Calibration of Analog Scales Based on a Metrological Comparison Between the SIM Guide and OIML R 76-1

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Abstract

This work compared the guidelines established by the OIML R 76-1 and SIM Guide for Calibration of analog non-automatic weighing instruments. Once the data were obtained in the accredited metrological laboratory, the task of tabulating, calculating and then comparing, by means of statistical tools, the similarities, advantages and disadvantages among the four different calibration processes was performed. Comparing the results obtained for the different tests carried out, the results consolidated in this research will give solid tools to a metrology laboratory: (i) define a classification of the methods that offer the lowest uncertainty associated with the measurement. (ii) reformulate the cost / benefit criteria for the calibration of scales, once it is known that better results can be obtained by the application of a particular method; (iii) analyze an unquestionable economic impact, since it constitutes a large part of the solution of technical-economic challenges such as the one mentioned above. In addition, the methodology used here can be recreated for another type of analog non-automatic weighing instrument and thus build a real contribution to the state of the art of mass metrology.

Keywords: Calibration, uncertainty measurement, analog non-automatic weighing instruments
1 Introduction

This work was motivated by technical-economic challenges imposed by mass metrology, in particular, on issues concerning methods of calibration of non-automatic weighing instruments of analog type (i.e.: analog scales). In terms of contextualizing the problem, in the industry are different processes of mass measurement that are controlled by analog scales, e.g.: mass of liquids, chemicals, food, body mass of a person. In these processes, the balance is used in the following four conditions for mass measurement: (i) ascending and descending charge, returned to zero; (ii) ascending and descending load, without the need to return to zero; (iii) only with ascending load and (iv) only with descending load. In this context, and maintaining the principles for the calibration of a measuring instrument in which it must be performed in the same instrument operation conditions, metrology laboratories are in need of knowing the metrological reliability for each calibration scenario. So, this is, exactly, the main motivation for the development of the research documented here. In relation to the current regulations for the calibration of this technology, two organizations define the general guidelines: (i) at the American Continent, the Inter-American Metrology System (SIM), through the SIM Guide (2009) [1] and (ii) globally, the International Organization of Legal Metrology, through the OIML recommendation R-76-1 (2006) [2].

The OIML recommends applying five tests to evaluate the metrological reliability of an analog scale: accuracy, repeatability, eccentricity, mobility and zero point constancy. For its part, the SIM Guide states that an analog scale can be evaluated by applying only three tests, i.e.: accuracy, repeatability and eccentricity. In both cases, it is emphasized that the accuracy and repeatability tests are critical for the evaluation of metrological reliability, that is, for the estimation of the uncertainty associated with the mass measurement, within a specified probability level.

Thus, this paper was addressed with the main focus of evaluating these tests. So, three analog scales of the baby weighing type. In short, the OIML proposes a single method of execution for calibration processes for accuracy and repeatability tests: upward and downward load without return to zero, while the SIM Guide proposes that four possible calibration processes can be executed for the same tests (within which the method proposed by the OIML is adopted, i.e.: Upload up and down without return to zero), these processes are:

• Up and down load with return to zero;
• Upload up and down without return to zero;
• Upload load;
• Down load.

In this regard, within this research and with the support of the work of a Metrology Laboratory Accredited by the ONAC (National Accreditation Body of Colombia), the experimental study was conducted, in order to guarantee: (i) certified calibration of the instrumentation; (ii) metrological traceability of the results.
2 Calibration process of Non-automatic Weighing Instruments of mechanical operation

First, it should be noted that the use of certified measurement standards in a given calibration process ensures that the results of this process are reliable from the metrological point of view. The metrological traceability to international measurement standards (BIPM) is fully met if the standards used (normally national) are certified.

For the realization of the experiments in the laboratory, a standard dough set certified with M1 accuracy class (20 kg) was used, whose manufacturing material is cast iron. In the same way, a standard mass set with an accuracy class F1 (material: stainless steel, density: 7940 kg / m$^3$) was used [3-5]. In terms of analog scales, for this research a quantity of 3 scales with the same operating principle was chosen, same manufacturer and with identical metrological characteristics (range and resolution), the above was done to: i) show that, despite of equal metrological characteristics, the scales do not necessarily have the same performance, this is influenced by different factors, among which we have: location, use form, maintenance, time of use, application. These factors undoubtedly affect the metrological performance of an analog type scale [6-9]. The metrological characteristics of the three scales are detailed in Table 1.

Table 1. Description of the scales.

<table>
<thead>
<tr>
<th>INTERNAL ID</th>
<th>T131-16</th>
<th>T132-16</th>
<th>T133-16</th>
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<tbody>
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<td>Name of the instrument</td>
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<td>Scale weighs baby</td>
<td>Scale weighs baby</td>
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<tr>
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<td>386S</td>
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<td>0 to 50</td>
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<tr>
<td>Resolution</td>
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<td>0.25</td>
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<tr>
<td>Unity</td>
<td>lb</td>
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</tr>
</tbody>
</table>

3 Metrological analysis of the calibration process

For a better understanding of the metrological analysis (i.e.: calculation of apparent mass, adjusted, errors and uncertainties), this section exposes the main parameters associated with the calibration of Non-automatic Weighing Instruments [10]. The calibration process essentially seeks a relationship between the apparent mass and the indicated mass of the instrument. The apparent mass is defined as the value indicated by the balance taking into account the factors of the acceleration of gravity and the push factor. Equation 1 illustrates the mathematical expression used in this grade work for the calculation of the apparent mass.

$$m_{ap} = m_0 \left(1 - \frac{\rho_{ar}}{\rho_0} \right) \left(\frac{g}{g_{ref}}\right)$$ (1)
In this equation, $g_{ref}$ corresponds to the acceleration of gravity in the manufacturing site of the balance, additionally $\rho_{ar}$ is the density of the air where the calibration process is performed, $\rho_0$ is the density of the standard masses; $g$ is the acceleration of gravity instead of use and $m_0$ is the nominal mass of the measurement pattern [11].

In order to determine the air density ($\rho_{ar}$), it is necessary to apply the equation of the ideal gases for each temperature and pressure value measured at each point of the process [12-13]. Equation 2 illustrates the ideal gas ratio:

$$\rho_{ar} = \frac{P}{RT} \tag{2}$$

In this equation R is the universal constant of the ideal gases (8.3144 J/mol·K). The calculation of uncertainty ($u$) associated with the mass measurement process using the analog scales is determined from the following sources of uncertainty: 

*Uncertainty of adjustment* ($u_a$); 
*Uncertainty of the measurement pattern* ($u_p$); 
*Uncertainty of the balance* ($u_{inst}$).

The adjustment uncertainty ($u_a$) corresponds to the smallest quadratic mean deviation ($s$) resulting from the relationship between the apparent mass and the mass indicated by the balance. The mean square deviation ($s$) is calculated from a certain polynomial of degree $m$ that relates the values of the indicated mass and the apparent mass. Equation 3 illustrates the mathematical relationship for calculating the value of $s$.

$$s^2 = \frac{\sum_{i=1}^{n}(m_{ap} - m_a)^2}{n - m - 1} \tag{3}$$

In this equation $m_a$ corresponds to the adjusted mass from a given polynomial of fit, $n$ is the number of points measured and $m$ refers to the degree of the polynomial of adjustment. Once the polynomial that generates the lowest value of ($s$) is determined and in this way we can determine the adjustment uncertainty ($u_a$).

The uncertainty of the measurement pattern ($u_p$) is calculated from the combination of the uncertainties of the standard masses used at each measurement point using equation 4.

$$u_p = u_{m_t} = \sqrt{u_{m_1}^2 + u_{m_2}^2 + \cdots + u_{m_{i-1}}^2 + u_{m_i}^2} \tag{4}$$

In relation to the uncertainty of the balance ($u_{inst}$), its obtaining is given from the best adjustment polynomial and the resolution of the balance, equation 6 illustrates this mathematical relationship.
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\[ u_{\text{inst}} = C_m x^m + C_{m-1} x^{m-1} + \cdots + C_{m-m} x^{m-m} \] (5)

In the above equation, \( x \) corresponds to the resolution of the instrument divided by \( \sqrt{3} \) and \( C_m; C_{m-1}; C_{m-m} \) are the coefficients of the polynomial that best relates the values of the indicated mass with the apparent mass. Once the procedure for calculating each of the main sources of uncertainty (\( u \)) has been defined, the mathematical expression to calculate \( u \) will be presented.

\[ u = \sqrt{u_a^2 + u_p^2 + u_{\text{inst}}^2} \] (6)

The expanded uncertainty (\( U \)) is calculated from multiplying \( u \) by a safety factor (\( k \)), said uncertainty \( U \) is that expressed in the final result of a given measurement.

4 Results of the experimental data and evaluation of calibration methods

For the Method #1 (Upward and downward load with return to zero), from the experimental data it was possible to determine the apparent mass. Next, a "type" calculation of the apparent mass for a nominal mass (\( m_0 \)) of 1 kg is presented, taking for this equation 1 and the barometric pressure, it was possible to calculate the apparent mass:

\[ m_{ap} = (1 - \frac{10,192}{8314,472(28 + 273,15)} \frac{8000}{9,82862(9,79999)}) \]

\[ m_{ap} = 1,003 \text{ kg} \]

Consequently, when performing the same procedure for each mass point indicated by the instrument during the ascending and descending load, respectively, we proceed to construct the representative curves and to evaluate each one of the polynomials resulting from these curves, to determine which of these adjusts the behavior of the balance better. Figure 1 shows the curve constructed when evaluating the polynomial mentioned in each of the data collection points.
Figure 1. Adjustment curves polynomial grade 2. Method #1

Once the polynomials are obtained, the adjusted mass values are found corresponding to each experimental point. With the values of the mean square deviation for each of the polynomials, we proceed to calculate the adjustment uncertainty. In Table 2, it is highlighted that the value obtained for the polynomial grade 2 is the lowest, which dictates that said polynomial adjusts in a better way to the behavior of the instrument.

Table 2. Uncertainty of adjustment, method #1: Up and down charge with return to zero

<table>
<thead>
<tr>
<th>Adjustment uncertainty</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
<th>Grade 4</th>
</tr>
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<tr>
<td>0.0885</td>
<td>0.0820</td>
<td>0.0941</td>
<td>0.1626</td>
<td></td>
</tr>
</tbody>
</table>

Using the equation 4, the uncertainty of each of the standard masses ($u_p$) was calculated. The uncertainty of the scale ($u_{inst}$) was calculated using equation 5 appropriate to the polynomial of degree 2 of equation 8. The values of $u_a$; $u_p$ y $u_{inst}$ were multiplied by a conversion factor equal to 2.204 lb/kg. Using equation 6, Table 6 below shows the results of the calculation of the uncertainty associated with the measurement process ($u$) and the expanded uncertainty ($U$). Finally, Figures 6 and 7 illustrate the behavior of the error in relation to the adjusted mass, for the ascending and descending load, respectively.
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Figure 2. Method #1: Results of the calibration process

In an analogous manner to the procedure performed for methods #2, #3 and #4 and the evaluation and metrological comparison of the four calibration methods used was carried out with reference to the expanded uncertainty (U) resulting from each method. Figure 3 shows the comparison between the scales used in the experimental procedure. Which compares the different values of U obtained according to each method applied in the three scales.

Figure 3. Metrological comparison of the different calibration methods

According to the figure above, Calibration Method #3 (Purely ascending load) generates the lowest process measurement uncertainty for each of these scales. The experimental data and values with which the curves of the scales confirmed the importance of the paper and the contribution for the metrological mass science.

5 Conclusions

It was possible to obtain the adjusted calibration curves of the non-automatic weighing instruments of the analog type and thereby show in detail the calibration
curves for the measurement process attached to each balance. The uncertainty associated with non-automatic weighing instruments of the analog type was estimated and the measurement uncertainties were calculated for each of the four calibration methods proposed by the SIM Guide.

Finally, the results of this research allow to compare qualitatively and quantitatively the calibration methods proposed by the OIML-R-76-1 (2006) and the SIM Guide (2009), in order to define applicability guidelines depending on a given measurement process, since it was observed that, for all the scales evaluated, the calibration method #3 (purely ascending load) proposed by the SIM guide generated the lowest measurement uncertainty. Due to the above, the metrological results of this work of degree provide indications aimed at defining the calibration by means of the purely ascending load as the option that generates less uncertainty associated with the measurement.

References


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