AIR PRESSURE CONTROLLED MASS MEASUREMENT SYSTEM

RUILIN ZHONG, JIAN WANG, CHANGQING CAI, HONG YAO, JIN'AN DING,
YUE ZHANG, and XIAOLEI WANG

*National Institute of Metrology, No.18, Bei San Huan Dong Lu, Chaoyang Dist, Beijing, P. R. China
zhongrl@nim.ac.cn*

Abstract: Mass measurement is influenced by air pressure, temperature, humidity and other facts. In order to reduce the influence, mass laboratory of National Institute of Metrology, China has developed an air pressure controlled mass measurement system. In this system, an automatic mass comparator is installed in an airtight chamber. The Chamber is equipped with a pressure controller and associate valves, thus the air pressure can be changed and stabilized to the pre-set value, the preferred pressure range is from 200 hPa to 1100 hPa. In order to keep the environment inside the chamber stable, the display and control part of the mass comparator are moved outside the chamber, and connected to the mass comparator by feed-throughs. Also a lifting device is designed for this system which can easily lift up the upper part of the chamber, thus weights can be easily put inside the mass comparator. The whole system is put on a marble platform, and the temperature and humidity of the laboratory is very stable. The temperature, humidity, and carbon dioxide content inside the chamber are measured in real time and can be used to get air density. Mass measurement cycle from 1100 hPa to 200 hPa and back to 1100 hPa shows the effective of the system.

Keywords: Air pressure controlled mass measurement system; mass; air density; mass comparator.

1. Introduction

The environment of mass measurement will have a great influence on mass measurement results for weights of high accurate class, thus the environment must be stable. Typically such class weight is calibrated or verified under laboratory environment, and the temperature and humidity are precisely controlled. But usually air pressure of the laboratory is not controlled. Thus the variation of air pressure will have a influence on mass measurement. In order to reduce such influence, NIM has developed an air pressure controlled mass measurement system. In this system, the air pressure is precisely controlled, and the whole system is installed on a marble platform, the temperature and humidity is stabilized by the air conditioner of the mass laboratory, thus the environment of the mass measurement is much more stable.

This is an Open Access article published by World Scientific Publishing Company. It is distributed under the terms of the Creative Commons Attribution 3.0 (CC-BY) License. Further distribution of this work is permitted, provided the original work is properly cited.

2. Configuration of the system

The whole system is shown in figure1. It includes several parts:

- 1) an automatic mass comparator to measure mass value of weights;
- 2) an air-tight chamber which brings stable mass measurement environment for the mass comparator;
- 3) an air density measuring device which includes platinum resistance thermometers, a hygrometer, a CO₂ transducer and associate electronic components, the device can gather temperature, humidity, CO₂ content, and also air pressure, and also calculate the air density using BIPM formula;
- 4) air pressure control part which includes a pressure controller/calibrator, pumps, a gas cylinder, and associate pipelines and valves;
- 5) computers to control the system and gather all measurement data. Typically two computers are used, one is used to control the mass comparator, and record the measure data of mass value, the other is use to receive the environment parameters, and also get mass value from the previous computer and finish air buoyancy correction.

Figure 1 Photograph of the system.

The type of mass comparator is AX1006, the readability of the comparator is 1 g, and the repeatability is 2 μ g. It has 4 positions on turntable. The electronic measure range is 11 g. According to the dimension of the mass comparator, an air tight chamber is designed to contain the mass comparator. The chamber is divided into two parts-upper part and lower part. The mass comparator is installed on a plate in the lower part. The chamber is made of stainless steel. The upper part need to be open when weights need to be put in the mass comparator, but the upper part is almost 35 kg and is not easy to open by hand, a special designed lifting system is used to open and close the upper part. Figure 2 shows the lifting system, it includes a serve-motor, a reducer, a ball screw, a guide rail and two arms. It can be easily controlled by a pulse generator. In order to keep the environment

stable inside the chamber, the control and display part of the comparator AX1006 is moved outside the chamber and connected to the measuring part by feedthroughs.

Eight PT100 platinum resistance sensors are used to measure the temperature inside the chamber, among them two sensors are used to measure the weighing position. Eight sensors are connected to ASL F200, it shows the temperature indication of each sensor. The readability is 1 mK, and the uncertainty is 2.5 mK. A hygrometer HMT100 is used to measure the humidity inside the chamber, the readability is 0.1 %RH and the uncertainty is 0.2 %RH. The whole system is installed in the mass laboratory of Changping campus. And the temperature and the humidity of the mass laboratory is precisely controlled, so the temperature and the humidity of the chamber is quite stable.

Figure 2 Lifting device of the system.

A pressure controller/calibrator PPC4 is used to control and measure the air pressure inside the chamber. The designed air pressure range is from 200 hPa to 1100 hPa. In order to increase the air pressure larger than 1 standard atmosphere pressure, compressed air inside a gas cylinder is used as positive air resource. Mechanical pump is used to reduce the air pressure inside the chamber. In order to reduce the vibration of the pump, the pump is installed far from the chamber and on a different base below the marble platform. The gas cylinder and the pump are both connected and controlled by the pressure controller/calibrator.

3. Experiment Results

3.1. Stability of the air pressure

In order to prove the stability of the air pressure in the air-tight chamber, a test cycle was performed. The chamber was closed, the test was began at air pressure 1100 hPa, for each time the air pressure decrease 100 hPa until it reach 200 hPa, the air pressure increase 100 hPa each time until it reach 1100 hPa. In each air pressure, the hydraulic pressure controller/calibrator PPC4 control and measure the air pressure for almost two days. Figure 3(a), (b), (c) shows the variation of the air pressure at 1100 hPa, 600 hPa, 200 hPa, the maximum variation at 1100 hPa, 600 hPa and 200 hPa were 0.020 hPa, 0.021 hPa and

0.020 hPa. In contrast, Fig. 3(d) shows the variation of the air pressure at normal atmosphere condition for about 7 hours. The maximum variation was 1.945 hPa.

Figure 3 Variation of air pressure.

Table 1 shows the maximum variation at each air pressure, it shows that the maximum variation was 0.032 hPa at 800 hPa. From the figure and the table, the air pressure is much more stable in the air-tight chamber with the air pressure control part working.

Table 1 Maximum variation of air pressure at each air pressure.

Air pressure (hPa)	Maximum variation (hPa)	Air pressure (hPa)	Maximum variation (hPa)
1100	0.020	300	0.019
1000	0.021	400	0.021
900	0.029	500	0.018
800	0.018	600	0.022
700	0.020	700	0.019
600	0.021	800	0.032
500	0.019	900	0.018
400	0.022	1000	0.031
300	0.020	1100	0.030
200	0.020		

3.2. Mass measurement at each air pressure

Mass measurement was taken at each air pressure. The mass standard of 1 kg is put on position 1 of the turntable, three test weights of 1 kg were put on the other three positions. At each air pressure, weights on position 2, 3, 4 were compared the mass standard separately. For each weight, the cycle ABA was performed 10 times. The standard deviation was calculated as follows:

$$\Delta I = I_t - \frac{I_{r1} + I_{r2}}{2} \tag{1}$$

$$\Delta \bar{I} = \frac{1}{n} \sum_{i=1}^n \Delta I_i \tag{2}$$

$$s = \sqrt{\frac{\sum_{i=1}^n (\Delta I_i - \Delta \bar{I})^2}{(n-1)}}. \tag{3}$$

Here the subscripts “r” and “t” denote the standard weight and test weight respectively. ΔI_i is the indication difference from measurement sequence i , $\Delta \bar{I}$ denote the average value of ΔI_i , s denote the standard deviation of ΔI_i . Table 2 lists the test result. In the Table 2, P2 Vs P1 means the weight on positing 2 compared with the standard weight on position 1, and P3 Vs P1, P4 Vs P1 are the same meaning.

Table 2 Maximum variation of air pressure at each air pressure.

	Air pressure (hPa)	200	300	400	500	600	700	800	900	1000	1100
P2 Vs P1	$s\ (\mu\text{g})$	1.1	0.8	0.6	1.3	0.9	1.0	1.3	1.3	1.0	0.8
	Average standard deviation	0.3	0.3	0.2	0.4	0.3	0.3	0.4	0.4	0.3	0.3
P3 Vs P1	$s\ (\mu\text{g})$	1.1	0.7	1.3	1.1	1.4	1.1	1.0	1.4	1.0	1.1
	Average standard deviation	0.3	0.2	0.4	0.3	0.4	0.3	0.3	0.4	0.3	0.3
P4 Vs P1	$s\ (\mu\text{g})$	1.1	1.2	1.0	1.1	1.0	1.1	0.6	1.3	0.8	1.3
	Average standard deviation	0.3	0.4	0.3	0.3	0.3	0.3	0.2	0.4	0.3	0.4

From the table, the average standard deviation can reach 0.4 μg for all positions, that means the system is quite stable.

4. Conclusion

In order to bring stable air pressure for mass measurement, and perform mass measurement under desired air pressure, air pressure controlled mass measurement system was constructed. The air pressure range is from 200 hPa to 1100 hPa. A test cycle from 1100 hPa to 200 hPa, and back to 1100 hPa was performed to prove the effective of the system. The variation of air pressure at each desire air pressure was quite stable, the maximum variation was 0.032 hPa. At each air pressure, mass measurement was also performed, and the average standard deviation can reach 0.4 μ g. Since the air density varies with the air pressure, the system can be further used to measure the volume of weights.

Acknowledgments

Authors would like to thank the committee of APMF 2013.

References

1. *OIML R111* Weights of classes E₁, E₂, F₁, F₂, M₁, M₁₋₂, M₂, M₂₋₃ and M₃ Part 1: Metrological and technical requirements (2004).
2. M. Ueki, S. Mizushima, Y. Nezu. A Mass Comparator Installed in an Air-tight Chamber. *In proc. XVI IMEKO World Congress*, (Austria, Vienna, 2000). Vol. III, pp. 281-286.