AN ECONOMIC WAY TO HAVE SMALL TEMPERATURE VARIATION CONTROLLED IN MASS MEASUREMENT

Feng-yu Yang[1], Sheau-shi Pan[2] and Sheng-Jui Chen[3]

[1,2,3] Center for Measurement Standards (CMS), Industrial Technology Research Institute (ITRI),
Hsinchu, Taiwan, R.O.C.,
BoyscoutYang@itri.org.tw[1], Sheau.shi.Pan@itri.org.tw[2], SJ.Chen@itri.org.tw[3]

Abstract: In APMF2011, we introduced a simple way by building a two-layer insulation chamber with two mass comparators inside to have small temperature variation in our laboratory [1]. In this paper, we will introduce a economic method by adding a simple active control unit on the aluminum chamber to control the temperature inside the chamber at (20 ± 0.1) ℃ nearly, while the room temperature of the air-conditioning laboratory is active controlled at (21.5 ± 1.5) ℃. Using this method, the transient phenomenon of temperature was observed.

Keywords: Temperature variation / fluctuation, passive / active control, two-layer insulation chamber.

1. INTRODUCTION

It is necessary to obtain a good measurement with good laboratory facility and environment. The instability of the air currents, the temperature gradient, magnetic or electrostatic fields, and so on will be the sources of uncertainty. The environmental thermal equilibrium is the key to mass calibration. This is why the weights must be placed in a stable environment more than 24 hours to reach the thermal equilibrium before measurement. The lack of a thermal equilibrium will produce thermal convection to affect the balance readings. From the NIST study [2] showed that 3 mg of errors were obtained for a 1-kg load when the temperature gradient was 2 ℃.

Besides, when an object is weighed while immersed in a fluid environment such as air, that object is subject to a buoyancy effect from the surroundings. From Archimedes's principle, it explains the effect by the environment when it is weighed. For a very high accuracy weighing, these uncertainties must be evaluated. The effect will also be introduced in weighing at different times when the air density conditions change. Air density is usually measured indirectly. While it is calculated using the measurements of air temperature, atmospheric pressure and dew point temperature or relative humidity. Therefore, the temperature is also an important key factor when determining the air density for buoyancy corrections made when comparing weights of different volume in air.

2. PRINCIPLES

2.1 BUOYANCY CORRECTION

As recommended in the recommendation R111 (2004) from the International Organization for Legal Metrology (OIML) [3] for mass comparison, the conventional mass difference, Δm_c, between the test weight and the reference weight of a cycle, i, is :

$$\Delta m_c = m_{ct} - m_{cr} \tag{1}$$

$$\Delta m_{ci} = \Delta I_i + m_{cr} C_i \tag{2}$$

Where the air buoyancy correction is :

$$C_i = (\rho_{ai} - \rho_0) \times \left(\frac{1}{\rho_t} - \frac{1}{\rho_r} \right) \tag{3}$$

2.2 AIR DENSITY

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

$$\rho_a = \frac{pM_a}{ZRT} \left[1 - \chi_v \left(1 - \frac{M_v}{M_a} \right) \right] \tag{4}$$

Where: p = pressure; M_a = molar mass of dry air; Z = compressibility; R = molar gas constant; T = thermodynamic temperature using ITS-90; x_v = mole fraction of water vapor; and M_v = molar mass of water.

The most accurate formula of air density is the CIPM formula (1981/91). But an approximate formula may also be used in the annex E of the OIML R111 (2004):

$$\rho_a = \frac{0.34848 p - 0.009 (hr) \times \exp(0.061t)}{273.15 + t} \tag{5}$$

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, expressed as a percentage; and the temperature, t, in ℃.

3. EXPERIMENT

3.1 CHAMBER DESIGN

As the dimension of our laboratory is about 814 cm x 663 cm x 305 cm by temperature controlled actively within the range of (21 ± 1.5) ℃, it is necessary to build an independent chamber to isolate the mass comparators from the laboratory environment. The chamber shown as in figure 1 is made mostly from aluminum and polystyrene. Each wall, door and cover of the chamber consists of an aluminum-forming frame, two aluminum plates and two polystyrene plates wrapped with aluminum sheets. The polystyrene plate wrapped with aluminum sheets are mounted to each side of the aluminum-forming frame and covered by aluminum plate bolted on the frame as shown in figure 2.

Figure 1: Exterior of the chamber

Figure 2: Interior of the chamber

The gap inside the frame between two polystyrene plates is used as the air passageway to provide encircling cooling to make the chamber passive-temperature-controlled. To make an unbroken circumfluence, equidistant holes are bored in the vertical direction of the adjacency between walls and doors as shown in figure 3. The active control was achieved by using the water under certain temperature. We use the hoses to circle around the chamber of the mass comparator and the flow of water inside the hose passage with constant temperature by a water bath controller. Because of the capacity of the water bath controller, temperature control of the environment can reach a stabilizing effect.

Figure 3: Air passageway holes on the side of the door

3.2 EXPERIMENT EQUIPMENT

Two temperature probes, two barometers and one hydrometer are used as shown in figure 4 to observe the ambient condition between the inside and outside of the chamber.

Figure 4: Equipment for measuring the ambient condition

3.3 EXPERIMENT DESIGN

To observe the difference of the ambient condition between the inside and outside of the chamber, firstly we collect the measurement data from the thermometer, barometers and hydrometer day and night without any mass comparison performing on the mass comparators inside the chamber. And then, the mass comparisons on Sartorius CC10000U-L are performed to find out if there are any influences when performing mass comparison. The phenomenon of heat in temperature's transient was observed.

4. RESULT AND DISCUSSION

The results for measuring the ambient condition were shown in table 1 and table 2. The temperature was raised when the comparator start the measurement. The chart of temperature was shown in figure 5. The measurement starts from the left side of the chart and stops at the red dashed line. The temperature curve of the left part of the red dashed line was expressed in figure 6 and the temperature curve of the right part of the red dashed line was expressed in figure 7. These data were curve-fitting by exponential decay formula. The formulas obtained were shown in equation (6) and equation (7) respectively.

Table 1: Results for measuring the ambient condition while the comparisons performing

	max	min	mean	variation
P	1000.66	993.69	997.22	6.97
H_t	20.1	18.4	20.0	1.7
H_h	63.5	35.7	50.6	27.8
T_{in}	20.373739	20.088150	20.315031	0.285589
T_{out}	20.136600	19.692070	19.843109	0.444530
ρ_{in}	1.183	1.175	1.179	0.009
ρ_{out}	1.185	1.176	1.181	0.009

Table 2: Results for measuring the ambient condition while the comparisons un-performing

	max	min	mean	variation
P	994.99	992.37	993.39	2.62
H_t	20.2	20.0	20.1	0.2
H_h	53.5	45.7	50.6	7.8
T_{in}	20.384171	20.133410	20.207689	0.250761
T_{out}	20.494450	19.837429	20.027695	0.657021
ρ_{in}	1.177	1.173	1.175	0.003
ρ_{out}	1.178	1.173	1.176	0.005

$$T_{se} = 20.345 \cdot \left(1 - e^{-(t+0.00421)/RC_1}\right) \qquad (6)$$

$$T_{se} = 20.067 \cdot \left(1 + e^{-(t+0.00427)/RC_2}\right) \qquad (7)$$

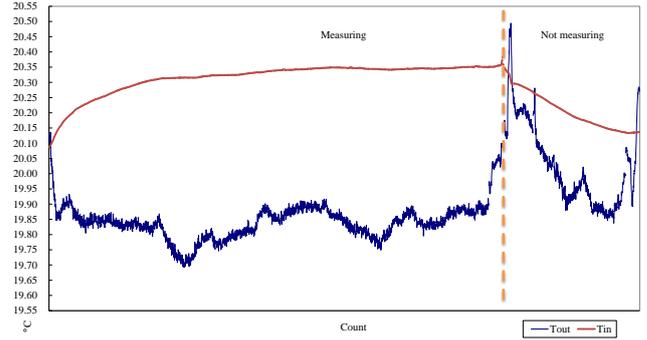Where $RC_1 = 520$ minuites, $RC_2 = 758$ minuites.

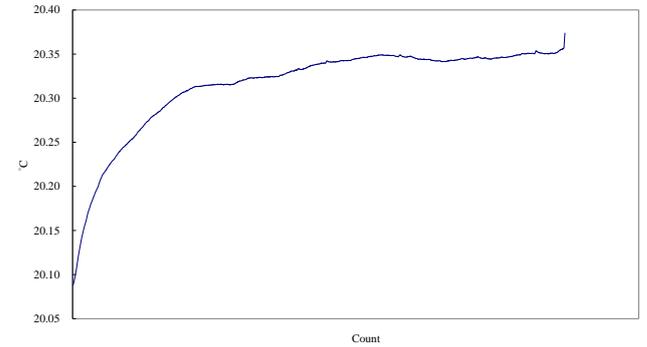**Figure 5: The temperatures inside and outside of the chamber**

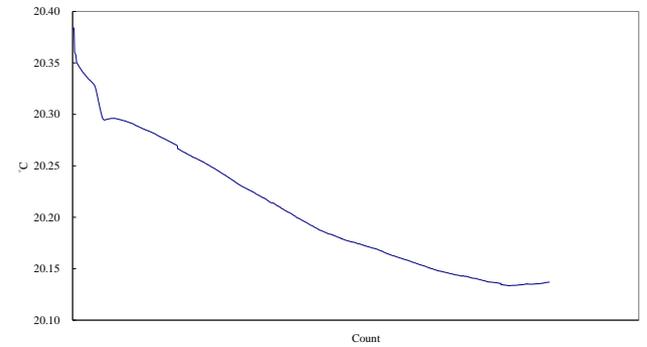**Figure 6: The temperatures while measurement performing**

Figure 7: The temperatures while measurement stoped

When the measurements begin, the new equilibrium state develops. After about eight hours, the new state achieved. It is similar with a capacitor charge procedure and the "RC" constant is nearly 520 minutes. While the measurements stop, similar with the discharge of a capacitor, the "RC" constant 758 minutes were obtained to return to the original equilibrium temperature.

The charts curve-fitting by exponential decay formula were shown in figure 8 and figure 9 respectively.
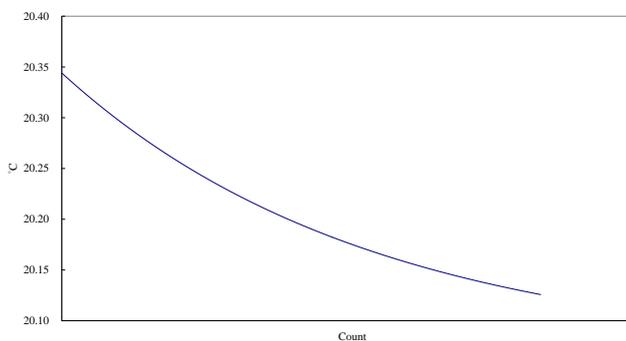
5. REFERENCES

[1] Feng-yu Yang and Sheau-shi Pan, "A simple way to have small temperature variation controlled in mass measurement", APMF2011, pp. 49-55, Sept. 2011.
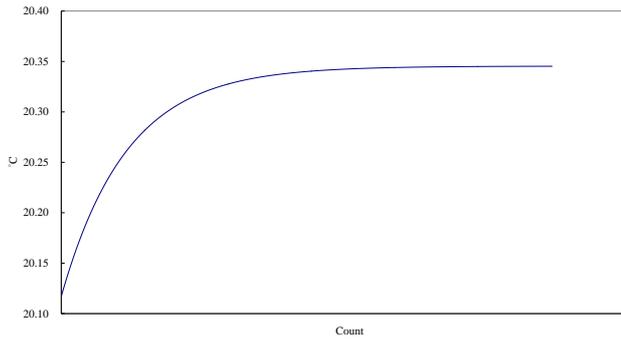
$$T_{se} = 20.345 \cdot \left(1 - e^{-(t+0.0042\,i)/RC_1}\right)$$

Figure 8: Curve-fitting while measurement performing

$$T_{se} = 20.067 \cdot \left(1 + e^{-(t+0.00427)/RC_2}\right)$$

Figure 9: Curve-fitting while measurement stoped

[2] "Good Measurement Practice: Understanding Factors Affecting Weighing Operations", GMP 10, NIST, Mar, 2003, pp. 1.

[3] "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 R 111-1 Edition 2004 (E), International Organisation of Legal Metrology (OIML) International Recommendation, 2004.