# Evaluation of the magnetic field and its influence in mass calibration in the national mass laboratories of Brazil and Uruguay


*Joselaine Caceres* [1], *Victor M. Loayza* [2], *Luiz C. Benyosef* [3], *Fabio L. Cacais* [4], *Claudia C. de Castro* [5]

[1] LATU, Montevideo, Uruguay, jcaceres@latu.org.uy
[2] Inmetro, Xerém, Brazil, vmloayza@inmetro.gov.br
[3] Observatório Nacional, Brazil, benyosef@on.br
[4] Inmetro, Xerém, Brazil, facacais@inmetro.gov.br
[5] Inmetro, Xerém, Brazil, cscastro@inmetro.gov.br



**Abstract:** Magnetic fields are present in all common mass laboratories, since most of them are not magnetically shielded. Although magnetic interactions may be present during weighing procedures, in mass metrology mathematical models, magnetic forces are usually treated as negligible. In this paper, the environmental magnetic field inside the Mass Laboratories of two NMI's, LATU and Inmetro, has been measured. In addition, the magnetic interactions during mass calibration of high accuracy mass standard have been evaluated. Based on these evaluations, it was verified that the magnetic interactions can in fact be neglected in mass determinations carried out in both laboratories.



**Key words:** mass, calibration, mass comparators, magnetic field, magnetic force.


## 1. INTRODUCTION

Mass comparators are instruments used in mass laboratories with the aim of determining mass differences between mass standards. High resolution comparators can detect mass differences of a few micrograms in 1 kg mass standards. Nevertheless, such comparators are, in fact, force sensors. In mass metrology the forces taken into account for mass determinations are the weight and the air buoyancy [1]. The net force applied on the weighing pan along the vertical axis is sensed by the weighing system of mass comparators. Other forces that could be present, such as the magnetic force, are treated as if they were negligible [2].

In order to make this assumption, mass standards must comply with magnetic properties tolerances stated in the recommendation R-111 of the International Organization of Legal Metrology (OIML) [2]. This recommendation establishes tolerances according to nominal mass values as well as the accuracy class for stainless steel standard weights. However, magnetic force arises as an interaction between mass standards, which depends on their magnetic properties, and environmental magnetic fields, such as those inside mass comparators, that can be present during mass calibration. Inside laboratories, there are many sources of magnetic field. It can arise from electric devices neighbors and materials used in laboratory construction which could become magnetized; other source of magnetic field is the electromagnetic compensation system which is part of the mass comparator

. Commonly, the vertical component of the magnetic force, $F_z$, is expressed as [3]:

$$F_z = (\chi - \chi_A)\mu_0 \int \boldsymbol{H}_0 \cdot \frac{\partial \boldsymbol{H}_0}{\partial z} dV \qquad (1)$$

where $\chi$ is the volume magnetic susceptibility of mass standards, $\chi_A$ is the volume magnetic susceptibility of air ($3.6 \times 10^{-7}$), $\mu_0$ is the magnetic permeability in vacuum, $\mathbf{H}_0$ is the environmental magnetic field, z is the coordinate along the vertical axis and V is the volume of the mass standard.

Only the vertical force component is considered in mass determination because it is the only one that can affect those determinations by weighing.

Magnetic force on mass standards depends on their magnetic properties and the environmental field, as can be seen by equation (1). So, it is advisable to have a complete knowledge of the magnetic fields and their gradients inside the mass laboratory as well as inside the weighing chamber of mass comparators. In this way, it is possible to determine if there are some points in the laboratory where the mass standards should not be stored in order to avoid increasing their magnetization. In addition, it is also possible to verify if magnetic force is in fact negligible during a mass standard calibration [4].

In this study, we evaluated the environmental magnetic field strength in Inmetro's and LATU's mass laboratories, in order to estimate the magnetic force magnitude during mass determination in the two institutes.

## 2. METHODS

### 2.1 Magnetic field measurements

Environmental magnetic field measurements were carried out inside two National Mass Laboratories, Inmetro and LATU. A fluxgate magnetometer from Globalmag model TLMP FLG was used in both laboratories. This instrument is capable of measuring magnetic fields of up to

1000 mG (100 μT) with a resolution of 4 mG (0.4 μT). It has been calibrated in Instituto de Pesquisas Tecnologicas (IPT) and has traceability to Inmetro. We kept the sensor in a vertical position, considering positive values of the field pointing upwards. The plane perpendicular to the vertical axis (z) was scanned at 1.2 m above the floor level. This height was chosen in order to simulate the approximate level at which the mass standards are transported and stored in the laboratory. Measurements were taken at a regular interval of 0.5 m along the length and width of the laboratory.

Using a more accurate fluxgate magnetometer with a smaller sensor (see figure 1), built by the Laboratório de Desenvolvimento de Sensores Magnéticos (LDSM) from Observatório Nacional (ON), Brazil, the vertical component of the magnetic fields inside mass comparators were determined, as well as their gradients. This magnetometer is able to measure magnetic fields of up to 64 μT with a resolution of 0.001 μT. It has traceability to the Vassouras Magnetic Observatory in Brazil from the global network of magnetic observatories INTERMAGNET .

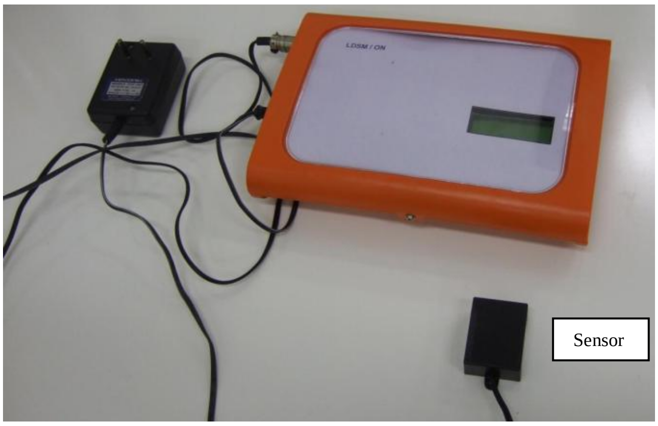


**Figure 1:** Magnetometer developed at LDSM/ON.

In each comparator from LATU, magnetic fields were measured along the vertical axis inside the weighing chamber, keeping the sensor in a vertical position on the center of the pan (level 1) (see figure 2). Considering the magnetic field linear as a function of the distance along the vertical z axis [5], its gradient was determined by raising the sensor to a known distance (level 2) and the fields were determined at both levels.

In two mass comparators from Inmetro, the magnetic fields were measured in more than two levels, along the vertical axis of the comparators centered at the pan. Measurements were taken at regular level intervals of 5 mm and the magnetic field gradient was determined as a function of those levels. This procedure was undertaken to verify the magnetic field linearity along the vertical axis.

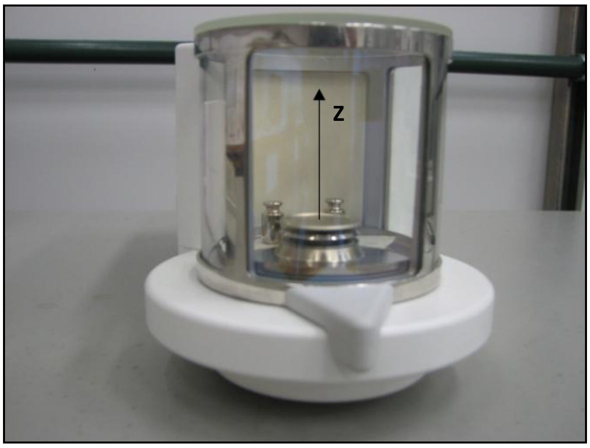


**Figure 2:** Vertical z axis centered on Mettler Toledo UMT5 mass comparator pan. Mass Laboratory – Inmetro.

### 2.2 Magnetic force calculations

For the magnetic fields and their gradients experimentally obtained, the corresponding magnetic force on mass standards was theoretically calculated assuming that the standards had magnetic properties at the maximum value specified by International Recommendation OIML R111 for the highest accuracy class ($E_1$).

For this calculation, the magnetic fields measured in LATU were assumed linear and their gradients constant along the z axis.

This linear assumption was tested in Inmetro by measuring the magnetic field at more than two levels in two comparators. The linear model for the magnetic field was contrasted with a polynomial fit for the experimental data.

Thus, the magnitude of the magnetic influence in a mass standards calibration was estimated for the specific condition of each NMI investigated in this work.

## 3. RESULTS

### 3.1 Environmental magnetic field measurements

Results of the magnetic field intensities along the vertical axis inside the NMI's Mass Laboratories are shown in figures 3 and 4. The white blocks represent the local position of appliances in each laboratory.

Uncertainty on measurements has been estimated on 1,3 mG.

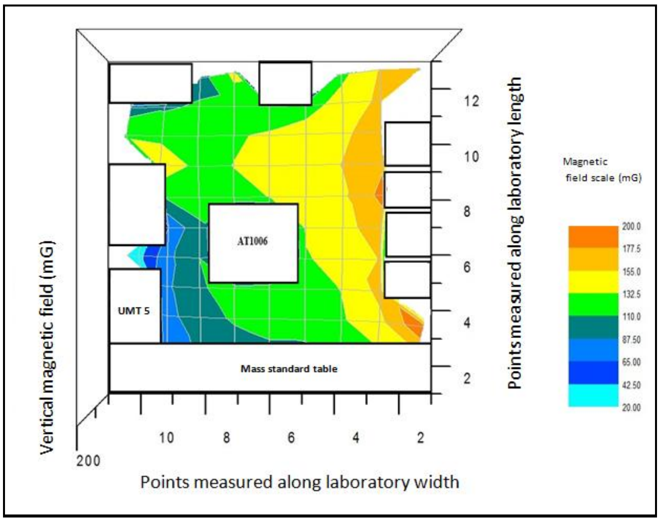


**Figure 3:** Magnetic field intensities measured in the circulation areas of the Mass Laboratory of Inmetro. Measurements were carried out at points in regular intervals of 0.5 m over the xy plane. Only the mass comparators under study are identified.

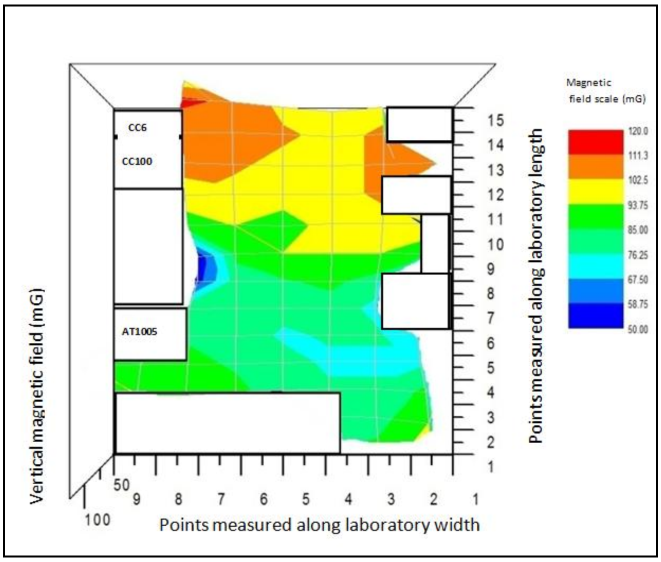


**Figure 4**: Magnetic field intensities measured in the circulation areas of the Mass Laboratory of LATU. Measurements were carried out at points in regular intervals of 0.5 m over the xy plane. Only the mass comparators under study are identified.

## 3.2 Magnetic field measurements inside mass comparators

In table 1 the magnetic field measured along the vertical axis inside LATU´s mass comparators are presented.

**Table 1:** Mean magnetic field intensities measured inside LATU´s mass comparators.

| Mass comparator model | Mean magnetic field /(A/m) | | Distance between levels/ (m) | Magnetic field gradient /(A/m$^2$) |
|---|---|---|---|---|
| | Level 1 | Level 2 | | |
| **Sartorius CC6** | 12.394 | 8.550 | 0.068 | -56.54 |
| **Sartorius C100** | 9.506 | 7.799 | 0.112 | -15.29 |
| **Mettler Toledo AT1005** | 12.423 | 8.312 | 0.049 | -83.04 |

In figure 5, magnetic field intensities along the vertical axis inside the weighing chamber of Inmetro's Mettler Toledo AT1006 mass comparator are shown.

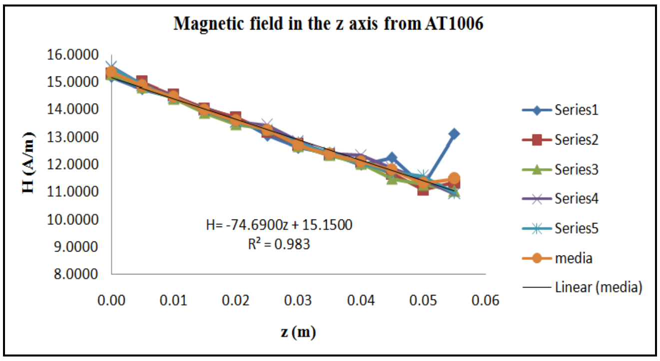


**Figure 5**: Magnetic field intensities along the vertical axis inside Mettler Toledo AT1006 mass comparator from Inmetro's Mass Laboratory.

In figure 6, magnetic field intensities along the vertical axis inside the weighing chamber of Inmetro's Mettler Toledo UMT5 mass comparator are shown.

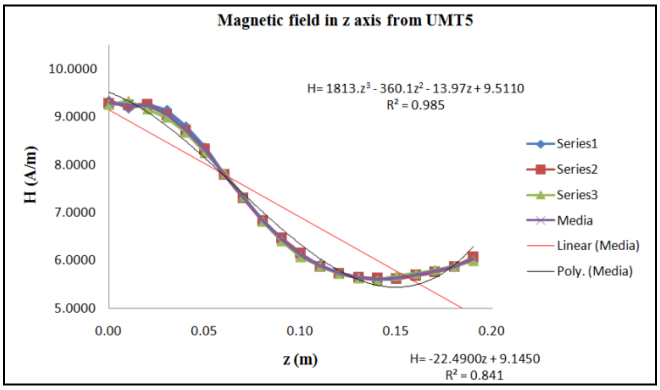


**Figure 6**: Magnetic field intensities along the vertical axis inside Mettler Toledo UMT5 mass comparator from Inmetro's Mass Laboratory.

Uncertainty on magnetic fields measured with LDSM/ON magnetometer has been evaluated on 0,079 A/m, and uncertainty on gradients determination on 0,99 A/m$^2$.

## 3.3 Evaluation of magnetic force magnitude

In table 2, results for the calculated vertical magnetic force using equation (1) are presented for each mass comparator. For such calculation, the magnetic field intensities along the vertical axis measured inside mass comparators were used. In order to estimate the maximum magnetic force that could be present during a mass calibration procedure, the volume magnetic susceptibility for mass standards was assumed to be the same as the tolerance values for class $E_1$ weights specified in the International Recommendation OIML R111. The symbols featured in table 2 represent the following: D and L are mass standard diameter and height respectively; $\chi$ is the mass standard volume magnetic susceptibility; $F_Z$ c is the calculated magnetic force and $F_Z$ d is the minimum force that each comparator can sense. $F_Z$ d has been estimated by considering the product between the resolution of each comparator and the local gravity acceleration. The mass standard dimensions have been chosen according to the dimensions of weights corresponding to the maximum capacity of each comparator. For example, the mass standard dimensions considered for Mettler Toledo AT1005 are those corresponding to a cylindrical weight of 1 kg, as 1 kg is the maximum capacity of this comparator.

**Table 2**: Evaluation of the maximum vertical magnetic force during a calibration of mass standards in LATU´s mass comparators. Refer to the text for the meaning of symbols.

| Mass comp | $H_0$ /(A/m) | $\partial H_0/\partial z$ /(A/m$^2$) | D/(m) | L /(m) | χ | Fz c /(μN) | Fz d /(μN) |
|---|---|---|---|---|---|---|---|
| **Sartorius CC6** | 12.394 | -56.54 | 0.008 | 0,015 | 0.06 | 0.00003 | 0.00098 |
| **Sartorius CC100** | 9.506 | -15.29 | 0.022 | 0.038 | 0.02 | 0.00004 | 0.00979 |
| **Mettler Toledo AT1005** | 12.423 | -83.04 | 0.054 | 0.055 | 0.02 | 0.0028 | 0.0979 |

Uncertainty on LATU's mass comparators has been estimated on 3% of force values on table 2.

In tables 3 and 4, results for Inmetro´s Mettler Toledo AT1006 and UMT5 mass comparators are presented, repectively. The calculations were based on the same criteria applied to the calculations for LATU's mass comparators. The magnetic field parameters were obtained by linearly fitting the experimental data. The meaning of the symbols that appear in tables 3 and 4 is the same as in table 2.

**Table 3**: Evaluation of the maximum vertical magnetic force during a calibration of 1 kg mass standards in Inmetros´s Mettler Toledo AT1006 mass comparator. Refer to the text for the meaning of symbols.

| Mass comp | Parameters according to linear fit presented in figure 5 | | D/(m) | L/(m) | χ | Fz c /(μN) | Fz d /(μN) |
|---|---|---|---|---|---|---|---|
| | $H_0$ /(A/m) | $\partial H_0/\partial z$ /(A/m$^2$) | | | | | |
| **Mettler Toledo AT 1006** | 15.150 | -74.69 | 0.054 | 0.055 | 0.02 | 0.0031 | 0.0098 |

**Table 4**: Evaluation of the maximum vertical magnetic force during a calibration of 5 g mass standards in Inmetro´s UMT5 mass comparator using a linear fit for the measured magnetic field. Refer to the text for the meaning of symbols.

| Mass comp | Parameters according to linear fit presented in figure 6 | | D/(m) | L/(m) | χ | Fz c /(μN) | Fz d /(μN) |
|---|---|---|---|---|---|---|---|
| | $H_0$ /(A/m) | $\partial H_0/\partial z$ /(A/m$^2$) | | | | | |
| **Mettler Toledo UMT5** | 9.145 | -22.49 | 0.008 | 0,015 | 0.06 | 0.000011 | 0.00098 |

In table 5, results for the maximum vertical magnetic force during a calibration of 5 g mass standards in Inmetro´s UMT5 mass comparator are shown. In this case, calculations were undertaken using a polynomial fit for the measured magnetic field (see figure 6). For the other quantities, the same criteria used in the previous calculations apply.

**Table 5**: Evaluation of the maximum vertical magnetic force during a calibration of 5 g mass standards in Inmetro´s UMT5 mass comparator using a third order polynomial fit for the measured magnetic field presented in figure 6. Refer to the text for the meaning of symbols.

| Mass comp | D/(m) | L /(m) | χ | Fz c /(μN) | Fz d /(μN) |
|---|---|---|---|---|---|
| **Mettler Toledo UMT5** | 0.008 | 0,015 | 0.06 | 0.000009 | 0.00098 |

Uncertainty on Inmetro's mass comparators has been estimated on 4% of force values on tables from 3 to 5.

## 5. DISCUSSION

Considering the experimental evaluation of the environmental magnetic field in the mass laboratories investigated in this work, if one compares with the maximum values specified by the International Recommendation OIML R111 for the accuracy classes $E_1$ and $E_2$ (see table 6), the measured values are far below the tolerances of the Recommendation. This result indicates that there are no points in the laboratory that could permanently change the magnetic properties of any mass standard.

**Table 6**: Maximum environmental vertical magnetic field measured in each laboratory compared with limit of magnetic field exposition for weights specified in OIML R111.

| Highest vertical magnetic fields measured at each laboratory | | | |
|---|---|---|---|
| | mG | μT | A/m |
| **LATU** | 120 | 12.0 | 10.00 |
| **Inmetro** | 477 | 47.7 | 38.00 |
| Tolerances of exposition to magnetic field specified by OIML R111 | | | |
| Class | | Tolerances (A/m) | |
| $E_1$ | | 2000 | |
| $E_2$ | | 800 | |
| All other classes | | 200 | |

In all calculations it was assumed that the magnetic field inside mass comparators from LATU were linear. In order to support this assumption, the magnetic field in two mass comparators from Inmetro were measured along the vertical axis in more than two levels and polynomial fittings were applied to the experimental curves presented in figures 5 and 6. For Mettler Toledo AT1006 (see figure 5), the linear fit was adequate (regression coefficient obtained was 0.983). This indicates that the linear model for the vertical magnetic field in this case is a good approximation to the actual vertical component of the magnetic field.

Notwithstanding, the linear fit for UMT5 mass comparator did not produce good agreement with the experimental curve (see figure 6). In this case, a third order polynomial fit produced a better agreement with the experimental data ($R^2$ = 0.985). With the aim of evaluating the difference of the linear model assumption relative to the polynomial model for the magnetic field, the vertical magnetic force was calculated in both instances: the linear and the third order polynomial fits applied to the vertical component of the magnetic field. The results shown in tables 4 and 5 demonstrate that such difference is of the order of 10 %.

It is important to notice that the calculated vertical magnetic force inside all the comparators investigated in this work is smaller than the minimum force that each comparator can sense, as demonstrated by the results in tables from 2 to 5. In this way, the magnetic force can in fact be neglected when determining mass differences in the mass laboratories of LATU and Inmetro.

## 6. CONCLUSION

In this paper it has been demonstrated that the vertical component of environmental magnetic fields in the mass laboratories of LATU and Inmetro are much smaller than the values of tolerances stated in the International Recommendation OIML R111.

It was also investigated the validity of assuming a linear model for the vertical component of the magnetic fields inside mass comparators. Is has been shown that this assumption is reasonable for actual magnetic fields.

In addition, the vertical component of magnetic forces in mass comparators was estimated in order to determine their influence in mass determination in the mass laboratories of LATU and Inmetro. Results demonstrate that magnetic interactions can be neglected in both cases.

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