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Technical Paper

# INTERCOMPARISON BETWEEN CENAM, BIPM, AND TROEMNER TO DETERMINE THE VOLUME MAGNETIC SUSCEPTIBILITY OF A 100 g WEIGHT

# INTERCOMPARISON BETWEEN CENAM[1], BIPM[2] AND TROEMNER[3] TO DETERMINE THE VOLUME MAGNETIC SUSCEPTIBILITY OF A 100 g WEIGHT

J Nava[1], R S Davis[2] and J Moran[3]
[1] Centro Nacional de Metrología, CENAM, Mexico.
[2] Bureau International des Poids et Mesures, BIPM, Sèvres Cedex, France
[3] Accredited Laboratory by NVLAP, USA.

**Abstract.** Magnetic interactions may lead to errors in mass measurements of high accuracy. Requirements of magnetic susceptibility and permanent magnetization on the mass standards (weights) have been included in the new draft of OIML R111. Measurement methods and instruments for characterizing these magnetic properties of the weights have been developed as well. The BIPM susceptometer has been adopted by a number of primary laboratories with responsibility for mass standards. We report a comparison of susceptibility results by three different laboratories using this instrument.

## 1. Introduction

The BIPM Susceptomer has been adopted by a number of primary laboratories that they have the responsibility of the mass standards of high accuracy. The new draft OIML R111 has included new requirements on volume magnetic susceptibility and permanent magnetization [1] for mass standards (weights). Volume magnetic susceptibility can be measured quantitatively using the BIPM susceptometer and permanent magnetization can be detected.

Normally, the weighing of a body using a weighing instrument is based on the gravitational force on the body. However, the presence of the magnetic forces due to magnetic properties of the body and also from the ambient magnetic field generated by the weighing instrument (electrical circuits, coils and permanent magnets) should not be considered negligible [3].

The aim of this comparison is to check the use of the susceptometer described in [2] to determine the volume magnetic susceptibility of a Class $E_2$ 100 g standard.

The test procedure that CENAM, BIPM and TROEMNER used is proposed in [2] and is similar to that described in [1].

## 2. Weight

One 100 g weight was used to this comparison, it was manufactured by TROEMNER. The 100 g weight complies with the OIML R111 requirements [4].

The weight dimensions were given directly by TROEMNER and were checked by the others two participants.

## 3.- Model for Magnetic Errors in Mass Metrology

The z-component of a force on a sample with a magnetic susceptibility $\chi$ and magnetization *M* in a magnetic field is obtained from:

$$F_z = -\frac{\mu_0}{2}\frac{\partial}{\partial z}\int(\chi H * H)dV - \mu_0 \frac{\partial}{\partial z}\int(M * H)dV \qquad (1)$$

Where $\chi$ is the volume magnetic susceptibility of the standard, ***M*** is its permanent magnetization (defined as the magnetic moment per unit volume in zero field), ***H*** is the local magnetic field strength and the z-axis is parallel to the gravitational acceleration, *g* [2]. The integrals are taken over the volume of the sample.

## 4.- BIPM susceptometrer

CENAM, BIPM and TROEMNER used the susceptometrer described in [2], the difference was the weighing instrument adopted at the susceptometrer, such characteristics are describe in the following table 1:

**Table 1.** Weighing instrument characteristics adopted at the susceptometer:

| Institute | Weighing instrument |
|---|---|
| CENAM | MX 5 *d*= 0,001 mg |
| BIPM | UMT 5 *d*= 0,000 1 mg |
| TROEMNER | UMT 5 *d*= 0,000 1 mg |

Figure 1 shows the apparatus schematically, the design details also are described in [2].

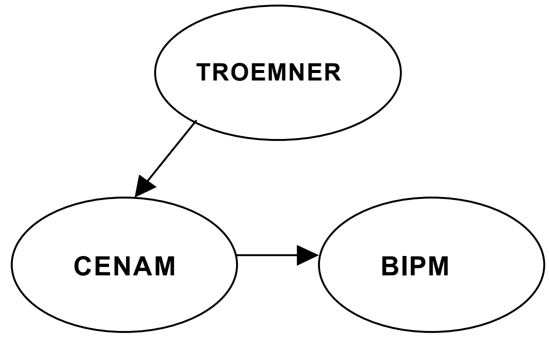
**Fig.1** View of the apparatus. A small rare-earth magnet is placed on a supporting column, which is on the pan balance. A nonmagnetic bridge, the height of which may be increased using blocks, spans the weighing chamber. The body (weight) is placed on the bridge.

**5. Traceability**

**CENAM** determined the distance between the magnet and the bridge ($Z_0$) [2] by using two different methods; one method was using a reference standard of magnetic susceptibility whose value was determined by the BIPM. and the second method was using a set of gauge blocks and LVDT probe head these are traceable to the National Length Laboratory in Mexico. Balance readings are traceable to National Mass Laboratory (CENAM). The magnet was calibrated at the BIPM. The dimensions (for the geometry correction) of the weights were given by TROEMNER.

**BIPM** determined the distance $Z_0$ [2] by using a reference standard of magnetic susceptibility whose value was determined by the BIPM with respect to calibrated susceptibility standards obtained from a number of national measurement institutes. Balance readings are traceable to Mass Section of the BIPM. The magnet was calibrated at the BIPM [2,6]. The dimensions (for the geometry correction) of the weights were given by TROEMNER.

**TROEMNER** determined the distance $Z_0$ [2] by using a reference standard of magnetic susceptibility whose value was determined by the BIPM. Balance readings are traceable to National Mass Laboratory (NIST). The magnet was calibrated at the BIPM. The dimensions (for the geometry correction) of the weights were given by TROEMNER.




**6. Measurements**.

The measurements were carried out as follows:

The measurements were carried out by TROEMNER at March 2001, CENAM in April 2001 and the last measurements the BIPM in May 2001.

**7. Results**

The results of the comparison are presented in the following table 2:

**Table 2.** Results of the comparison

| | |
|---|---|
| **TROEMNER** | |
| Magnetic susceptibility $\chi$ | 0,003 0 |
| $U_\chi$ | 0,000 6 |
| Magnetic flux density (max.) | 0,8 mT |
| $Z_0$ | 27,71 mm |
| **CENAM** | |
| Magnetic susceptibility $\chi$ | 0,003 1 |
| $U_\chi$ | 0,000 6 |
| Magnetic flux density (max.) | 1,4 mT |
| $Z_0$ | 22,16 mm |
| **BIPM** | |
| Magnetic susceptibility $\chi$ | 0,003 1 |
| $U_\chi$ | 0,000 3 |
| Magnetic flux density (max.) | 0,9 mT |
| $Z_0$ | 26,64 mm |

## 8.- Uncertainty

The propagation of uncertainty from various sources is given in the following table 3, where $u_r(x)$ represents the relative standard uncertainty of a parameter *x*:

**Table 3**. Relative standard uncertainties of a parameter *x*

| Source of Uncertainty | Contribution to $u_r(\chi)$ |
|---|---|
| $u_r(m_a)$ | $u_r(m_a)$ |
| $u_r(m_a(s))$ | $\left[1+\frac{Y_f}{2}\right]u_r(m_a(s))$ |
| $u_r(m)$ | $Y_f u_r(m)$ |
| $u_r(\chi_s)$ | $\left[1+\frac{Y_f}{2}\right]u_r(\chi_s)$ |

Where $m_a(s)$*g = $F_a(s)$, g is the local acceleration of gravity and $F_a(s)$ is the force between the magnet and the standard. Thus $m_a(s)$ is the average balance reading found when measuring the standard and $m_a$ is the corresponding value of the unknown, *m* is the magnetic moment of the magnet, and $\chi_s$ is the magnetic susceptibility of the standard $Y_f$, which is approximately 0,5 for these measurements, takes account of correlations between $Z_0$, *m*, and $\chi_s$[6].

The $E_n$ values are presented in Table 3 in order to quantify the degree of agreement [5] between the participants

**Table 3.** The $E_n$ values are presented in this table

| | $E_n$ |
|---|---|
| BIPM-CENAM | 0 |
| BIPM-TROEMNER | 0,14 |
| CENAM-TROEMNER | 0,12 |

$$|E_n| \leq 1$$

The degree of agreement among the participants is seen to be excellent. In other words the reproducibility of susceptibility measurements made with the BIPM susceptometer is excellent. Similar agreement has also been obtained in another recent comparison [7].

## 9. Conclusions

The new magnetic susceptibility and permanent magnetization requirements that proposed [1,3] are among the most important influence factors to be considered. We have shown that the reproducible measurements of the susceptibility of a 100 g OIML-shaped standard can be obtained using the BIPM susceptometer.

## 10 References

[1] Draft OIML R111 Weights of classes $E_1$, $E_2$, $F_1$, $F_2$, $M_1$, $M_2$, $M_3$ ( including weights for testing of high capacity weighing machines) Part 1: Metrological and Technical Requirements February 2000.

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