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PT-IR PROTOTYPE KILOGRAM AS A BUOYANCY ARTEFACT FOR IN SITU DIRECT DETERMINATION OF AIR DENSITY

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Abstract: The density of air was directly measured by using a Pt-Ir kilogram and a stainless steel kilogram weight as buoyancy artefacts (BAs) in a comparator equipped with an automatic weight exchanger capable of handling four weights. The other two stainless steel weights loaded on the same weight exchanger were compared with the prototype kilogram by using the air density measured in situ. The in situ BA method determined the mass values with less uncertainty than the CIPM equation method.

Keywords: Air density, Buoyancy artefacts, Prototype kilogram, Mass measurement

1. INTRODUCTION

In the field of mass metrology, many countries use a Pt-Ir kilogram as the national peak reference standard of a traceability hierarchy. The mass standard is then disseminated to the standards of stainless steel. In a mass comparison of two weights of different densities such as of Pt-Ir and stainless steel in air, a major uncertainty arises from the determination of the air density. For instance, an uncertainty level of about 10 μg is expected in the buoyancy correction in a comparison of a Pt-Ir prototype kilogram with stainless steel standards [1].

Commercial balances with an automatic turntable for a mass comparison of a 1 kg capacity and a 1 μg readability level are now readily available. Accordingly, teams of the Consultative Committee for Mass and related quantities (CCM) studied to directly determine air density via buoyancy artefacts (BAs) with aims to achieve an uncertainty level of a few parts in 10^5 for air density measurements [2,3]. In one method, they measured the apparent mass difference of two BAs made of stainless steel or quartz, which are of equal surface area and mass but different volume.

Even after the redefinition of kilogram, the national Pt-Ir prototypes are expected to play one of key roles in the dissemination of the kilogram. About 90 Pt-Ir kilogram prototypes are maintained by national metrology institutes. To date twenty-one institutes maintain more than two Pt-Ir prototypes respectively. The Korea Research Institute of Standards and Science maintains three Pt-Ir kilogram prototypes. One of the prototypes is the peak standard and the others are check standards. The other prototype kilograms could be used for other purpose not simply as a check standard. Here a new method is proposed for the direct measurement of air density. The new method uses a Pt-Ir prototype kilogram and a stainless steel kilogram weight as BAs; they have a about threefold difference in density difference. The in situ weighing and determination of air density can improve the measurement efficiency because the determination of air density via the BAs and mass values of test weights can be done simultaneously.

Through a mass comparator equipped with an automatic weight exchange turntable capable of four weights, the mass values of the other two stainless steel weights as test objects could be determined by comparing them with the prototype kilogram and using the air density measured in situ.

2. IN SITU MEASUREMENT OF AIR DENSITY

The apparent mass difference of the BAs can be expressed as follows:

$$\delta M = (M_A - \rho V_A) - (M_B - \rho \mathrm{V_B}) \tag{1}$$

where M_A and V_A are the mass and volume of the prototype kilogram, respectively, and M_B and V_B are the mass and volume of the stainless steel kilogram, respectively. The air density can then be expressed as follows:

$$\rho = [(M_A - M_B) - \delta M]/[V_A - V_B]\,. \tag{2}$$

The values of M_A, V_A M_B and V_B can be used together with a measurement of the apparent mass difference to determine the air density. Table 1 shows the values of the mass and volume of the BAs (namely, kilogram prototype No. 39 and the stainless steel kilogram). The values of M_A and V_A of the prototype kilogram were determined at the BIPM [4]. While those of the stainless steel kilogram were determined by the comparison with the prototype kilogram by using the air density equation of CIPM [3]. The accuracy and uncertainty of the stainless steel kilogram almost determines the final uncertainty of the measurement. Thus the determination should be based on the long term stability and the least amount of uncertainty. The gravity compensation for the difference in the centre of mass was set at 3 μg for the determination of M_B. The uncertainty of M_B was found to be 20 μg.

Table 1. Mass and volume values of the BAs.

	Pt-Ir kilogram	Stainless steel kilogram
Mass in g	999.999206	1000.011308
Volume in cm3, t in ℃	46.4030[1+(25.863+ 0.00562 t) x10^{-6}t]	M_B/[7.99892- 0.00036714 t]

3. SURFACE AREA EFFECTS

The effects of water vapour adsorption on the surface were considered because of the significant difference in the surface areas of the prototype kilogram and the stainless steel kilogram weights. Kobayashi's empirical formula was used to compensate for the effects of water vapour adsorption on the surface [5]. The formula can be expressed as follows:

$$A_C = (0.0092H - 0.103)(S_k - S_s) - 0.01S_k, \quad (3)$$

where A_c is the correction for compensation in micrograms, S_k is the surface area of the prototype kilogram in square centimetres, S_s is surface area of the stainless steel kilogram in square centimetres, and H is the relative humidity in percentage. Because the mass of the stainless steel kilogram of the BAs was determined for a specific humidity H_r, equation (3) is adjusted as follows:

$$A_C = 0.0092(H - H_r)(S_k - S_s), \quad (4)$$

where, S_k is 71.7 cm^2 and S_s is 156.8 cm^2. The measured values of (H-H_r) were within 1.1 %; this value yields an A_c value of 0.86 μg, which indicates that the effect of water vapour is not significant compared to the effect of air density in this study.

4. EXPERIMENTAL RESULTS

A mass comparator with a readability of 1 μg and an automatic weight exchange device (Mettler-Toledo, HK1000MC) was used in the air. Equation (2) was used for the direct measurements of air density. In the measurement, the apparent mass difference between the prototype kilogram and the stainless steel kilogram on the weight exchange pan was measured. Six measurements were taken in 20 minutes to obtain the air density value, and the corresponding air density was also calculated from the CIPM air density equation [4]. The relative uncertainty of the air density from the direct measurements is in the order of 10^{-4}, which is the same level of uncertainty as the calculated air density. The major contribution comes from the uncertainty of M_B which was determined by using the air density value derived from the CIPM equation. Therefore for long term purpose, the mass could be measured with less uncertainty by a greater number of measurements.

Two methods of determining the air density were compared. For that purpose, the air densities from the CIPM equation were determined by measuring temperature (Hewlett-Packard, 2804A), relative humidity (Hygrodynamics, 15-3080), atmospheric pressure (Tokyo Kokukeiki, DG-430K), and CO_2 concentration (Horiba, PIR-2000). The instrument uncertainties of 95.5 % confidence level were 2 mK, 0.5 %, 0.03 mmHg and 2 ppm, respectively. Thus the relative uncertainty of the air densities resulting from the CIPM equation was 8×10^{-5}.

The differences, δρ, between the directly measurement, ρ_{BA} and the calculated air density, ρ_{EQ}, are plotted in Fig. 1.

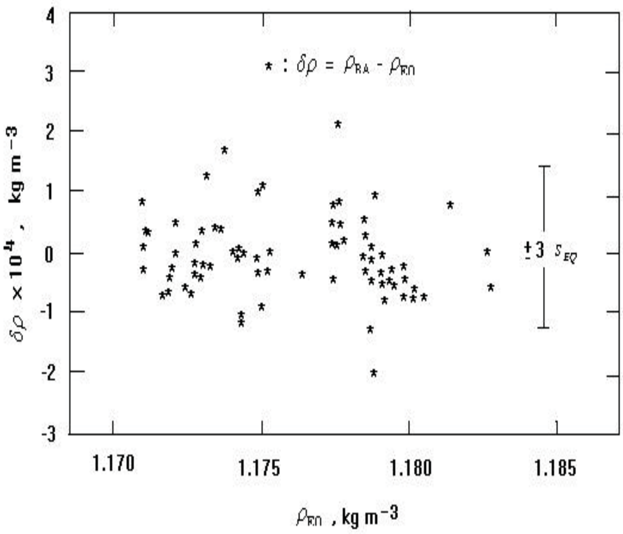

Fig. 1 Comparison of air density values via BAs with those from the CIPM equation.

Pairs of mass values of the two 1 kg stainless steel weights, which were used as test objects, were determined by comparing the weights with the prototype kilogram. The air density values obtained from the direct measurement and from the CIPM equation were simultaneously obtained for the respective buoyancy compensation. The prototype kilogram and the stainless steel kilogram weight, which were used as BAs, were placed side by side on the pan. Two other 1 kg weights (test objects C and D) were positioned on the remaining sites.

The determination of the mass values of the two weights required 30 rotations of the turn table and it took 4.5 hours. In the results shown in Fig. 2, 'EQ' indicates the correction value from the CIPM equation and 'BA' also indicates the correction value from the BAs, with their respective boundaries of standard deviation. The standard deviation of the 'BA' was shown to be less than that of the 'EQ' in all of the six measurements. The standard deviation of the "BA' in the 6 measurements was found to be less than 5 μg. The test weight D showed almost the same results. These results indicate that the in situ BA method produces less uncertainty than that the CIPM equation.

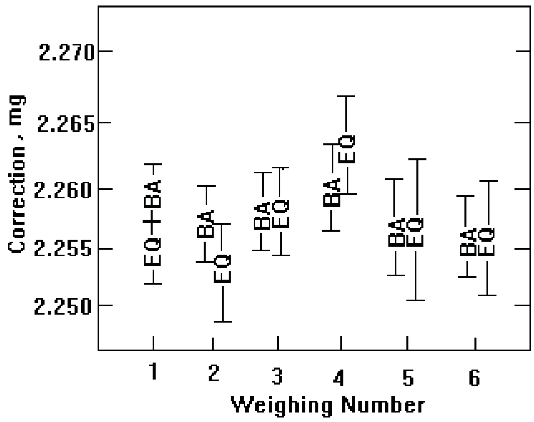

Fig. 2 Comparison of mass values of weight C from the BAs method with those from the CIPM equation.

5. CONCLUSIONS

A Pt-Ir prototype kilogram was used not only as a mass standard but also as a BA paired with a stainless steel weight. The BAs can be used to measure the air density.

With a comparator equipped with an automatic turntable capable of handling four weights, the air density for the buoyancy correction can be directly determined for the purpose of calibrating the other two test weights loaded on the same pan.

The in situ BA method produced mass values of test weights with less uncertainty than the one by the CIPM equation method.

6. REFERENCES

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