Improvement of Mass Determination Using AT-1006 Comparator in NIS – Egypt

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ABSTRACT

A major factor determining the uncertainty associated with the value of a standard mass at any level is the performance of the mass comparators employed at various levels in the traceability chain. Improvement in the uncertainty of mass standards is thus dependent on the research and developments of better mass comparators. The National Institute for Standard (NIS) Egypt was equipped in 1997 with Mettler AT-1006 comparator to compare masses in four positions. The comparator capacity from 50 to 1000 g is of particular interest, since this range is the range in which the comparisons against the national prototype kilogram are carried out. Controlling software has been adopted to work with the Mettler AT-1006 comparator for driving the balance to execute any comparison scheme. New climatic system for measuring the air density was established for Measuring the ambient parameters and combining them in the well-known BIPM 1990 formula enable measuring of the air density in the laboratory indirectly. The performances of the system were studied as well as an estimation of expanded standard uncertainty calculations were carried out. Improvement in the comparator performance after using the new control software has been achieved and the climatic system.

INTRODUCTION

The maintenance and propagation of a mass scale internationally relies on the coordination of national kilogram standards, through the Bureau International des Poids et Mesures (BIPM), Sevres, France, with the primary measurement laboratory of each nation. Dissemination of the mass scale to other levels of mass and accuracy is the task of each national measurement laboratory, sometimes collaboration with other laboratories. A major factor determining the accuracy with which the mass of a standard at any level is given, the traceability to the International Kilogram at the BIPM, is the performance of the mass comparators employed at various levels in the traceability chain.

Improvement in the accuracy of mass standards is thus dependent on the research and development of better mass comparators. In recent years, automation of the weighing process has led to considerable improvement in weighing accuracy [1]. Also, the measurement of air density is necessary in the field of mass measurements to allow buoyancy corrections to be carried out when comparing weights of different volumes in air. It is particularly important when comparing weights of different materials or when performing mass measurements to the highest accuracy. For the calibration of kilogram weights air buoyancy corrections range from a few milligrams when comparing similar materials such as stainless steel, to nearly 100 milligrams when comparing stainless steel and platinum-iridium and over 450 milligrams when comparing platinum iridium and silicon.

THE GENERAL LAYOUT OF THE SYSTEM

The system consists of, the balance, the temperature and humidity indicator, the manometer and the computer as shown in figure (1). The temperature and humidity indicator has three sensors inserted inside the balance chamber, two of them are for temperature and one for humidity. The manometer is sensing the air pressure via a tube, the beginning of which is inside the balance chamber and the end is attached to the manometer sensor. All the system is connected to the computer to obtain the data during the measurement.

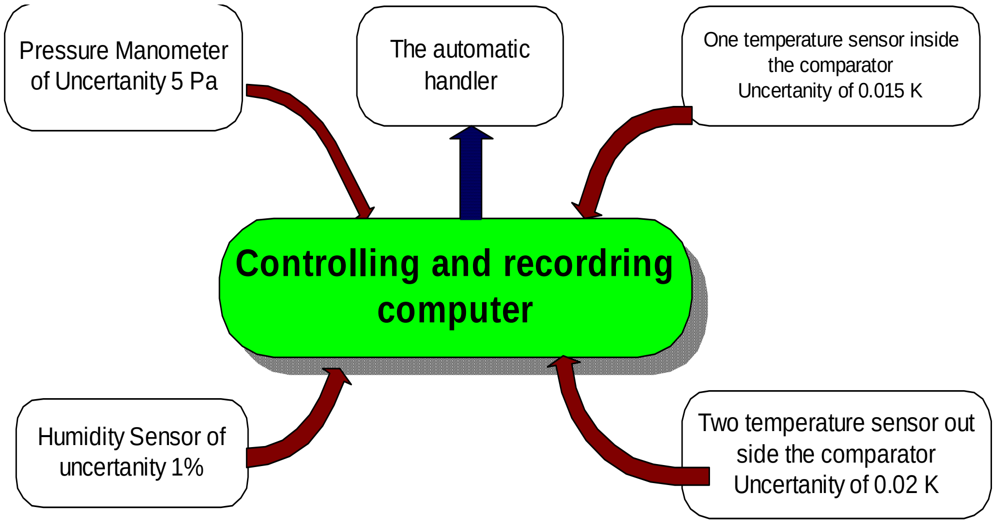

Fig. 1: The general layout of the system

Comparator

The balance is the well-known Mettler AT – 1006 mass comparator, is manufactured by Mettler-Toledo AG, with which the National Institute for Standards (NIS) Egypt was equipped in 1997. The balance capacity is 1 kg, resolution 1 µg. The short-term standard deviation of the balance in routine calibrations of secondary kilograms using the scheme described in paragraph 2 is 3 µg. This balance is fully automated and controlled by the computer to compare masses in four positions. Balance capacities from 50 to 1000 g are of particular interest, since this range is considered as the range in which the comparisons against the national prototype kilogram are carried out.

New Software

A new controlling software control has been developed. It is used to control the Mettler AT-1006 comparator to drive the balance to execute any comparison scheme. The preliminary tests show improvement in the comparator performance after using the new control software. The software provided by the manufacturer was suitable to obtain the comparison just in one scheme (S – T – S – T) in fixed steps, but not sufficient for our mass comparisons and researches. The new software is a programmable software i.e. it gives the user a wide variety of choice to select the experimental set up also it provides the possibility to make any number of preloading that is required to be sure from the eccentricity of the mass. The program gives the user the possibility to make a stability time that needed to eliminate any error could be arise from the handling of the masses during the transportation from the storage the comparator pan.

Ambient Conditions measurements

Irrespective of the weighing process, weighing principle, etc. the following quantities or the changes in such quantities influence the weighing result. In weighing in air, temperature, atmospheric pressure, atmospheric humidity, the composition as well as the purity of the air influence the balance, standard and weighing sample. Temperature, pressure, moisture and the composition of the air are incorporated in the air buoyancy correction. Changes in the temperature causes long term changes in the weighing system and thus a systematic deviation or increase in the standard deviation. Similar effects are shown by changes in the atmospheric pressure, which lead to dynamic effects in the weighing system. The relative humidity and the purity of the air influence the adsorption layer and dust/aerosol deposits and hence the balance, standard and weighing sample [2].

Air density was not measured in our laboratory before establishing this system. The new system allows to measure the ambient parameters and combining them in the well-known BIPM 1990 formula. The equipment used for measuring the various quantities is described in the following section.

Temperature:

The calibration constants, yearly determined, are introduced in the instrument, so that its output is directly the value of the temperature sought for. One of the three thermometers is inside the weighing chamber as close as possible to the standard on the pan. The standard uncertainty of the measurement is $u(T) = 0.015$ K.

Pressure:

Digital barometer is calibrated by comparison with our national standard, with a calibration standard uncertainty of 5 Pa. Stability of the instrument is in the same range.

Humidity:

Humidity is calibrated at NIS. Standard uncertainty of R.H is 1 % R.H .

These instruments are computer driven and a set of data is taken whenever the balance sends a datum to the computer. The resulting standard uncertainty of air density is $u(\rho_a) \sim 1.8$ g·m^{-3}, corresponding to a relative standard uncertainty $u(\rho_a)/\rho_a \sim 1.5 \cdot 10^{-3}$.

MEASUREMENTS

Reference Standard

Two OIML E1 & E2 standards were used as references, namely, 707E1 and 707E2. The two reference standards were calibrated in November 1999 by comparison with IMGC reference standard. Based on this comparison, the estimated masses m_{iref} of the reference standards are

707E1 = 1.000000043 kg   707E2 = 1.000000383 kg

With standard uncertainties

$u(m_{1ref}) = u(m_{2ref}) = 15$ µg and $\nu_{eff} > 20$.

Volumes of the two references at 20 °C are

V_{707E1} = 124.919 cm^3 V_{707E2} = 124.890 cm^3

with standard uncertainties $u(V_{1ref}) = u(V_{2ref}) = 0.0025$ cm^3. Volumetric coefficient of expansion about 20 °C is $\alpha = 45.0$ ppm/K. The height of the centre of mass of both standards is $h = 25$ mm. The uncertainties associated to these two quantities were not taken into account in our model.

Weighing method

Certain influences such as unequal lever lengths, inhomogeneous gravitational field, linearity errors and also some calibration errors are cancelled when substitution weighing following the Borda method is performed. This method allows to dispense with correction due to gravitational fluctuation caused by the attraction by stars and planets, above all the sun and the moon on the rotating earth. For example, the greatest gravitational force due to the sun and the moon on a 100 g is 0.03 mg. To exclude linear drift, particularly that due to temperature gradients, repeated comparisons of the test specimen (T) with the standard (S) are performed. Each weighing cycle comprises four successive weightings:

Standard	Test specimen	Test specimen	Standard
S	T	T	S

Weighing scheme

The redundancy inherent in the set, combined with the flexibility offered by the 4-positions carousel of the balance, allowed an accurate calibration with a reasonable number of degrees of freedom. A known weighing scheme was designed [3]. The details of the runs are given in Table 1. Each run involves 12 cycle of (S-T-T-S) comparisons, thus resulting in 48 readings of the balance.

Kg 1	kg 2	kg 3	kg 4
1	2	3	4
1	2	3	4
1	2	3	4
1	2	3	4
1	2	3	4
1	2	3	4
3	4	1	2
3	4	1	2
3	4	1	2
3	4	1	2
3	4	1	2
3	4	1	2

Table 1: Runs on the balance. The numbers 1 to 4 refer to the position of the relevant standard on the carousel of the balance.

Experimental design

Twenty series of measurements were performed from 22 February to 26 February 2001. Each series was the routine calibration we use at IMGC for reference kilograms. The design matrix $X_{(12x4)}$ of a series is given in Table 2, in which the first row refers to the vector of unknowns $\beta^T_{(1x4)}$.
Each row involves an S-T-T-S comparison. Therefore, a complete series involves 48 readings of the balance. All series were run overnight, two for each night. Two further series were discarded due to a failure of the automatic acquisition system.

kg 1	kg 2	kg 3	kg 4
1	-1	0	0
1	0	-1	0
1	0	0	-1
0	1	-1	0
0	1	0	-1
0	0	1	-1
-1	1	0	0
-1	0	1	0
-1	0	0	1
0	-1	1	0
0	-1	0	1
0	0	-1	1

Table 2: Design matrix X and vector of unknowns β^T (first row) of a measurement series

Environment

Gravitational gradient in the laboratory was not taken in account, since both the standards and unknowns have the same centre of mass height. ambient conditions during the measurements were mostly stable with variations of :

In temperature not more than ± 0.1 K.
In relative humidity not more than ± 2 %.
In barometric pressure ± 30 Pa

DATA PROCESSING AND UNCERTAINTY EVALUATION

From each of the 20 series, 12 in-air mass differences were obtained, and individually corrected for sensitivity and buoyancy. The resulting mass differences were averaged in pairs, and the 6 results were taken as the appropriate components of the $Y_{(6\times1)}$ vector, that is, of the vector of the "observations". The unknown mass values were obtained by a standard least-squares adjustment [4]. The resulting estimates of the masses, with the standard deviations s_i of the adjustments, are given in Table 5.

The standard deviations between the series are 1.5 µg for 1 kg 2 and 0.5 µg for 1 kg 4. The combined uncertainty u_c for the mass is calculated in accordance with [7].

4- RESULTS AND CONCLUSION

The estimated mass values were calculated as the averages of the estimates obtained in each series. The estimates and their standard combined uncertainties are given in Table 3.

kg Under Test	*m* [g]	*u* [µg]
1 kg 2	1000.000039	17
1 kg 4	999.999846	17

Table 3: estimates and standard combined uncertainties

Comparing the obtained conventional masses of the two nass standards with IMGC certificate no. 328/2001 20/6/2001 a maximum difference of +14 µg could be found which is within the standard uncertainty of the two measurements.

These results validate the measurements carried out at NIS mass laboratories and allow transferring the traceability of our mass standards from our National Primary Standard kg No. 58. This new system allows performing the comparisons of masses of different densities.

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