use plastic box as small draft shield.

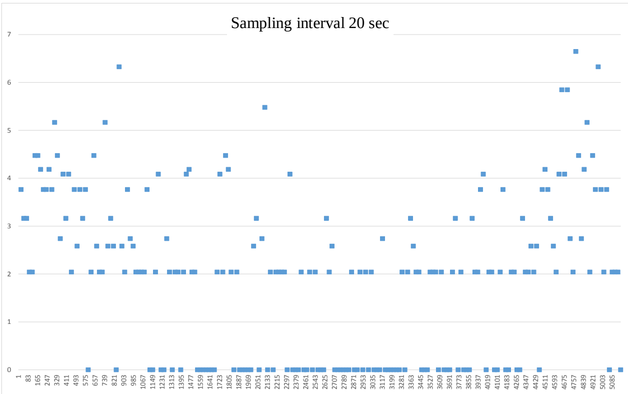


Figure 18. "$\sigma < 7.0$ μg" using carton box as small draft shield.

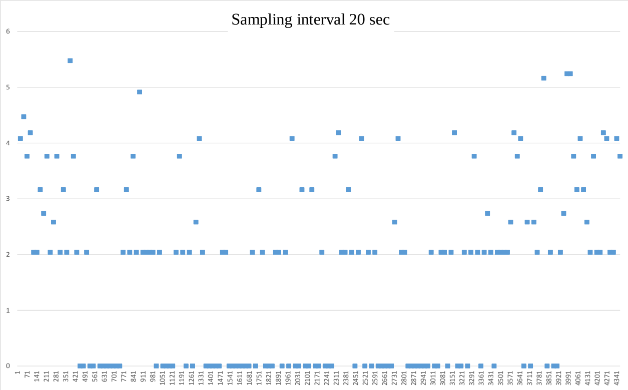
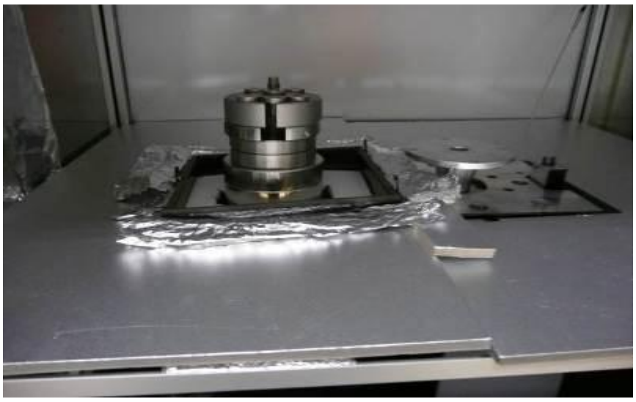
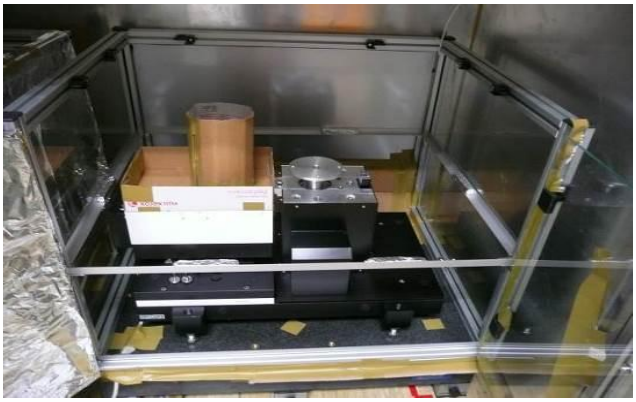


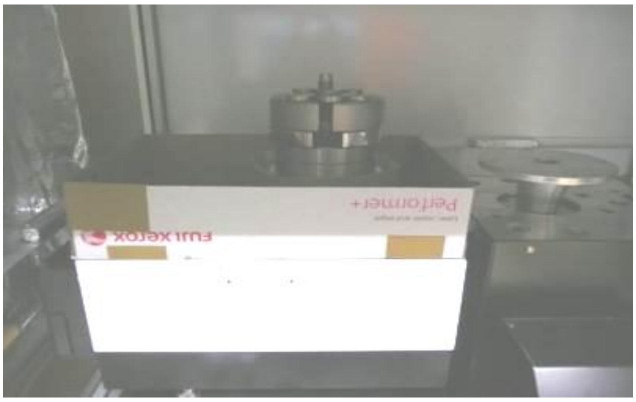
Figure 19. "$\sigma < 6.0$ µg" using plastic box as small draft shield.



(a) $\overline{\sigma} = 32.5$ µg

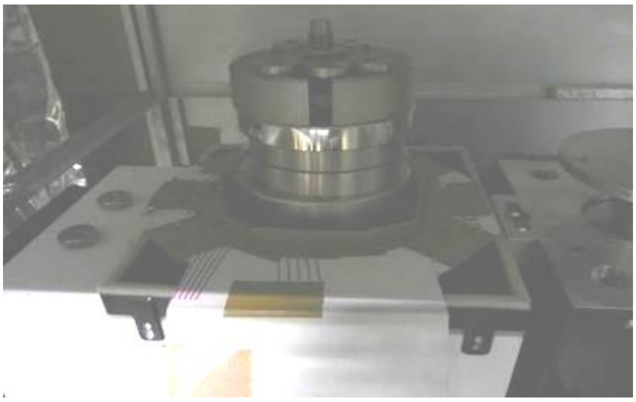


(b) $\sigma < 7.0$ µg



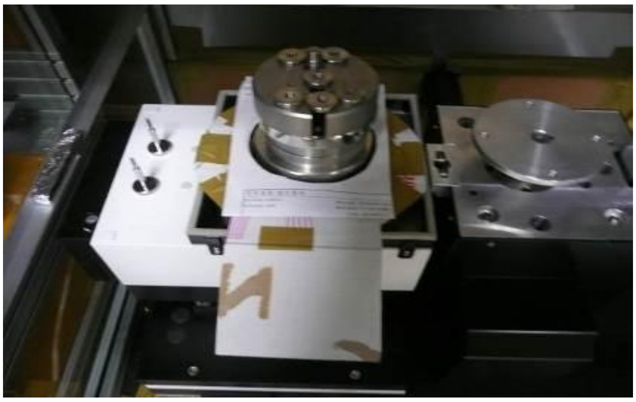
(c) $\sigma < 30.0$ µg

(d) $\sigma < 53.0$ µg



(e) $\sigma < 54.0$ µg

(f) $\sigma < 37.0$ µg



(g) $\sigma < 29.0$ µg

(h) Centermatic pan on the weighing cell

Figure 20. Different types of carton and its results respectively.

It took times to take so many measurements so we have to have the final installation. After the final installation by the technician from Germany, we got poor measurement results but the technician still insisted that it was something about vibration in spite of our finding. After some discussion, the technician agreed with our finding finally and we made new paper draft shield as shown in Fig. 21 to take more measurements. We had 84 measurements for 4-weight comparison and the percentage of the standard deviation obtained from each measurement to meet with the specifications (< 50 µg) is about 90.5 % as shown in Fig. 22. It is acceptable.

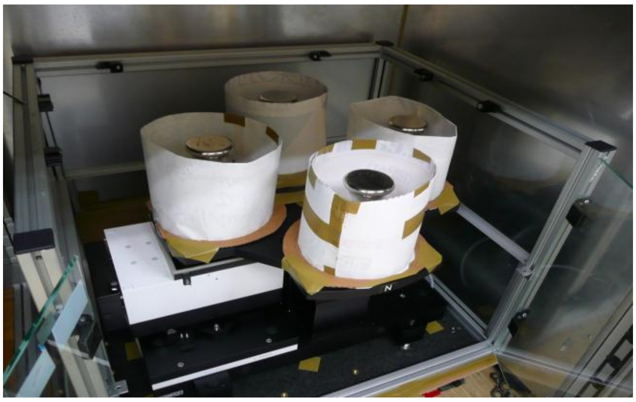


Figure 21. Paper draft shield for weights on load alternator platform.

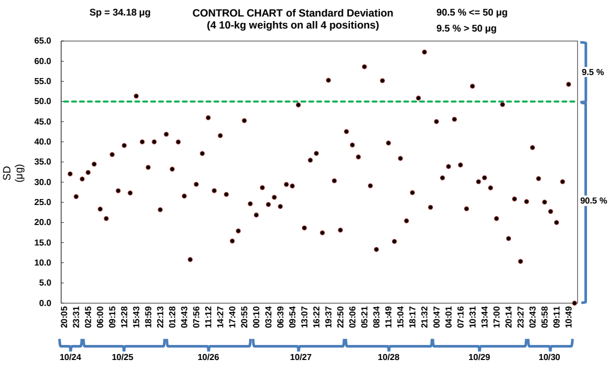


Figure 22. The standard deviation after final installation.

4. DISCUSSION AND CONCLUSION

It is weird for this new comparator to encounter the temperature issue. We doubt there are heat flows upward from the weighing cell. Maybe these come from the electronic components inside the new CCE10000U-L which are different from the old CC10000U-L.

When the technician from Germany agreed with our finding, he gave us a sheet of article specification – "Special aluminium draft shield for weights on load alternator platform for Mass Comparators CC10000U-L / CC20000S-L / CCE10000U-L". The draft shield as shown in Fig. 23 is not regular accessory. It was designed for the similar issue happened in other country's laboratory. This means there indeed are some issues for this comparator.

Figure 23. Special aluminium draft shield VF 1114 for weights on load alternator platform. (These photos refer to the sheet of article specification from Sartorius.)

Because the draft shield mentioned above take lots of money, we built four aluminium draft shields and a bigger draft shield to fit the granite table by ourselves as shown in Fig. 24. In the future, we will perform an experiment to observe the temperature gradient on the top of weighing cell.

Figure 24. Four aluminium draft shields and a bigger draft shield.

ACKNOWLEDGMENTS

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[1] "Weights of classes E_1, E_2, F_1, F_2, M_1, M_{1-2}, M_2, M_{2-3} and M_3, Part 1: Metrological and technical requirements", *OIML R111-1*, OIML, pp. 65 & 76, 2004.

[2] Feng-yu Yang and Sheau-shi Pan, "A simple way to have small temperature variation controlled in mass measurement", *APMF 2011*, pp. 49-55, Sept. 2011.