

## AN AIR DENSITY MEASUREMENT SYSTEM FOR MEASURING WEIGHTS

WANG Xiao-lei /Presenter, ZHANG Yue, CAI Chang-qing, WANG Jian, ZHONG Rui-lin, YAO Hong,  
 DING Jing-an

National Institute of Metrology, Beijing 100013, China, No.18, Bei San Huan Dong Lu, Chaoyang  
 Dist, Beijing, P.R.China

**Abstract:** A measurement system of air density that for high accuracy measurement of measuring weights is developed base on the CIPM-2007 equation. Measurements of temperature, humidity, CO<sub>2</sub>, pressure and air density are performed by this system automatically. The experimental results prove that measurement accuracy of measuring weights can be improved by using this system process air buoyancy correction.

**Keywords:** Air density; Weight; Air buoyancy correction; CIPM-2007 equation.

### 1. INTRODUCTION

Measurement of measuring weights will be influenced by air buoyancy when measuring in air. This kind of influence is very important for high accuracy measurement of measuring weights and air buoyancy correction need be processed to reduce it. The major component of air buoyancy correction is the determination of the density of moist air. The method that most of measurement inspection institutions and laboratories used to determine air density is base on CIPM-81/91 equation presented in [1-2]. CIPM-2007 equation is the newest equation that was endorsed by the International Committee for Weights and Measures (CIPM). Compare with CIPM-81/91 equation, the newest equation has detailed uncertainty statements, latest references data and the difference between the equation and experiment has been removed. Thus, we develop a measurement system that integrated measurement of temperature, humidity, pressure and CO<sub>2</sub> to determine air density auto automatically according CIPM-2007 equation. It can provide real-time air buoyancy correction for high accuracy measurement of measuring weights. In this paper, the designing of equipment and support software is introduced.

### 2. AIR DENSITY MEASUREMENT PRINCIPLE

CIPM-2007 equation has the same form as CIPM-81/91 equation. The density of moist air is evaluated using an equation of state

$$\rho_a = \frac{p \times M_a}{ZRT} \left[ 1 - x_v \left( 1 - \frac{M_v}{M_a} \right) \right] \quad (1)$$

where the quantities and units are  $P$  /Pa: pressure,  $t$ /°C: air temperature,  $T$  /K: thermodynamic temperature = 273.15 +  $t$ /°C,  $x_v$ : mole fraction of water vapour, Ma/(g mol<sup>-1</sup>): molar mass of dry air,  $M_v$ /(g mol<sup>-1</sup>): molar mass of water,  $Z$ : compressibility factor,  $R$ /(J mol<sup>-1</sup> K<sup>-1</sup>): molar gas constant.

For the CIPM-2007 equation, we take the new values of  $R$  and  $x_{Ar}$  as<sup>[3-5]</sup>:

$$R/(J \text{ mol}^{-1} \text{ K}^{-1}) = 8.31447215 \quad (2)$$

$$x_{Ar} = 0.0093323 \text{ mmolmol}^{-1} \quad (3)$$

Its similar form is written as equation (4):

$$\rho_a = [3.483740 + 1.4446 \cdot (x_{CO_2} - 0.0004)] \cdot \frac{p}{ZT} (1 - 0.3780x_v) \quad (4)$$

And CIPM-81/91 equation can be written as equation (5):

$$\rho_a = [3.48349 + 1.4446 \cdot (x_{CO_2} - 0.0004)] \cdot \frac{p}{ZT} (1 - 0.3780x_v) \quad (5)$$

Compare with equation (4) with (5), only the first term is different. As the consequence, this difference leads to a relative increase of  $72 \times 10^{-6}$  in the calculation of  $\rho_a$ . Therefore, the buoyancy correction for 1 kg of stainless steel with respect to a national prototype will increase by about:

$$(125 - 46.4) \text{ cm}^3 \times 0.0012 \text{ gcm}^{-3} \times 72 \cdot 10^{-6} = 6.8 \mu\text{g}$$

This increase can't be neglected for high accuracy measurement of measuring weights. Thus we design measurement system of air density to measure four environment parameters, temperature, humidity, pressure and CO<sub>2</sub>, and then calculate  $\rho_a$  base on CIPM-2007 equation for the buoyancy correction.

### 3. HARDWARE AND SOFTWARE DESIGNING

Figure 1 shows the structure of the hardware module. Four corresponding sensors take on measurement of environment parameters (temperature, humidity, pressure and CO<sub>2</sub>). Communication module is used to control communication between sensors and MCU or MCU and computer. MCU handles collection of measurement signals

and calculation of air density. All of these devices are installed in a box which has small size for carrying and using conveniently. More functions can be used through connect with computer. An application software of PC is developed to extends the capabilities. It provides higher accuracy of floating-point calculation, creation of data chart and measurement data storage service automatically. Figure 2 shows the air density measurement system.

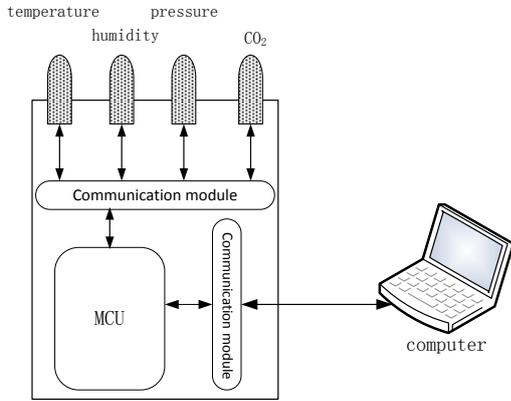


Figure 1. Hardware module structure



Figure 2. Air density measurement system

#### 4. EXPERIEMENTS RESULT ANSLYSIS

An experiment using this system has been made in an air-conditioned room from 2011/03/12 00:00 to 2011/03/23 00:00. The experimental results were shown in Figure 3 to Figure 7:

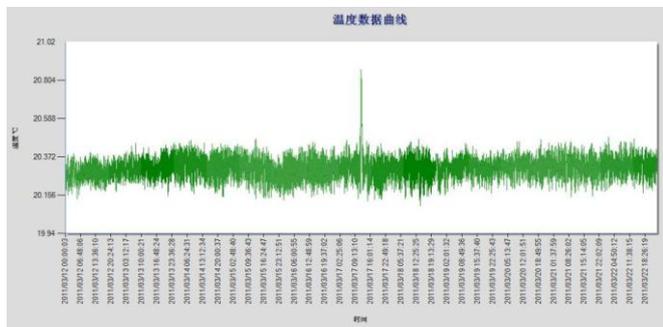


Figure 3. Temperature data chart

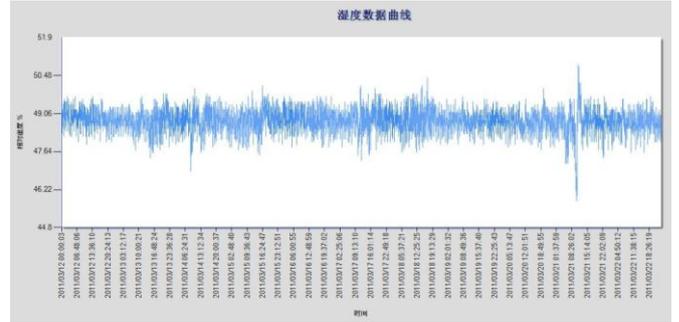


Figure 4. Humidity data chart

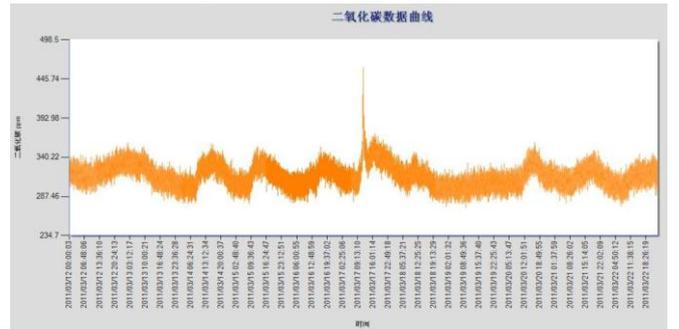


Figure 5. CO<sub>2</sub> data chart

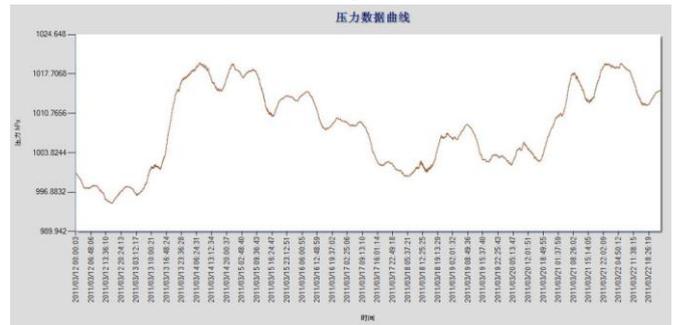


Figure 6. Pressure data chart

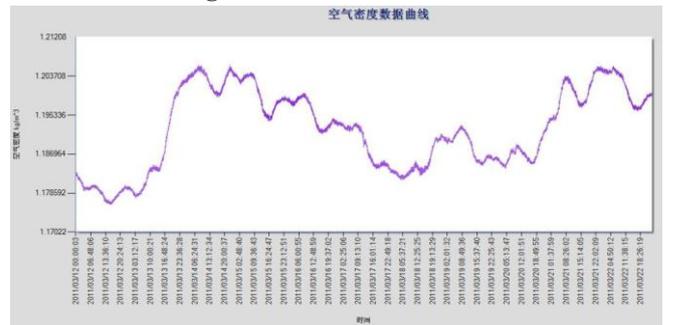


Figure 7. Air density data chart

From experimental results we can know that: In our air-conditioned laboratory, temperature and humidity are controlled well. So the change ranges of them are small (20.10°C~20.87°C and 45.9%~50.9%). The change of CO<sub>2</sub> is also small if there is no influence of human ( $272.4 \times 10^{-6} \sim 350.8 \times 10^{-6}$ ). There are obvious changes on temperature and CO<sub>2</sub> from 2011/03/17 11:00 to 12:00, the reason is that there are workers in lab at that time. But the influences of temperature, humidity and CO<sub>2</sub> can be neglected compare with pressures. Pressure and air density have the same change curve at experimental period. The primary influence factor on air density is pressure. This influence can't be

ignored for high accuracy measurement of measuring weights. For example, the change of air density caused by pressure is  $0.0299 \text{ mg/cm}^3$  from 2011/03/12 to 2011/03/14, the buoyancy correction for 1 kg of stainless steel with respect to a national prototype will be changed by about:

$$(125 - 46.4) \text{ cm}^3 \times 0.0299 \text{ mg/cm}^3 = 2.35014 \text{ mg} .$$

For class  $E_1$  weights, this change is greater than maximum permissible errors ( $\pm 0.5 \text{ mg}$ ).

Thus, for a long time high accuracy measurement of measuring weights, this system can provide real-time air density data to processing air buoyancy correction. On the other hand, this system can also provide monitoring on environment parameter of lab.

## 5. CONCLUSION

Based on CIPM-2007 equation, a measurement system of air density is introduced. Experimental results prove that, this measurement system can provide a great help for our high accuracy measurement of measuring weights.

## 6. REFERENCES

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