BIPM Capacity Building & Knowledge Transfer Programme

2018 BIPM - TÜBİTAK UME Project Placement

REPORT

Project Name	Determination of the Solid Density of Mass Standards
Description	The calibration of mass standards is highly affected by the densities of the artifacts used. Research was performed on the accurate determination of the density of mass standards using two different techniques.
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Abstract

Research was conducted on the methods and system for solid density measurements to gain in-depth knowledge and experience in the area with the aim of improving the accuracy of mass measurements performed at the National Metrology Institute of Ethiopia (NMIE).

Alternative hydrostatic techniques comparing the test weight with a reference weight: (i) two different reference weights weighed in air and (ii) reference weights weighed in air and in the liquid are used in the study. The first technique is carried out manually and the second automatically. This report presents the result of the comparisons of the test weight with two different reference weights weighed in air, one with the test weight in air and the other with the test weight in water.

Motivation& Introduction

In the performance of high level mass calibrations, the accuracy is affected by the density of the artifacts used. It is necessary to know the value of the density of the mass artifacts to make buoyancy corrections during mass calibration. The NMIE Mass and Volume Laboratory sought training on this subject in a well-equipped external laboratory in order to gain knowledge and experience in line with the aim of improving the accuracy of its mass calibration services. The BIPM and the National Metrology Institute of Turkey (TÜBİTAK UME) joint training initiative entitled 2018 "BIPM - TÜBİTAK UME project placements" presented a good opportunity to obtain the required knowledge and experience.

The hydrostatic measurement system apparatus installed in the NMIE Mass and Volume Laboratory, some years ago, is suitable for both hydrometer calibration and solid density measurement in a limited range. However, it has not been used for the measurement of solid density due to a lack of required knowledge and experience. The objective of the research was to gain theoretical knowledge and practical experience to carry out measurements to determine solid density, understand the measurement system, identify system elements, develop the necessary calibration procedures and then to perform measurements.

The overall intention of establishing the capability to measure the density of weights at NMIE is to enable the calibration of weights at higher accuracies (E1 and E2 accuracy level).

For the work described in this report, a 1 kg weight of accuracy class E1 was calibrated in distilled water by using UME hydrostatic weighing system, consisting of a PR1003 Mettler balance and a thermostatic bath.

Research

The measurement of solid density was carried out by means of two comparisons: one in which the reference weight and test weight were both measured in air, and another one in which the reference weights were measured in air while the test weight was measured in water. These were performed based on OIML R 111-1-e04, B.7.4.2, Method A1. This technique was chosen to provide good technical experience through exercising each step manually. For the measurement, UME class E1 1 kg (id No. 003) was used as a test standard while class E1 1 kg weight (id No. 01) and combination of weights 500 g, 200 g, 100 g, 50 g, 20 g, 2 g, 1 g, 200 mg, 100 mg, 50 mg, 20 mg, 10 mg, 10 mg* (id No. 003) were used as reference mass standards for (in air) and (in water) measurements respectively.

Fig.1. Manual Solid Density measurement system at UME

Measurement principle

For each comparison measurement, the difference Δm, between test weight and reference weight is the difference in their apparent weight (balance indication) values (I).

$$\Delta m = I_T - I_R$$

I_T = balance indication value of the test weight and

I_R = balance indication value of the reference weight.

For in air comparisons,3 series of measurements with 6 cycles each (total 18 ABBA) were carried out and the average weighing difference, Avg. (Δma),was calculated:

Series		Avg. diff (g)		St. Dev. (g)		Avg. pressure (hPa)	Avg. Temp (oC)	Avg. Rh (%)
1		-0.0006091		0.0000009		993.73	19.97	54.78
2		-0.0006091		0.0000008		993.53	19.98	54.22
3		-0.0006095		0.0000003		993.33	20.00	54.13
	Avg.(Δm_a)	-0.0006092	STDV	0.0000002	Avg.	993.52	19.98	54.38

For in water comparisons, 2 series of measurements with 3 cycles each (total 6 ABBA) were performed and the average weighing difference, Avg. (Δmw),was calculated:

Series		Avg. diff (g)		St. Dev. (g)		Avg. pressure (hPa)	Avg. Temp (^{o}C)	Avg. Rh (%)	Avg. water temp. (^{o}C)
1		0.01067		0.00076		999.650	21.383	50.483	19.488
2		0.01050		0.00150		1000.083	21.233	52.050	19.553
	Avg.(Δm_w)	0.01059	STDV	0.0001202	Avg.	999.867	21.308	51.267	19.521

Data Analysis

Model Equation

The density of the test weight at 20 ^{o}C is calculated as follows:

$$\rho_{T,20} = \frac{\left(M_{Ra} + \Delta M_a + \rho_a * \left(V_{T,20} - V_{Ra,20}\right)\right)}{\mathrm{V}_{T,20}}$$

Where,

$$M_{Ra} = 999.99981 \text{ g}, \text{the value of reference standard used in air comparison}$$

$$\Delta M_a = I_{Ta} - I_{Ra} = -0.0006092 \text{ g}, \text{the weighing difference in air comparison}$$

$$\rho_a = 1.175472795 \text{ kgm}^{-3}, \text{density of air}$$

$$V_{Ra,20} = 124.8318 \text{ cm}^3, \text{Volume of reference standard at reference temperature}$$

$$V_T = \frac{(M_{Ra} - \rho_a V_{Ra} + \Delta M_a) - (M_{Rw} - \rho'_a V_{Rw} - M_p + \Delta M_w)}{\rho_w - \rho_a} = 126.9452 \text{ cm}^3$$

But,

$$V_{T,20} = V_T * (1 + (20 - t) * \beta)$$

$$V_{T,20} = (126.9456 \pm 0.01220) \text{ cm}^3, \text{volume of test standard at reference temperature}$$

Where

$$V_T = \text{volume of test reference at observed temperature, t}$$

$$M_{Rw} = 873.3899294 \text{ g}, \text{value of reference standard used in water comparison}$$

$$\rho_a' = 1.1774160 \text{ kgm}^{-3}, \text{value of air density during in} - \text{water comparison}$$

$$V_{RW} = 108.5055 \text{ cm}^3, \text{Volume of reference standard used during in} - \text{water comparison}$$

$$M_P = 0, \text{weight of additional suspension pan (if any)}$$

$$\Delta M_w = 0.0105850 \text{ g}, \text{weighing difference during in} - \text{water comparison}$$

$$t = 21.308 \text{ o}_C, \text{observed temperature}$$

$$\beta = 6.15 * 10^{-6} C^{-1}, \text{Coefficient of cubical expansion of the test weight material}$$

$$\rho_{T,20} = 7877.40573 \text{ kgm}^{-3}$$

Uncertainty

$$U_{\rho,20} = \frac{U_{V,20}}{V_{20}} * \rho_{T,20} = 0.00076 \text{ gcm}^{-3}$$

Conclusions and Future Work

As a result of the work performed, it was found that the theoretical and technical capability of personnel in charge, preparation of test weight, availability of different tools and accessories, preparation of appropriate standard weights, selection of appropriate balance, controlling the temperature of the bath (thermostatic bath), availability of appropriate deionized or distilled water, environmental monitoring devices and water thermometer, stable laboratory environment are factors which affect the accuracy of the mass measurements.
The knowledge and experience gained through this study will be used to carry out measurement of the density of a 1 kg E1 class standard weight, assuring the achievement of the objective of the program. Further, the experience gained would be used to establish a solid density measurement system at NMIE.

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