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Air Density Determination By Using Buoyancy Artefacts at SASO NMCC

M. S. Alghamdi, R. A. Alyousefi, S. M. Alqarni, A. A. Aljuwayr and S. Kacmaz***

Saudi Standards, Metrology and Quality Organization, Riyadh, Kingdom of Saudi Arabia, r.yousefi@saso.gov.sa
TÜBİTAK-UME National Metrology Institute, Gebze-Kocaeli, Turkey

Abstract: In this study, the air density has been determined with relative uncertainty of $1{,}75 \times 10^{-5}$ (k=1)) by using experimental method to establish SASO NMCC's mass scale at the highest accuracy. Hollow and tabular type buoyancy artefacts, which have the same surface area, but a different volume of 279, 1196 cm^3, have been compared under the vacuum of 5×10^{-6} mbar and in air by using 1 kg vacuum mass comparator.

Keyword: air density, buoyancy artefacts, vacuum mass comparator

1. INTRODUCTION

To disseminate the unit of the mass of the highest accuracy, the prototype of platinum-iridium must be used which are traceable to the international prototype of the kilogram.When the platinum-iridium prototype of the SASO (Figure 1) is compared with 1 kg of stainless steel in air at the SASO Mass Laboratory, the buoyancy correction factor amount is about $\Delta V \rho_a$ = 89 mg, since ρ_a = 1,12 $kg.m^{-3}$. The uncertainty of the buoyancy correction depends on the uncertainties of *V*, and ρ_a. The volume, *V*, of a solid standards can be determined with an uncertainty (1σ) of 1 part in 10^6.

Figure1. The National Kilogram Prototype of the Saudi Arabia, numbered 93.

The density of air ρ_a is calculated by using the CIPM-2007 revised formula[1]. The uncertainty of the mass of stainless steel masses is at least 11 parts in 10^9 [2]. Mass comparisons are carried out under the constant pressure by using commercial specially mass comparator with standard deviations of 5 parts in 10^{10}. For reducing the uncertainty of air density, one of the best way is to use air buoyancy artefact methods[3].

The buoyancy artefact pair consists of same in nominal mass and also in surface area, but different in volume. Two weighings are necessary to determine the air density ρ_a, one in air and one in vacuum:

$$\rho_a = \frac{\Delta m_{vacuum} - \Delta m_{air}}{\Delta V} \qquad (1)$$

where Δm_{vacuum} and Δm_{air} represent respectively the apparent mass difference between the two masses in vacuum and in air and ΔV is their volume difference. Surface adsorption and water desorption of water vapour are negligible because the adsorption coefficient of water vapour and surface area difference between two artefacts are very small.

In this study, performance of the SASO_One vacuum mass comparator has been characterized vacuum / air conditions and cyclic measurements at ambient, intermediate and full vacuum were done and also the air density ρ_a, has been determined by experimentally and compared by CIPM -2007 revised formula.

2. EXPERIMENTAL CONDITIONS AND RESULTS

The balance used is an electromagnetic force compensated mass comparator (Mettler, SASO_One). The maximum capacity of the balance is 1001,5 g and the resolution is 0,1 µg. The electromagnetic force compensation range is 1,5 g. Masses smaller than 1 kg are measured by using dial weights externally. The comparator has an automatic mass exchange mechanism which holds six mass standards of maximum diameter 90 mm and 100 mm for cylindrical and spherical and also maximum height 100 mm (Figure 2).

The standard deviation of the balance for a single mass comparison is 0,5 µg typically. However, the standard deviation of the balance from the measurements made in the air and the vacuum was determined as 0,3 µg and 0,2 µg for in air and under vacuum. A vacuum pump and control system provides a pressure value of $5x10^{-6}$ mbar.

Klimet A30V is utilized for recording environmental conditions during the measurements. It also has pressure tight system for measuring under constant pressure as comparison of platinum-iridium with stainless steel. Three platinum resistance thermometers were incorporated for temperature measurements.

Figure 2. The SASO_One vacuum mass comparator, vacuum system and Klimet A30 V

Two of the temperature sensors are inside the balance and one other sensor is in the vacuum chamber. The temperature value of the laboratory is 20 ^{0}C ± 1,0 ^{0}C. The figure 3 shows the temperature variation inside the balance is about 0,1 K over 10 hours. The measurement uncertainty of the temperature is 0,02 K (k=2).

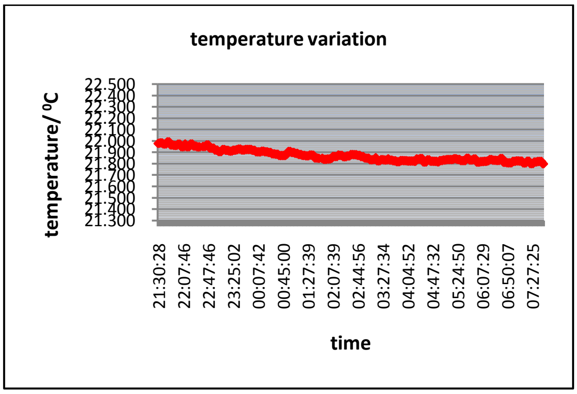

Figure 3. The temperature variation inside the balance as variation is app. 0,1 K for 10 hours

Pressure measurement range is between 35 hPa and 1110 hPa with an uncertainty of 3 Pa (k=2) and that of the humidity range is between 20 % and 80 % with an uncertainty of 0,15% (k=2).

The performance of the SASO_One vacuum mass comparator has been characterized under vacuum and in air conditions. The Figure 4 shows difference between vacuum and air measurements. The air buoyancy correction was applied on the air measurements and consequently, the difference between vacuum and air measurements is smaller than 10 µg for short time measurements.

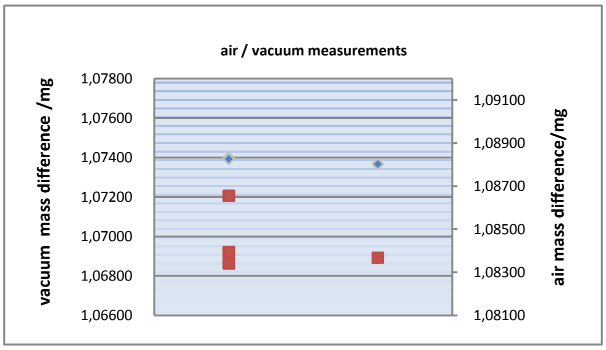

Figure 4. The characterized measurements for vacuum and air. Average mass differences are 1072,6 µg and 1082,2 µg for vacuum measurements and for in air measurements in short time

The cyclic measurements at ambient, intermediate and full vacuum were done. The measurements were taken in a complete cycle from ambient to vacuum on the comparative mass values of the weights. Table 1 and Figure 5 summarize the results for this cycle for the weights of stainless steel. The maximum mass difference between vacuum and air is about 9,6 µg.

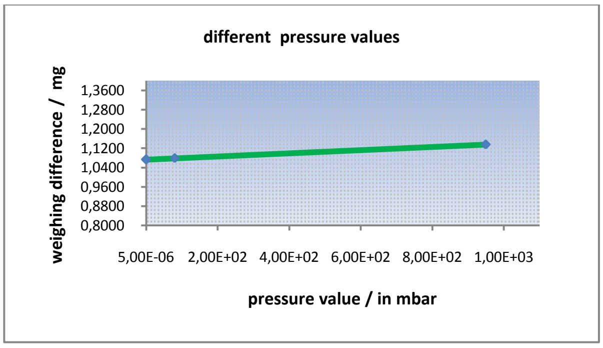

Figure 5. The cyclic measurements at ambient, intermediate and full vacuum.

Table 1. Results of SASO _One at the different pressure level

Measurement Run	Pressure Level mg	Mass Change µg
1	949	1082,2
2	80	1077,4
3	$5x10^{-4}$	1072,6
4	$5x10^{-6}$	1073,8

The apparent masses in air and in vacuum of two artefacts, each of 1 kg nominal mass (Figure 6) have been compared for determining air density by experiment.

Stainless steel artifacts were produced by Mettler. Artefacts are tabular and hollow types, which have the same surface area, but different volumes as density value of the hollow artifact is about 2475,156 $kg.m^{-3}$ with an uncertainty of 0,059 $kg.m^{-3}$ (k=2) and density of the tabular artifact is about 8006,706 $kg.m^{-3}$ with an uncertainty of 0,070 $kg.m^{-3}$ (k=2).

Figure 6. Air buoyancy artifacts. From left to right; hollow type and tabular type.

The weighing procedure consists of substitution method, cycles of 6 and series of 6 and measurements have been carried out first in vacuum and than in air respectively according to weighing procedure. Sorption effects were neglected for the adsorption coefficient of water vapor and surface area difference between artifacts were as small.

As a results, calculated the air density value ρ_a by using revised CIPM formula is 1,1203038 kg.m^{-3} and the air density value ρ_a by experiment is 1,1203231 kg. m^{-3}. The difference between the CIPM-2007 revised air density formula and that obtained by experiment is 1x10^{-5} kg.m^{-3}.

Table 2 summarizes uncertainty parameters for the CIPM-2007 revised air density formula and air density obtained by experiment in the short time.

Table 2. Contributions to the estimated relative uncertainty (k=1) of the air density value ρ_a by using revised CIPM the air density formula and by experiment. Assumed the mole fraction of CO_2 : 400 µmol.mol^{-1}

Source of Uncertainty	Uncertainty (k=1)	Relative Uncertainty Contribution (k=1)
Pressure, p	1,5 Pa	1,5x10^{-5}
Temperature, T	0,01 K	-4x10^{-5}
Relative humidity, Rh	0,075 %	-7,5x10^{-6}
Mole fraction of CO_2 , X_{CO2}	0	0
the combined relative uncertainty of ρ_a for the air density formula	**4,34x10^{-5}**	
Vacuum weighing difference, Δm_{vacuum}	8,02x10^{-13}	8,02x10^{-13}
Weighing difference in air, Δm_{air}	3,21x10^{-12}	3,21x10^{-12}
Volume difference, ΔV	3,78x10^{-10}	3,78x10^{-10}
the combined relative uncertainty of ρ_a for the experiment	**1,75x10^{-5}**	

3. CONCLUSION

The performance of the SASO_One vacuum mass comparator has been characterized under vacuum and in air conditions. The difference between vacuum and air measurements is smaller than 10 µg in short time measurements.

The cyclic measurements at ambient, intermediate and full vacuum were done. The measurements were taken in a complete cycle from ambient to vacuum on the comparative mass values of the weights. The maximum mass difference is about 9,6 µg.

Calculated the air density value ρ_a by using revised CIPM formula is 1,1203038 kg.m^{-3} ± 4,34x10^{-5} (k=1) and the air density value ρ_a by experiment is 1,1203231 kg. m^{-3} ± 1,75x10^{-5} (k=1) . The difference between the CIPM -2007 revised air density formula and that obtained by experiment is 1x10^{-5} kg.m^{-3}.

4. REFERENCES

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