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EXPERIMENTAL RESEARCH ON MASS DETERMINATION OF NON-METAL WEIGHTS

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Abstract:
With the revision of the definition of the kilogram, more and more weights made of non-metal material, such as silicon spheres and PM 2.5 film, need to be determined with high accuracy. As conventional mass is commonly used in mass metrology, this paper discusses the mass-measuring process for silicon and PM 2.5 film. Electrostatic eliminators are used to eliminate the electrostatic effects of non-metal material to improve the stability of mass measurement. Due to the big difference of weights' densities, the air buoyancy correction and its uncertainty evaluation are also conducted.

Keywords: mass determination; non-metal weights; uncertainty evaluation; silicon sphere

1. INTRODUCTION

There are more and more demands in mass metrology for mass measurement of non-metal material [1-4]. As conventional mass is commonly used in mass dissemination of mass metrology, according to OIML R111 [5], altitude and corresponding changes in air density can affect the measurement process when using the conventional mass of weights. The mass of test weight, m_t, can be expressed by equation (1):

$$m_\mathrm{t} = m_\mathrm{r} + (V_\mathrm{t} - V_\mathrm{r}) \times \rho_\mathrm{a} + \Delta I \times m_\mathrm{cs} / \Delta I_\mathrm{s} \,. \quad (1)$$

in which m_t and m_r are the mass of test weight and reference weight; V_t and V_r are the volume of test weight and reference weight; ρ_a is density of moist air; ΔI is indication difference of the balance; m_cs is the conventional mass of the sensitivity weight; and ΔI_s is the indication difference of the balance when the sensitivity weight is put on the weighing pan.

Thus electrostatic effects and air buoyancy correction become the two most important aspects for the determination of mass object of non-metal material. To evaluate electrostatic effects and air buoyancy correction to the stability of weighing process of non-metal weights, a silicon sphere of 1 kg and PM 2.5 film are used to experimentally evaluate the standard deviation of weighing process. The PM 2.5 film is tested for its common use and need to be weighed with high accuracy in determination of air pollution. The air buoyancy correction is also investigated and the uncertainty evaluation is also conducted.

2. DESCRIPTION OF THE WORK

M-one mass comparator is used for mass determination below 1 kg. With 6 weighing positions, the electronic weighing range is (0 ~ 1.5) g and readability is 0.1 µg.

According to air density calculation formula of CIPM 2007, the density of moist air ρ_a can be expressed as:

$$\rho_\mathrm{a} = (pM_\mathrm{a}/ZRT) \times [1 - x_\mathrm{v}(1 - M_\mathrm{v}/M_\mathrm{a})] \,. \quad (2)$$

where: p is the air pressure; M_a is the molar mass of dry air; Z is the compressibility; R is the molar gas constant; T is the dynamic temperature using ITS-90; x_v is the mole fraction of water vapour; and M_v is the molar mass of water.

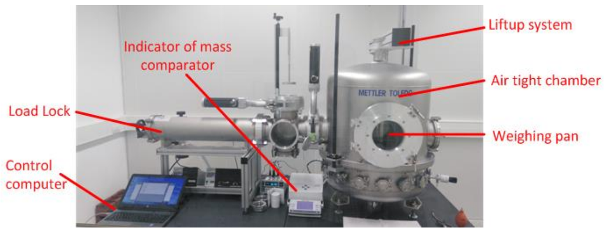

Figure 1: Picture of new M-one prototype mass standard comparator

The air density measuring system, developed by NIM, China, can measure the pressure, temperature, relative humidity, and carbon dioxide content, as shown in Figure 2. The mass comparator and PM 2.5 film are shown in Figure 3.

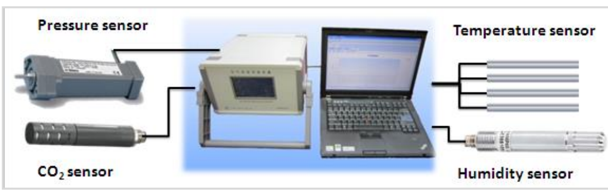

Figure 2: Pictures of air density measurement system

Table 1: Uncertainty budget for the density of moist air

Source X_i	**Standard uncertainty value** $u(X_i)$	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(\rho_a)$
Pressure, p	1.2 Pa	1×10^{-5} kg·m^{-3}·Pa^{-1}	1.2×10^{-5} kg·m^{-3}
Temperature, t	0.007 K	-4×10^{-3} kg·m^{-3}·K^{-1}	2.8×10^{-5} kg·m^{-3}
Relative humidity, hr	0.008	-9×10^{-3} kg·m^{-3}	7.2×10^{-5} kg·m^{-3}
Carbon dioxide content, x_{CO_2}	0.000 003 4	0.4 kg·m^{-3}	1.3×10^{-6} kg·m^{-3}
CIPM 2007 formula, u_F			22×10^{-6} kg·m^{-3}
Combined uncertainty of air density $u(\rho_a)$			8.3×10^{-5} kg·m^{-3}
$U(\rho_a)$ ($k = 2$)			1.7×10^{-4} kg·m^{-3}

Figure 3: Pictures of mass comparator, stainless steel standard weights and PM 2.5 polypropylene film

3. RESULTS AND DISCUSSION

According to equation (2), the uncertainty of air density, u_{ρ_a}, can be expressed as:

$$u_{\rho_a} = \sqrt{\begin{aligned} & u_F^2 + \left(\frac{\partial \rho_a}{\partial p} u_p\right)^2 + \left(\frac{\partial \rho_a}{\partial t} u_t\right)^2 \\ & + \left(\frac{\partial \rho_a}{\partial hr} u_{hr}\right)^2 + \left(\frac{\partial \rho_a}{\partial x_{CO_2}} u_{x_{CO_2}}\right)^2 \end{aligned}} \quad (3)$$

in which:

$$u_F = 22 \times 10^{-6} \rho_a \, , \qquad \frac{\partial \rho_a}{\partial p} = 10^{-5} \rho_a \ \text{Pa}^{-1}$$

$$\frac{\partial \rho_a}{\partial t} = -4 \times 10^{-3} \rho_a \ \text{K}^{-1}$$

$$\frac{\partial \rho_a}{\partial hr} = -9 \times 10^{-3} \rho_a \, , \qquad \frac{\partial \rho_a}{\partial \, x_{CO_2}} = 0.4 \rho_a$$

The uncertainty budget for the density of moist air is shown in Table 1.

The density of stainless steel weights is around 7950 kg·m^{-3}. The density of PM 2.5 film made of Teflon is 2300 kg·m^{-3}. According to equation (4), for the difference density and volume, the true mass of PM 2.5 film due to air buoyancy correction is around 59 μg, when comparing with stainless steel weights with density around 7950 kg·m^{-3}.

$$m_{ct} = m_{cr} + (V_t - V_r) \times (\rho_a - \rho_0) \pm \Delta I \times \frac{m_{cs}}{\Delta I_{cs}} \quad (4)$$

in which m_{ct} and m_{cr} are the conventional mass values of the test and reference weights respectively, ρ_0 is the reference air density value of 1.2 kg·m^{-3}, and ΔI_{cs} is the change in indication of the balance due to the sensitivity weight.

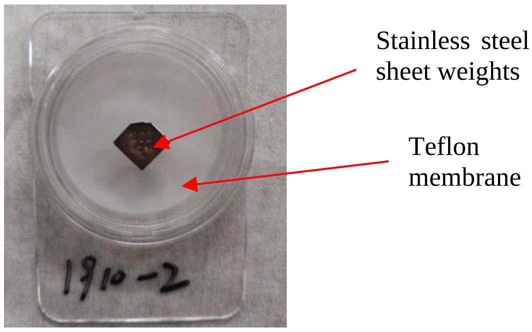

Figure 4: Volume difference of stainless steel weights and Teflon PTFE film (PALL) of 160 mg

When the air density is around 1.1834 kg·m^{-3}, the air buoyancy correction is around 0.8 μg. However, due to the air buoyancy effect, when measuring the mass of the non-metal material such as Teflon film, the mass deviation of 6 μg is observed between the ABBA weighing cycles, which can be seen in Figure 5.

When measuring the mass of silicon sphere using stainless steel weights, same mass deviation is also be observed. For the 1 kg silicon sphere, the density of silicon is (2320 ~ 2340) kg·m^{-3}, the air buoyancy for the true mass is around 370.795 mg. while measuring in air with density of 1.1834 kg·m^{-3}, the air buoyancy correction for the conventional mass can be 5.1 mg, which means that the air density including the air temperature, relative humidity, air pressure and contents of CO_2 need to be determined with high accuracy for the air buoyancy correction.

Table 2: Uncertainty budget for PM 2.5 Teflon membrane

Source of uncertainty	Standard uncertainty	Sensitivity coefficient	Uncertainty contribution / mg
Standard uncertainty of average ($\bar{s}$)	0.001 mg	1	0.001
Standard uncertainty of 160 mg standard	0.001 mg	1	0.001
Volume of stainless steel weights	0.000 2 cm^3	1.1834 $mg \cdot cm^{-3}$	0.000 237
Volume of Teflon	0.000 2 cm^3	1.1834 $mg \cdot cm^{-3}$	0.000 237
Air density	0.000 083 $mg \cdot cm^{-3}$	0.0494 cm^3	0.000 004 1
Balance linearity	0.000 000 7 mg	1	0.000 000 7
Combined standard uncertainty			0.001 5
Expanded uncertainty (k = 2)			0.003 0

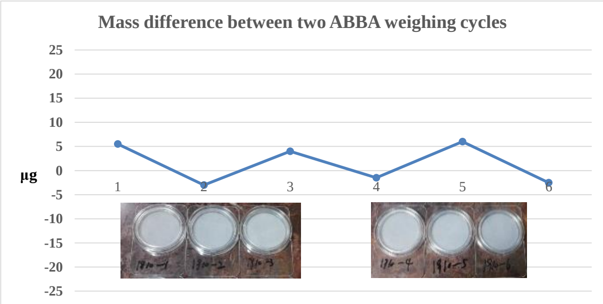

Figure 5: Mass difference of Teflon material between ABBA weighing cycles due to the air buoyancy correction

As shown in Figure 6, the electrostatic eliminator is used to decrease the influence of electrostatic effects. 11 ABBA weighing cycles are carried out between stainless steel weights and silicon sphere.

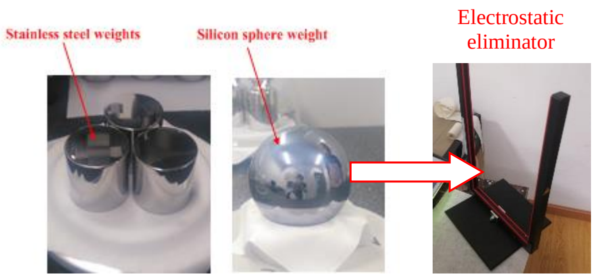

Figure 6: Volume difference of different weights between stainless steel weights and silicon sphere weights

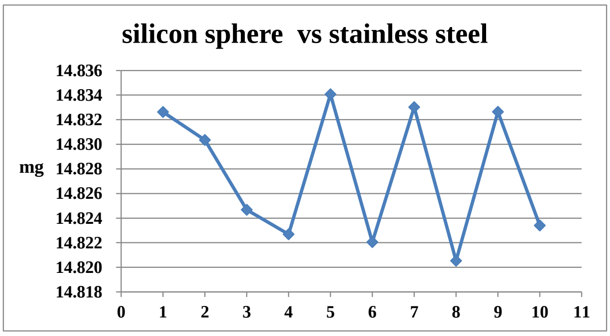

Figure 7: Mass difference of silicon sphere between ABBA weighing cycles due to the air buoyancy correction

As shown in Figure 7, the mass difference between different weight cycles can be up to 13.5 µg which were carried out over a period of 48 hours in the laboratory.

The uncertainty of air buoyancy correction due to volume difference between stainless steel weights and the non-metal material of PM 2.5 Teflon film are listed in Table 2. Due to the high accuracy determination and relative small nominal mass value and volume difference between Teflon membrane and stainless steel weights, the uncertainty contribution of air buoyancy correction is only 0.004 µg. The expanded uncertainty (k = 2) for the conventional mass of PM 2.5 Teflon film is 3 µg.

4. CONCLUSION

For mass determination of non-metal weights, it is important to ensure the limitation of electrostatic effects. For that conventional mass is commonly used in mass metrology, this paper discusses about mass measuring process for silicon and PM 2.5 membrane. Electrostatic eliminators are used to eliminate the electrostatic effects of non-metal material to improve the stability of mass measurement. Due to the big difference of density of weights, the air density including the air temperature, relative humidity, air pressure and contents of CO_2 need to be determined with high accuracy for the air buoyancy correction, the air buoyancy correction and its uncertainty evaluation are also conducted.

5. ACKNOWLEDGEMENT

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