

BILATERAL COMPARISON OF BUOYANCY ARTEFACTS BETWEEN PTB AND KRISS

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ABSTRACT

Buoyancy artefacts (BAs) are used for the experimental determination of air density. The artefacts used for this comparison were manufactured at the PTB and the KRISS respectively and consist of one hollow cylinder and one bobbin. Mass differences of the PTB and the KRISS BAs in vacuum and in air are measured simultaneously by using the PTB prototype mass comparator.

Results of the bilateral comparison including uncertainty budgets and the deviation between air densities obtained by the BAs and those calculated by the CIPM formula are presented. Additionally, a comparison with a correction of the CIPM formula based on recently measured values for the air composition is given.

1. INTRODUCTION

At present, the main uncertainty source is due to air density determination when disseminating mass standard from prototype kilogram to a 1 kg stainless steel mass standard. It is about 10 μg . To reduce this uncertainty, the determination of air density by using buoyancy artefacts is studied by many national metrology institutes (NMI) [1-3].

The CIPM formula to determine air density is a function of the temperature T , pressure p , dew-point temperature t_d and the CO_2 content of the air x_{CO_2} . The relative standard uncertainty of this formula itself is $6,5 \times 10^{-5}$ [4, 8]. The final relative standard uncertainty of air density is about 1×10^{-4} if the uncertainties for T , p , t_d , and x_{CO_2} are included [4, 5].

In this work, specially designed BAs are used to determine the air density.

The air density determined by the BAs weighing, ρ_{BA} , is simply expressed by

$$\rho_{BA} = \frac{(\Delta m_{vac} - \Delta m_{air} + \Delta m_s)}{\Delta V}, \quad (1)$$

where Δm_{vac} is the mass difference in vacuum between BAs, Δm_{air} the weighing difference in air between BAs, Δm_s the mass difference due to sorption effects and ΔV the volume difference between the BAs.

A discrepancy of about $8 \times 10^{-5} \text{ kg m}^{-3}$ between the CIPM formula and BA method was obtained at BIPM [3]. To verify it, the CCM suggested 2002 a re-determination of the concentration of argon in air. This re-determination was carried out by KRISS chemical group, which is a member of CCQM [6, 7]. In this paper, the results of the bilateral comparison including the uncertainty budgets and the discrepancy between air densities obtained by the BA method and those calculated by the CIPM formula are presented. Also, the air density values obtained by the CIPM formula corrected with the recently re-determined air composition are given.

2. EXPERIMENTAL CONDITIONS

The balance used for measuring the mass difference between the 1 kg BAs is a mass comparator (Mettler HK1000MC) which has a capacity of 1.00115 kg, a readability of 0.1 μg and a standard deviation(s) of less than 2 μg .

KRISS BAs were transported to the PTB in Germany for bilateral comparison. The balance was installed in a vacuum chamber (Figure 1) in which the pressure could be reduced to $p \leq 0.1$ Pa.



Figure 1: 1 kg mass comparator of PTB installed inside the vacuum chamber

The thermocouples for temperature measurement and tubes for dew-point-, pressure- and CO_2 -meters have been incorporated in the vacuum chamber and balance housing. The standard uncertainty of the temperature measurement is less than 0.01 K.

Separate pressure meters are used for different pressure ranges. These are, at ambient pressure, an instrument using a quartz vibrating cylinder sensor with a standard uncertainty of 3 Pa and, between 15 kPa and 0.1 Pa, a capacitive pressure meter having an uncertainty of about 10 % at a pressure of 1 Pa.

The CO_2 concentration of the air is measured by non-dissipative infrared absorption. The uncertainty of the CO_2 -measurement is less than 5 % and that of dew-point temperature t_d is 0.1 K.

Balance operation and data acquisition are controlled by a computer.

Mass comparisons at atmospheric pressure are done under constant pressure conditions with the vacuum chamber sealed.

The buoyancy artefacts (BAs) used for this comparison were manufactured at the PTB and the KRISS, respectively, and consist of one hollow cylinder and one bobbin. The detailed physical properties are given in Table 1. The mass differences in air and in vacuum of KRISS BAs and PTB BAs have been compared.

The weighing procedure consists of weighing cycles and series. A single A-B-B-A cycle for two positions comprises of four successive weighings. Six cycles are measured for two positions. A series usually comprises of 6×6 A-B-B-A weighing cycles for all four positions. A series is measured in one day, the measurements usually being taken during the night.

Table 1: Physical properties of KRISS BAs and PTB Bas

Physical Properties	KRISS BA			PTB BA		
	Hollow	Bobbin	Difference	Hollow	Bobbin	Difference
Volume / cm ³	221.318	127.214	94.104	205.143	124.274	80.869
Volume coefficient of thermal expansion	5×10 ⁻⁵ / K ⁻¹			5×10 ⁻⁵ / K ⁻¹		
Height of gravity center / cm	4.263	4.256	0.007	4.011	4.013	-0.002
Surface Area / cm ²	204.497	202.165	2.332	193.5	195.1	-1.6
Surface Roughness, R _a / μm	< 0.1			< 0.1		
Magnetic Susceptibility	< 0.0049			< 0.0039		

3. RESULTS

Figure 2 and Figure 3 show the results of the mass-comparisons in vacuum and in air, respectively. The results of 48 vacuum comparisons of the KRISS BAs and PTB BAs are:

$$\Delta m_{\text{vac}}(\text{Hollow-Bobbin})_{\text{KRISS}} = -2.6423 \text{ mg} \\ (n = 48, s = 0.0017 \text{ mg}, \text{ May 25 - June 23})$$

$$\Delta m_{\text{vac}}(\text{Hollow-Bobbin})_{\text{PTB}} = 96.4581 \text{ mg} \\ (n = 48, s = 0.001 \text{ mg}, \text{ May 25 - June 23})$$

The vacuum-comparisons are corrected for supplementary mass due to sorption, different centers of gravity, etc.

The corrections for supplementary masses used to reduce the differences of balance indications for different centers of gravity, for temperature-dependent volume changes and for sorption, are applied.

The adsorbed mass per surface area $\tilde{\mu}$ is estimated to be $(0.21 \pm 0.1) \mu\text{g cm}^{-2}$ for the PTB artefacts [1] and $(0.35 \pm 0.1) \mu\text{g cm}^{-2}$ for the KRISS artefacts [2].

The vacuum mass difference has to be corrected for the sorption influence on the small difference of surface area between BAs of KRISS and PTB.

These corrections are given by :

$$(\Delta m_s)_{\text{KRISS}} = \tilde{\mu} (A_{\text{Hollow}} - A_{\text{Bobbin}}) \\ = (0.8 \pm 0.2) \mu\text{g} \qquad (\Delta m_s)_{\text{PTB}} = \tilde{\mu} (A_{\text{Hollow}} - A_{\text{Bobbin}}) \\ = (-0.3 \pm 0.2) \mu\text{g}$$

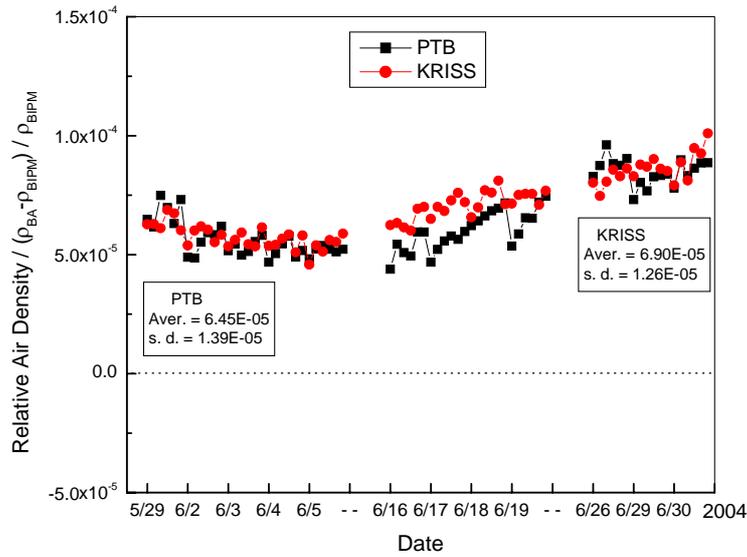


Figure 2: Relative deviation of air density between CIPM formula 81/91 and BA method

Figure 2 shows the relative discrepancy of air density between the CIPM formula 81/91 corrected with the new gas constant (8.314472) and BA method obtained by the PTB BAs and the KRISS BAs of 6.45×10^{-5} and 6.9×10^{-5} with standard deviation of 1.39×10^{-5} and 1.26×10^{-5} respectively. Both results are in a good agreement within the uncertainties and confirm the results recently presented by Picard et al. [3, 6].

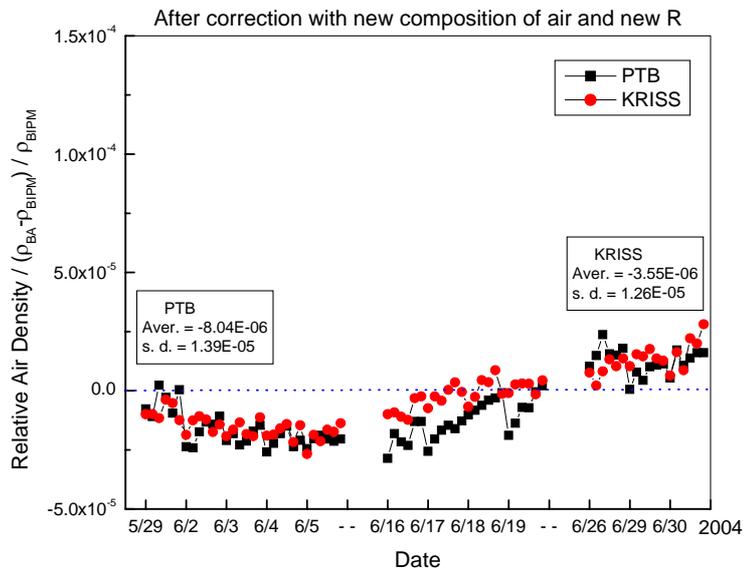


Figure 3: Relative deviation of air density between CIPM formula after correction with new composition of air and new gas constant and BA method

Figure 3 shows the relative difference between the CIPM formula and the BA method for the PTB BAs and the KRISS BAs after correction with the mole fraction of Ar (0.009332), N₂ (0.7808), O₂ (0.2095) and CO₂ (0.000374) in air [7] and the most recent CODATA recommendation for the molar gas constant (8.314472 J mol⁻¹ K⁻¹) [9].

4. UNCERTAINTIES

Table 2 shows the uncertainty budgets for the air density determined by the CIPM formula and BA method, respectively.

Table 2: Uncertainty budgets for the air density determined by the CIPM formula and BA method

Sources	$C_i = \delta\rho/\delta q_i$	$u(q_i)$	$C_i u(q_i),$ kg/m ³	Sources	$C_i = (\rho/q_i)$	$u(q_i)$	$C_i u(q_i),$ kg/m ³
p	$1.2 \times 10^{-5} \text{ kg m}^{-3} \text{ Pa}^{-1}$	3 Pa	$3,6 \times 10^{-5}$	$\Delta m_{\text{vac.}}$	$1.2 \times 10^4 \text{ m}^{-3}$	$1.7 \times 10^{-9} \text{ kg}$	2.1×10^{-5}
T	$4.8 \times 10^{-3} \text{ kg m}^{-3} \text{ K}^{-1}$	0.01 K	4.8×10^{-5}	Δm_{air}	$1.2 \times 10^4 \text{ m}^{-3}$	$1.3 \times 10^{-9} \text{ kg}$	1.6×10^{-5}
t_d	2.7×10^{-4}	0.1	2.7×10^{-5}	Δm_s	$1.2 \times 10^4 \text{ m}^{-3}$	$2.0 \times 10^{-10} \text{ kg}$	2.5×10^{-6}
X_{CO_2}	0.48	2.4×10^{-5}	1.2×10^{-5}	V	$1.5 \times 10^4 \text{ kg m}^{-6}$	$5.6 \times 10^{-10} \text{ m}^3$	8.4×10^{-6}
CIPM formula	1.0	7.8×10^{-5}	7.8×10^{-5}				
$u(\rho_{\text{CIPM}}) = 1.1 \times 10^{-4} \text{ kg m}^{-3}$				$u(\rho_{\text{BA}}) = 2.8 \times 10^{-5} \text{ kg m}^{-3}$			

5. CONCLUSION

The intercomparison of air density determination based on the BA method between PTB and KRISS was carried out at the PTB from April to June 2004.

As a result, the relative discrepancies between the mean value of the air density determined by the CIPM formula 1981/91 and by KRISS and PTB BAs are 6.5×10^{-5} and 6.9×10^{-5} , respectively. This confirms the results recently presented by Picard et al. [3, 6].

The average of the relative difference between the results obtained by KRISS and PTB BAs is only 4.5×10^{-6} .

The air densities determined by the CIPM formula are shifted in relative terms by 7.3×10^{-5} if the recently measured value of the mole fraction of Ar (0.009332), N₂ (0.7808), O₂ (0.2095) and CO₂ (0.000374) [7] and the most recent CODATA recommendation for the molar gas constant (8.314472 J mol⁻¹ K⁻¹) [9] would be applied.

REFERENCES

- [1] Gläser M., Schwartz R. and Mecke M., "Experimental Determination of Air Density Using a 1 kg Mass Comparator in Vacuum", *Metrologia* **28** 1991, pp. 45-50
- [2] Chung J. W., Chang K. H., Lee W. G., Kim K. P., "Air Density Determination Using 1 kg Buoyancy Mass Comparison", *Proceedings of IMEKO TC3/TC5/TC20*, Celle/Germany, 2002, pp. 273-277
- [3] Picard, A., Fang, "Mass comparisons using air buoyancy artefacts", *Metrologia* **41** (2004), pp. 330-332
- [4] Giacomo P., "Equation for the Determination of the Density of Moisture Air (1981)", *Metrologia* **18** 1982, pp. 33-40
- [5] Davis R. S., "Equation for the Determination of the Density of Moisture Air (1981/91) ", *Metrologia* **29** 1992, pp. 67-70
- [6] Picard, A., Fang, H., Gläser, M., "Discrepancies in air density determination between thermodynamic formula and a gravimetric method: Evidence for a new value of the mole fraction of argon in air", *Metrologia*, 2004, (accepted for publication)
- [7] Park, S. Y., Kim, J. S., lee, J. B., Esler, M. B., Davis, R. S., Wielgosz, R. I., "A redetermination of the argon content of air for buoyancy corrections in mass standard comparisons", *Metrologia*, 2004, (accepted for publication)
- [8] Picard, A., Fang, H., "Three methods of determining the density of moist air during mass comparisons", *Metrologia*, **39**, 2002, pp. 31–40
- [9] CODATA, <http://physics.nist.gov/cuu/Constants/>

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