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DESIGN AND PERFORMANCE OF THE NEW SARTORIUS 1 KG VACUUM MASS COMPARATOR AT PTB

M. Borys [1], *T. Fehling* [2], *T. Fröhlich* [2], *D. Heydenbluth* [3], *M. Mecke* [1], *R. Schwartz* [1]

[1] Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
[2] Sartorius AG, Göttingen, Germany
[3] Technical University, Ilmenau, Germany

Abstract: A new type of a 1 kg vacuum mass comparator was developed in a collaboration between the Sartorius AG, the Technical University Ilmenau and the BIPM. The first comparator of this new type was installed at PTB. In this paper the set-up of the system and the local conditions are described. First results of measurements in air and in vacuum are presented.

Keywords: mass comparator, prototype balance

1. INTRODUCTION

Within the scope of a scientific cooperation the new 1 kg vacuum mass comparator CCL1007 developed by Sartorius AG in collaboration with the Technical University Ilmenau and the BIPM was installed at PTB in November 2005. The aim of this scientific cooperation is the investigation and improvement of the performance of this new mass comparator with respect to applications with highest requirements in mass metrology and mass-related research projects, e. g.

- Link of primary mass standards to national kilogram prototypes,
- Dissemination of the mass scale in the range between 100 g and 1 kg,
- Experimental determination of the air density by comparison weighing of buoyancy artefacts in air and vacuum,
- Mass determination of 1 kg silicon spheres used as density standards and for the determination of the Avogadro constant,
- Experimental investigation of convection, sorption and cleaning effects and their influence on precision mass measurements.

Although the installation of the climate system for the measurement of the air density parameters is not yet finished and only a small part of the investigations is completed, the first results of measurements in air and in vacuum give an impression of the performance and potential of this new mass comparator.

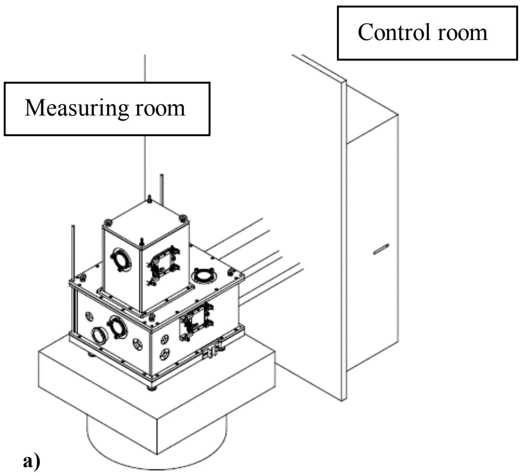
2. CONSTRUCTION AND SET-UP

A detailed description of the system and its specifications is given in [1] and [2]. In the following the main features of the construction and set-up at PTB will be given.

The 1 kg vacuum mass comparator CCL1007 consists of the main parts:

- Mass comparator with load alternator in a pressure-tight enclosure,
- Drive and control units with PC,
- Oil-free vacuum pumping system with a turbo-molecular and a membrane pump.

Since the main heat sources are the vacuum pump system and the drive and control units, these parts were installed in a separate control room (Fig. 1).



a)

b) c)

Fig. 1. a) Sketch of the comparator set-up in two rooms, b) Pressure-tight enclosure with integrated load alternator, mass comparator and load device in the measuring room, c) Drive and control units with PC in the control room

The remaining heat dissipation in the measuring room caused by the mass comparator and the load alternator is less than 100 mW. Both rooms are equipped with a separate air-conditioning system.

The pressure-tight enclosure is made from aluminium and consists of four main parts: the bottom plate, the base chamber in the middle, the top cover plate and the upper chamber for the weighing cell. These parts of the enclosure do not have to be dismounted after installation. The base chamber has a 160 mm square lock door through which the weights can be loaded onto the turntable. For this purpose a special external load device is used (Fig. 2). The centre of gravity of the weight relative to the position on the turntable is determined by three strain gauge systems. During the automatic loading procedure the eccentricity of the weight is adjusted in x-direction by translation of the load device and in y-direction by rotation of the turntable. The result of this adjustment is a pre-centred weight on the turntable which is ready for the weighing procedure.

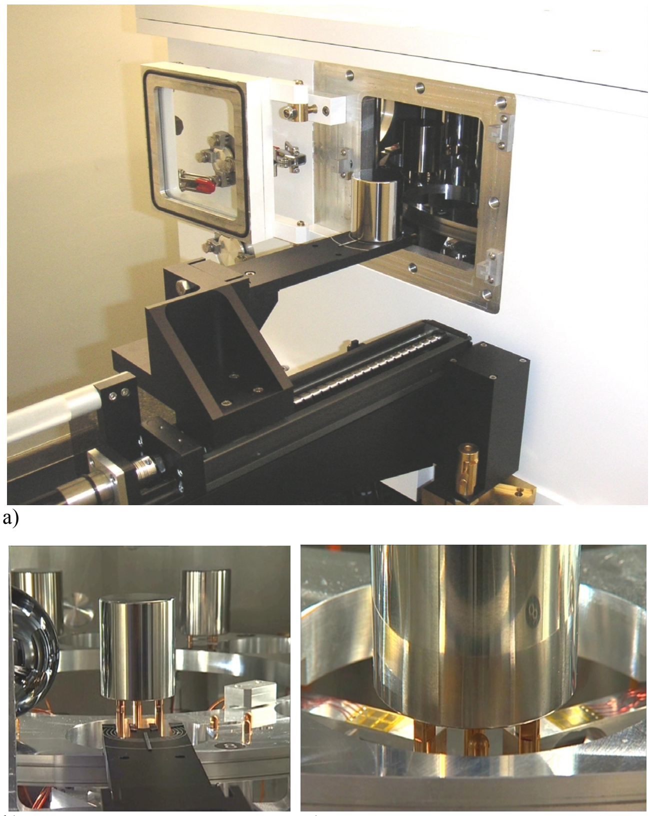

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Fig. 2. a) Loading of a 1 kg stainless steel cylinder onto the turntable with the external load device, b) Take-over of the weight by the lifting device, c) Determination of the centre of gravity by three strain gauge systems

Construction and functionality of the 8-position load alternator are based on the known BIPM FB2-technology [3]. The diameter was increased to 555 mm in order to meet the requirement that spherical weights up to a diameter of 100 mm can be carried on each position. The 8-position turntable provides sufficient space for a simultaneous weighing of reference weights, sorption artefacts, buoyancy artefacts and test weights (Fig. 3). A thin tungsten wire with a diameter of 0,125 mm drives the turntable. This wire is wound around the end face of the turntable. All heat sources of the drive mechanism are located outside the enclosure.

The mass comparator used (Fig. 4) is based on the commercial 1 kg Sartorius mass comparator CC1000S-L, which has a readability of 1 µg and a typical repeatability of 1 µg (standard deviation of six ABBA weighing cycles). For this application the weighing cell had to be changed in order to achieve more sensitivity. This has been realised by decreasing the spring constant of the flexures used in the universal joint (Fig. 5).

Fig. 3. Integrated turntable with eight positions

A special lever was designed for which the knowledge of the Sartorius monolithic manufacturing process was used. As a result a smaller movement of the lever caused by material tension and a reproducible positioning after load changes was achieved. The weighing cell had to be modified also for operation under vacuum conditions, e. g. no blind holes were allowed and any kind of electric wire had to be replaced by a suitable one with a special insulation made of PTFE or Kapton.

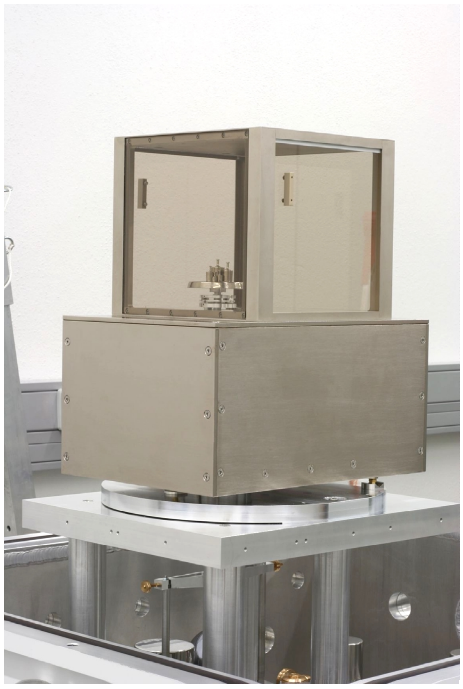
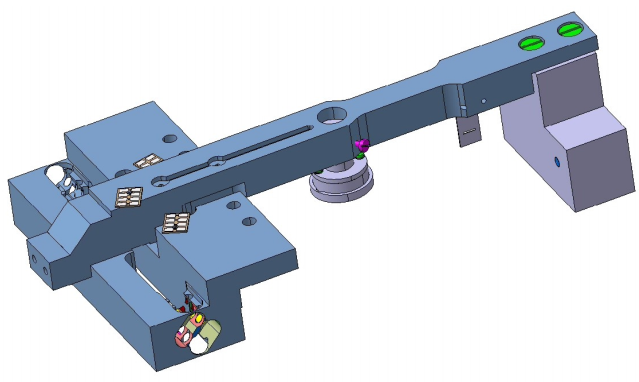


Fig. 4. Mass comparator

Another important difference to the CC1000S-L is the change from a top loading comparator to a design with a traditional suspension. The CCL1007 has no Centermatic pan. After pre-centring has been carried out at the end of the automatic loading procedure, the final centring of the weights is done by means of a suspension, which is designed like a pendulum.



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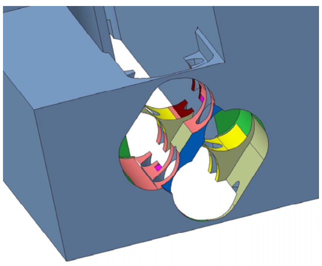

b)

Fig. 5. a) Lever with coil and counterweight, b) Monolithic universal joint (fixed)

3. RESULTS AND DISCUSSION

First measurements were performed with 1 kg stainless steel cylinders. For the loading of the weights onto the turntable the external load device was used as shown in Fig. 2. An example of the determination of the centre of gravity by the three strain gauge systems and the pre-centring of the weight is given in Table 1. The weights on the positions 2, 4, 6 and 8 had already been centred in the preceding weighing series on the positions 3, 5, 7 and 1 and just moved to the new positions. The free positions 1, 3, 5 and 7 were loaded with new weights. The zero position is defined by the position of the centre of gravity of a well-centred weight. For the example given in Table 1 the control software used a default value for the maximum deviation from the zero position of 40 µm in x-direction and 80 µm in y-direction. If the position of the centre of gravity exceeds these limiting values, the weight is adjusted in x-direction by translation of the load device and in y-direction by rotation of the turntable. In the example of Table 1 the pre-centred positions 2 and 4 were already within the limits. The other positions were centred with only one adjustment. For a centred weight the repeatability of the position was better than 20 µm. The relative expanded uncertainty of the determination of the centre of gravity by the three strain gauge systems itself is estimated to be smaller than 5 %.

Table 1. Example of the determination of the centre of gravity by the three strain gauge systems and the pre-centring of weights according to the indication given by the control software

Position	Weight identifier	1st Indication (x/y-direction in µm)	2nd Indication (x/y-direction in µm)
1	2 B	184/296	-4/13
2	16026058	-17/12	
3	16026054	1195/9	-19/11
4	17025283	-10/5	
5	17526210	253/162	-16/3
6	1 A	-44/-20	-24/-40
7	2 A	-435/13	-19/4
8	1 B	-54/62	-20/50

In the following first weighing results in air and vacuum are presented. In each case the measurements were performed in weighing cycles comprising six ABBA sequences.

3.1 Weighing in air

Results of a comparison of the weights on the positions 4 and 5 are shown in Fig. 6. Since environmental conditions are important for interpretation of the results, also the temperature in the measuring room is given. For a temperature stability of ±35 mK over a period of 48 hours a pooled standard deviation [4] of 0,16 µg could be achieved. The weighing differences are, with one exception (-0,94 µg), within a range of ±0,5 µg of the mean value.

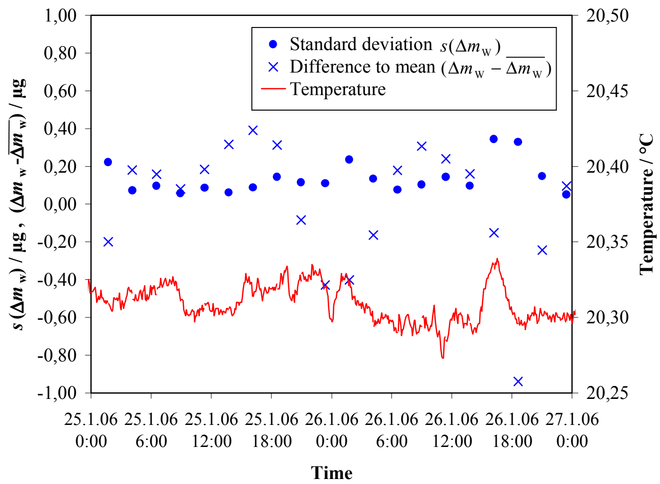

Fig. 6. Results of a comparison of two cylindrical stainless steel weights in air with temperature in the measuring room

Results of the first measurements in air indicate a sensitivity of the system with respect to short-time temperature variations in the measuring room. An example of this influence is given in Fig. 7. Because of a fault in the air-conditioning system the temperature in the measuring room oscillates with amplitudes of about 20 mK and periods of about 35 min. Under these conditions the weighing differences are within a range between -0,8 µg and +1,2 µg of the mean value. The pooled standard deviation increases to about 0,5 µg. Since the volume difference between the weights is smaller than 1 mm^3 and the system is closed, it is not assumed that these results can be explained by changes of the air density.

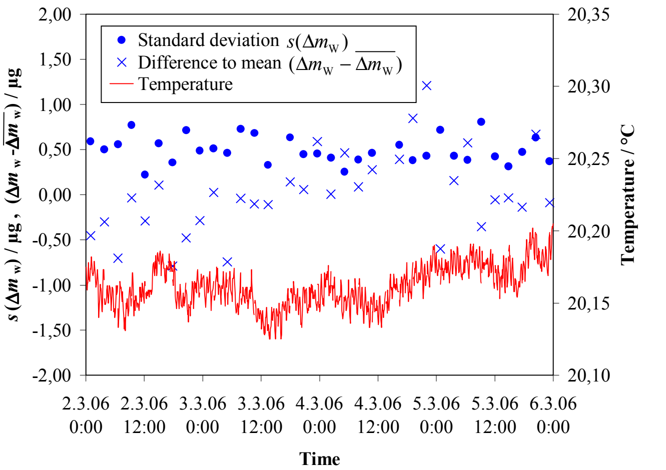

Fig. 7. Results of a comparison of two cylindrical stainless steel weights in air with temperature in the measuring room

3.2 *Vacuum weighing*

For measurements in vacuum the enclosure was evacuated by the vacuum pumps down to a pressure of about $5{\cdot}10^{-6}$ mbar ($5{\cdot}10^{-4}$ Pa). In Fig. 8 the pressure curve is given as a function of time. The membrane pump reduces the pressure in the first hour to about 3 mbar. At this pressure the turbo-molecular pump is switched on. After about 7 hours a pressure of $<10^{-5}$ mbar is achieved.

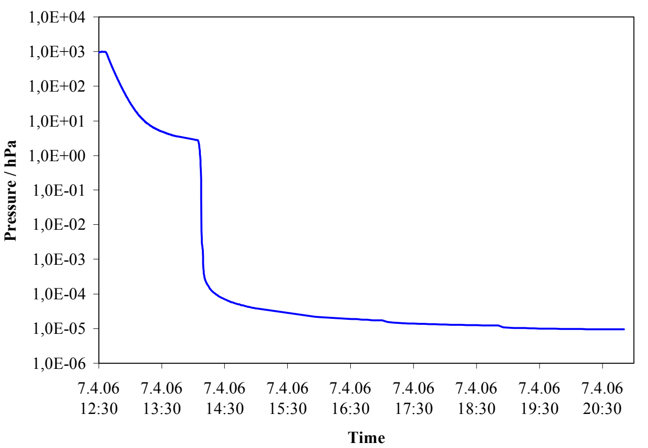

Fig. 8. Pressure as a function of time for the evacuation of the enclosure

Results of vacuum measurements are shown in Fig. 9 together with the temperature in the measuring room. At the time of the first peak in the temperature curve the measuring room was entered for more than one hour. The reason for the second peak is a fault in the air-conditioning system. Although the temperature is not as stable as during the measurements shown in Fig. 6, the pooled standard deviation is reduced to 0,06 µg. The weighing differences are in the range between -0,22 µg and +0,12 µg of the mean value.

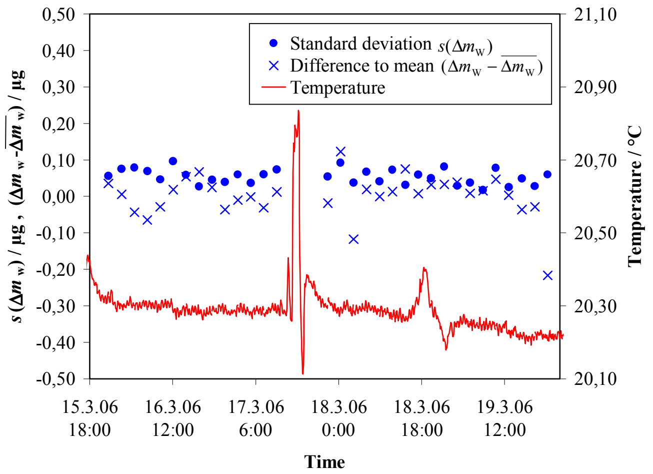

Fig. 9. Results of a comparison of two cylindrical stainless steel weights in vacuum with temperature in the measuring room

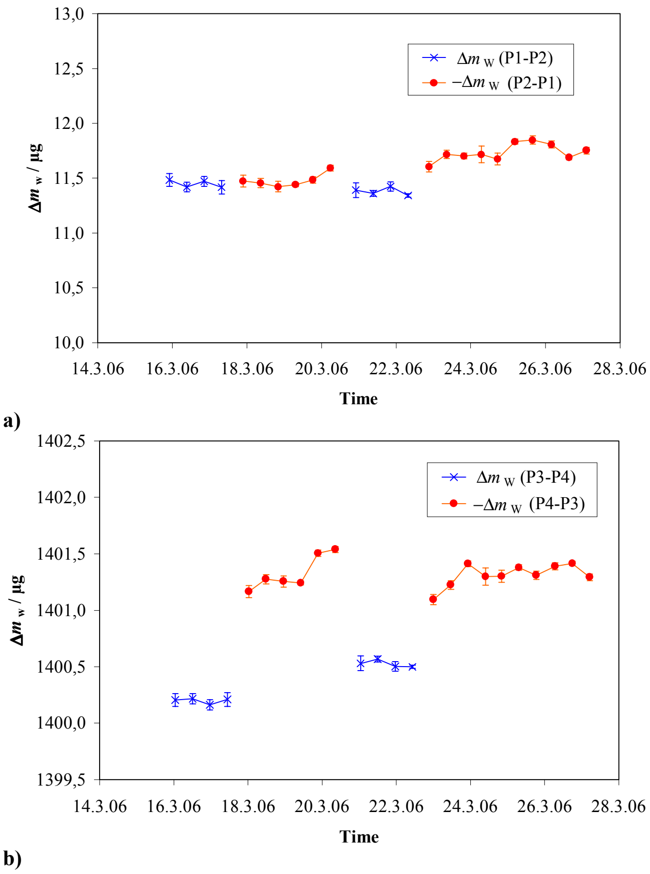

Fig. 10a-b. Weighing difference Δm_W for interchanged positions on the turntable (bars indicate standard deviation). a) Positions 1 and 2, b) Positions 3 and 4

Additional measurements were performed under vacuum conditions to estimate the interchanging difference between two weight positions on the turntable. In Fig. 10 two examples are given for the positions 1, 2 and 3, 4. The mean value for the interchanging difference between the positions 1 and 2 is 0,15 µg, and 0,9 µg between the positions 3 and 4, i. e. the interchanging error is expected to be smaller than 0,5 µg in both cases. Similar results were obtained for the other adjacent positions on the turntable, with one exception. Between the positions 1 and 8 an interchanging error of about 1 µg was determined. Therefore the adjustment of the positions will be checked.

SUMMARY AND CONCLUSIONS

A new 1 kg vacuum mass comparator Sartorius CCL1007 was installed at PTB. The set-up of the system was described and first results of measurements in air and in vacuum presented. For 1 kg stainless steel weights a pooled standard deviation of 0,16 µg in air and 0,06 µg in vacuum could be achieved. The weighing differences were in the range between -0,94 µg and +0,4 µg of the mean value in air and between -0,22 µg and +0,12 µg of the mean value in vacuum. Measurements in air indicate a sensitivity of the system with respect to short-time temperature variations in the measuring room. In order to reduce this sensitivity modifications of the thermal insulation are planned to reduce this sensitivity. Measurements of the interchanging error between adjacent positions of the turntable were performed. An interchanging error of less than 0,5 µg was determined, with one exception. Between position 1 and position 8 an interchanging error of 1 µg was measured. The adjustment of the positions will be checked. After completion of the climate system for the measurement of the air density parameters further measurements are planned with buoyancy artefacts, silicon spheres and Pt-Ir prototypes.

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