

CALIBRATING THE SENSITIVITY OF AN AX1007CP MASS COMPARATOR ACROSS THE ENTIRE ELECTRICAL RANGE USING MICRO MASS STANDARDS

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Abstract – A new type of mass comparator (AX1007CP), designed for use under a constant pressure has been evaluated. The comparator has a readability of 0.1 μg and an electrical weighing range of 1.5 g. It is installed inside an airtight stainless steel chamber allowing mass comparisons to be performed under fixed environmental conditions. This paper describes the use of micro-mass standards to assess the linearity of the comparator at points evenly distributed across the weighing range.

Keywords: Mass comparator, weight calibration, micro-mass standards

1. INTRODUCTION

Reducing the uncertainty in primary mass calibrations will become increasingly important in the near future as the SI unit of mass moves closer to becoming defined in relation to a fundamental physical constant instead of with a physical artefact [1]. The Consultative Committee for Mass and Related Quantities (CCM) [2] has recommended that the new realisation of the kilogram should have a relative uncertainty no larger than 20 μg which is considerably higher than the uncertainty of 2.3 μg assigned to national prototypes at the third verification [3].

National Measurement Institutes (NMIs) must therefore look to reduce other components in their uncertainty budgets when calibrating masses so that the increased uncertainty in the new kilogram definition has a limited effect on end users. One uncertainty component that could be reduced is the uncertainty attributed to the mass comparator used to measure the masses and an important contribution to this uncertainty value comes from the assessment of the sensitivity of the comparator's electrical weighing range. Hu M.H. et al. [4] have evaluated micro-mass standards and suggest that they could be used to calibrate the sensitivity of mass comparators with high accuracy. Davidson [5] has published results of a comparison to measure the mass of micro-mass standards undertaken at three European NMIs. All the participants demonstrated equivalence to the calculated reference values and showed that providing appropriate care is taken in their handling, micro-mass standards can be used to extend the mass scale to values below 1 mg. Previous work by Madec T. et. al. [6] used micro-mass standards to calibrate the sensitivity of two types of mass comparator and found that the comparators were free of any significant sensitivity errors over the ranges studied.

This paper describes the sensitivity calibration of a new mass comparator (AX1007CP) designed to operate at a constant pressure. The sensitivity calibration was performed at three points across the electrical weighing range using micro-mass standards ranging in value from 50 μg to 1 000 μg .

2. APPARATUS

2.1. Comparator and air density instruments

The apparatus is shown in Fig. 1 and the specifications of the measuring instruments are given in Table 1. It is sited in an air-conditioned room, controlled to 20 $^{\circ}\text{C} \pm 1$ $^{\circ}\text{C}$ with a variation over an hour of less than 0.2 $^{\circ}\text{C}$. The main part of the apparatus is the AX1007CP constant pressure mass comparator (METTLER-TOLEDO) sited within a stainless steel airtight chamber. The stainless steel chamber has a 450 mm diameter and height of 782 mm and the entire comparator, chamber and lifting mechanism fits within a 700 mm x 700 mm square footprint. The chamber is split into two parts separated by an O-ring seal. The top part is fitted with an access door allowing masses to be loaded and unloaded to the comparator without lifting the top of the chamber. The lower part is fitted with KF40 vacuum ports for connecting comparator control cables, thermometers, a humidity sensor and a manometer. To evaluate the ambient conditions and calculate the density of air within the chamber the pressure, temperature and dew point are measured.

Table 1. Measuring instrument information

Instrument	Type	Readability	u_c
Mass comparator	Mettler-Toledo AX1007CP	0.000 1 mg	
Manometer	Druck DPI 142	1 Pa	0.03 Pa
Thermometer	Sensing Devices Ltd. 100 Ω platinum resistance thermometer	0.001 $^{\circ}\text{C}$	0.005 $^{\circ}\text{C}$
Hygrometer	Vaisala HMT 228	0.01 $^{\circ}\text{C}$	0.08 $^{\circ}\text{C}$



Fig. 1. AX1007CP mass comparator and ancillary equipment.

2.2. Mass standards

Four stainless steel one kilogram mass standards and five aluminium and stainless steel micro-mass standards ranging in mass from 50 μg to 1 000 μg were selected, information on the masses is given in Table 2. Stainless steel tare masses with nominal values of 0.5 g and 1 g were also added to the tare pan of the AX10007CP to enable measurements at different points across the range of the comparator scale.

Three additional micro-mass standards manufactured from aluminium wire were constructed with nominal values ranging from 200 μg to 300 μg . These weights were added to the kilogram weights 63, 63DD and 63TD so that the mass difference between all four kilogram weights was no greater than 25 μg .

Table 2. Mass standard information

Identification	Nominal mass / g	Material	Density / g cm^{-3}
63	1 000	Stainless steel	7.959 9
63D	1 000	Stainless steel	7.962 1
63DD	1 000	Stainless steel	7.963 4
63TD	1 000	Stainless steel	7.960 7
1C(65)	0.001	Stainless steel	7.950 0
0.6(90)	0.000 6	Aluminium	2.700 0
0.2(90)	0.000 2	Aluminium	2.700 0
0.1(90)	0.000 1	Aluminium	2.700 0
0.05(90)	0.000 05	Aluminium	2.700 0

3. METHOD

3.1. Zero point of the electrical range

The four one kilogram stainless steel standards were loaded onto the four turntable positions of the AX1007CP comparator and then centred and left to stabilise for a period

of 24 hours before commencing the measurements. No additional weights were added to the tare pan at this stage. A weighing scheme with five series of four A-B-A comparisons was then run to obtain all possible mass differences, corrected for air buoyancy, between the four one-kilogram standards.

Micro-mass standards with nominal values of 50 μg , 100 μg and 200 μg were then added to the kilogram masses identified as 63D, 63DD and 63TD respectively before repeating the above weighing scheme. The micro-mass standards were then removed from the kilograms and the weighing scheme was repeated for a third time. Micro-mass standards with nominal values of 200 μg , 600 μg and 1 000 μg were then added to the kilogram masses identified as 63D, 63DD and 63TD before repeating the weighing scheme. These micro-mass standards were then removed from the kilograms and the weighing scheme was repeated again for the final time.

3.2. Measurements at 0.5 g and 1g of the electrical range

The entire sequence of measurements performed at the zero point of the electrical range (§3.1) was repeated at the 0.5 g and 1.0 g points on the electrical range. This was achieved by adding 0.5 g or 1 g stainless steel mass standards to the tare pan of the AX1007CP comparator.

3.3. Calculation of the sensitivity error

The weighing of the micro-mass was calculated from the following relationship:

$$\mu_2 - \mu_1 = [(M_2 + \mu_2) - (M_1 + \mu_1)] - [M_2 - M_1] \quad (1)$$

Where M_2 and μ_2 are the kilogram mass and micro-mass on the second station respectively and M_1 and μ_1 are the kilogram and micro-mass on the first station respectively. In equation 1, the term $[(M_2 + \mu_2) - (M_1 + \mu_1)]$ is the weighing of the kilogram masses with the micro-masses and the term $[M_2 - M_1]$ is the mean value of the mass difference between the second kilogram and the first kilogram, before and after weighing with the micro-standards. Note that there are no micro-masses assigned to turntable position 1 and therefore $\mu_1 = 0$ in this case.

The sensitivity error at the nominal value of the micro-mass standard is calculated by the following relationship

$$S = (\mu_2 - \mu_1) - (C\mu_2 - C\mu_1) \quad (2)$$

Where $(\mu_2 - \mu_1)$ is the result from equation (1) and $(C\mu_2 - C\mu_1)$ is the calibrated mass difference between the micro-mass standards.

4. RESULTS

The sensitivity errors and associated standard uncertainties measured at electrical range values of 0 g, 0.5 g and 1.0 g are shown in table 3, table 4 and table 5 respectively. Sensitivity errors and associated standard uncertainty are also shown graphically at electrical range values of 0 g, 0.5 g, and 1.0 g in fig. 2. The errors at each electrical range value have been fitted using a linear least squares data fit and the standard errors in the data fit are between 0.13 μg and 0.24 μg and have been included in the uncertainty budget.

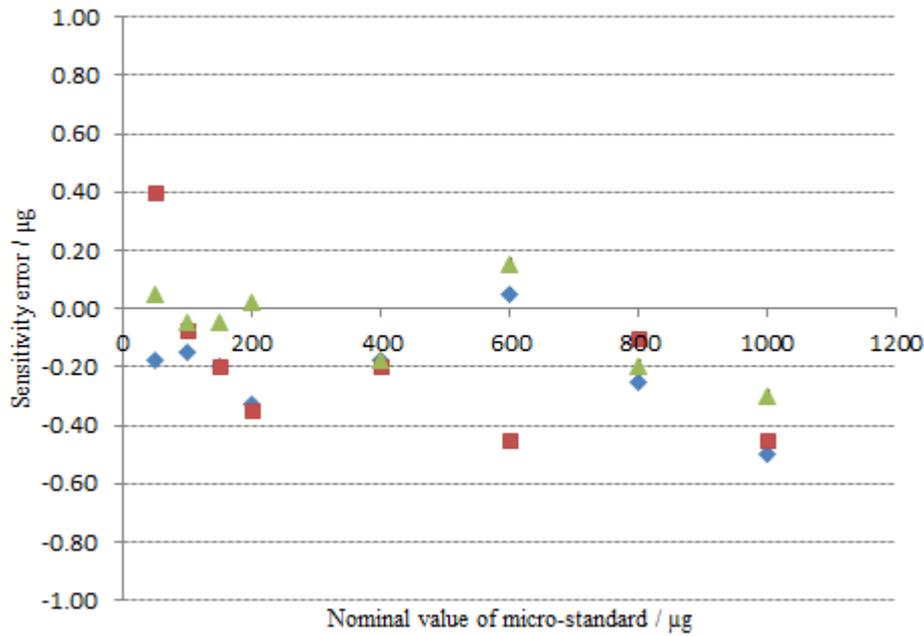


Fig. 2. Sensitivity errors of the AX1007CP mass comparator from 50 μg to 1 000 μg at 0 g load (blue diamonds), 0.5 g load (red squares) and 1.0 g load (green triangles). Standard uncertainty values are all less than 0.5 μg .

The standard uncertainty in each sensitivity error was calculated by combining in quadrature the following four uncertainty components;

- Micro-mass uncertainty
- Mass comparator resolution
- Mass comparator repeatability
- Least square error

At each point on the electrical range the slope of the linear fit is practically zero and within the standard uncertainty of the measurements the sensitivity errors identified are not significant.

Table 3. Sensitivity errors and associated standard uncertainty of the AX1007CP comparator at 0 g load of the electrical range.

Nominal value / μg	Sensitivity error / μg	Standard uncertainty / μg
50	-0.18	0.32
100	-0.15	0.31
150	-0.20	0.33
200	-0.32	0.31
400	-0.18	0.35
600	0.05	0.33
800	-0.25	0.33
1000	-0.50	0.32

Table 4. Sensitivity errors and associated standard uncertainty of the AX1007CP comparator at 0.5 g load of the electrical range.

Nominal value / μg	Sensitivity error / μg	Standard uncertainty / μg
50	0.40	0.37
100	-0.03	0.36
150	-0.20	0.38
200	-0.32	0.36
400	-0.20	0.39
600	-0.45	0.38
800	-0.10	0.38
1000	-0.45	0.37

Table 5. Sensitivity errors and associated standard uncertainty of the AX1007CP comparator at 1.0 g load of the electrical range.

Nominal value / μg	Sensitivity error / μg	Standard uncertainty / μg
50	0.05	0.31
100	-0.05	0.30
150	-0.05	0.31
200	0.02	0.30
400	-0.17	0.34
600	0.15	0.32
800	-0.20	0.32
1000	-0.30	0.31

CONCLUSIONS

An assessment of the sensitivity errors of an AX1007CP mass comparator at three points on its electrical range has been performed using micro-mass standards ranging in value from 50 μg to 1 000 μg . The sensitivity errors of the comparator were found to be negligible over the range tested and the slope of the linear fit of the errors was also found to be practically zero over this range. This confirmed that the AX1007CP mass comparator has an excellent characteristic regarding the linearity of its sensitivity curve. This meets the aim of reducing the mass comparator uncertainty component in the uncertainty budget for mass calibrations as the standard uncertainty assigned to the AX1007CP comparator can be taken as less than 0.5 μg .

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