XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

Calibration of nonautomatic weighing instruments

Author [1]*: Adriana Vâlcu*

[1] National Institute of Metrology, Bucharest, Romania, adriana.valcu@inm.ro

Abstract: This paper describes the metrological requirements and the measurements methods for calibrating nonautomatic weighing instruments. It also may be a useful guideline for operators working in calibration laboratories accredited in various fields. This paper is also intended to enable metrology laboratories to prove a given expanded uncertainty using suitable procedures. Two examples of calibration methods are given: one for electronic weighing instruments and another for the mechanical instruments. The described methods include information regarding the measurements standards used for calibration, environmental conditions, calibration procedures and estimation of the measurement uncertainty.

Keywords: electronic weighing instruments, mechanical weighing instruments, multiple ranges and multi-interval instruments.

Introduction

Calibration methods and the evaluation of the uncertainty described in the paper are in compliance with the OIML Recommendation OIML R 76-1 and ISO-GUM [3] (Guide to the expression of uncertainty in measurements-1995). The combined standard uncertainty results from both the type A and type B evaluations of the measurements uncertainty.

The environmental working conditions shall be suitable for the instrument to be calibrated. The room where the balances are installed must be temperature and humidity controlled. It is not allowed to place balances near equipment that generates vibration or in a room where dust may affect them. Also, heat transmission by solar radiation through the windows shall be prevented.

A. Calibration of electronic balances

Before calibration, an electronic weighing instrument should be checked on site to make sure it functions adequately for the intended application. The preliminary operations are:

- identification of the weighing instrument (type, model, serial number, etc.);
- checking the leveling;
- ensuring that electrically powered instruments have been switched on for a period of a least one hour (preferably overnight) and have reached room temperature;
- ensuring that the pan of the weighing instrument is clean and in good condition;
- pre-loading for several times the weighing instruments to near maximum capacity;
- adjusting the error close to Max, using internal or adequate external weights, to allow compensation for changing environmental factors such as temperature and, implicitly, air density.

Estimating the expanded uncertainty is based on:

- repeatability
- resolution
- eccentricity
- the influence of temperature variations at the site of use
- accuracy measurements
- the standards weights used in the accuracy measurements
- hysteresis

1. Repeatability

At least ten repeated measurements must be performed. This test should be done at or near the nominal maximum capacity of the weighing instrument or using the largest load generally weighed in applications. In the case of a zero deviation between the weighings, the instrument shall be reset to zero, without determining the error of the zero indication [1]. The uncertainty due to repeatability of the weighing process, u_w, is given by standard deviation s of several weighing results obtained for the same load under the same conditions. For multiple range instruments, this test shall be carried out for each range used, thus for n measurements:

$$u_W = s = \sqrt{\frac{\sum_{i=1}^{n}\left(I_i - \bar{I}\right)^2}{n-1}} \qquad (1)$$

where I_i is the indication of the weighing instrument and n is the number of repeated weighings:

$$\bar{I} = \frac{1}{n}\sum_{i=1}^{n} I_i \qquad (2)$$

2. Resolution

For balances having the resolution d (equal to the scale interval), the uncertainty of the rounding error, u_r, for each reading I is [2]:

$$u_r = \frac{d/2}{\sqrt{3}} = \frac{d}{\sqrt{12}} \qquad (3)$$

The uncertainty of the rounding effect for $I \neq 0$ is given by [6]

$$u_r = \sqrt{\frac{d_{I=0}^2 + d_{I=L}^2}{12}} \qquad (4)$$

Equation (4) is used for single and multiple range instruments. For multi-interval instruments, for the different scale intervals d_i, the uncertainty due to the rounding effect is:

$$u_r = \sqrt{\frac{d_1^2 + d_i^2}{12}} \quad (5)$$

where: d_1 is the smallest scale interval

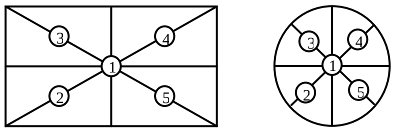
d_i is the scale interval of the appropriate partial range.

3. Eccentricity

It is preferable to use large weights instead of several small weights. The load *L* shall be applied on the pan in the positions indicated in Fig. 1 in a sequence of center, front, left, back, right, or equivalent.

After the first measurement, tare setting may be done when the instrument is loaded. For instrument having no more than four points (n ≤ 4) of support, the test load is 1/3 Max. [1].

Fig. 1



The load is first placed in position 1 and is subsequently placed in the other 4 positions in an arbitrary order. Acceptable solution for uncertainty due to eccentricity, u_{ex} is estimated as follows [2]:

$$u_{ex} = \frac{\Delta}{2\sqrt{3}} \quad (6)$$

here, Δ is the largest difference between off-center and central loading indications;

The eccentric test is not carried out in the case of weighing instruments with a suspended load receptor.

4. The effect of temperature variations, during the calibration, u_T is calculated from:

$$u_T = \frac{1}{\sqrt{12}} (\Delta_t \cdot TK \cdot 10^{-6}) \cdot L \quad (7)$$

where: *TK* is the effect of temperature on the mean gradient of the characteristic in *ppm/K* (estimated or taken from data information sheet).

$\Delta_t = t_{max} - t_{min}$ is temperature variation during the calibration, for load *L*.

5. Mass standards

The weights used as measurement standards shall comply with the specifications in the OIML R111. The traceability of the standards to the SI unit shall be ensured. The standards shall be adequately acclimatized before the calibration (to minimize the effect of convection). A thermometer kept inside the box with standard weights may be helpful to check the temperature difference.

- When the indication of the instrument is not corrected for the errors of the weights (the calibration weights are introduced as nominal values) the uncertainty of the reference weights, u_{ref}, is estimated as follows:

$$u_{ref} = \frac{\delta_i}{\sqrt{3}} \quad (8)$$

or, when two or more weights are used,

$$u_{ref} = \frac{\sum \delta_i}{\sqrt{3}} \quad (8')$$

where: δ_i is the maximum permissible error of the "*i*" applied weights

- When the indications of the instruments are corrected for the errors of the weights (the calibration weights are introduced as conventional values) the standard uncertainty from the calibration certificate *(u_{cert})* should be combined with the uncertainty due to the instability of the mass of the reference weight *(u_{stab})* as following [2]:

$$u_{ref} = \sqrt{u_{cert}^2 + u_{stab}^2} = \sqrt{\left(\frac{U}{k}\right)^2 + u_{stab}^2} \quad (9)$$

When two or more weights are used for *L*, the equation becomes:

$$u_{ref} = \sqrt{\left(\frac{\sum U_i}{k}\right)^2 + u_{stab}^2} \quad (9')$$

U_i (k=2) is the uncertainty of the applied weights from the calibration certificate.

The calculation of the uncertainty associated with the stability of the standard (u_{stab}) has to take into account a change in value between calibrations, assumed that a rectangular distribution. This component would be equivalent to the change between calibrations divided by $\sqrt{3}$:

$$u_{stab} = \frac{D_{max}}{\sqrt{3}} \quad (10)$$

where D_{max} represents the drift determined from the previous calibrations.

If previous calibration values are not available, the uncertainty from the calibrated certificate is considered to be an uncertainty associated to the drift.

6. Accuracy measurements

Weighing instruments should be calibrated throughout their range. When a weighing instrument is used only over a part of its capacity, the calibration may be restricted to this part of the measuring range. In this case, the part range that has been calibrated has to be explicitly mentioned in the calibration certificate and also a label with this information should be fixed to the weighing instrument.

Measurements are made at about five equal steps across the range of the balance (zero, 0.25Max, 0.50Max, 0.75Max and Max). If the balance is typically used for a particular load, the accuracy of the scale around this load should be measured.

- When :
  - the weighing instrument was adjusted before measurement,
  - the density of weights is close to 8000 kg/m^3 and
  - the air density is close to 1,2 kg/m^3,

the indication error, E_I , is obtained from the difference between the instrument reading *I* - upon application of a load *L* - and the value of this load (conventional mass value or nominal value).

$$E_I = I - L \quad (11)$$

The weights are applied in increasing and decreasing loads. The estimation of uncertainty associated with the indication error taking into account the influences of repeatability (u_w), resolution (u_r), reference weights (u_{ref}), temperature (u_T) and hysteresis (u_H).

Hysteresis occurs when a balance displays a different reading for the same load, when the load is applied increasing the weight and decreasing the weight.
If the difference is δ_x, the standard uncertainty due to hysteresis is given by [3]:

$$u_H = \frac{\delta_x}{\sqrt{12}} = 0{,}29\ \delta_x \qquad (12)$$

The expression of uncertainty associated with the determining the indication error is:

$$u_{(EI)} = \sqrt{(u_w)^2 + (u_r)^2 + (u_{ref})^2 + (u_T)^2 \cdot L^2 + (u_H)^2} \qquad (13)$$

The uncertainty u_{EI} should be calculated for each value of the load used.

From eq. (13), the relative standard uncertainty can be calculated as:

$$u_{(EI)\,rel} = u_{(EI)} / L \qquad (14)$$

and the largest uncertainty $u_{(EI)\ rel\ max}$ is taken into account for further calculations. The indication error is not the same when the weighing instruments are calibrated using standard weights under different conditions. In this case, the error of indication is:

$$E = I - (L+BC) = I - L - BC =$$

$$= I - L - \left[-L \cdot \left[(\rho_a - \rho_0) \cdot \left(\frac{1}{\rho_w} - \frac{1}{\rho_c}\right) + \frac{\rho_a - \rho_{a_{adj}}}{\rho_c}\right]\right] =$$

$$= I - L + L \cdot \left[(\rho_a - \rho_0) \cdot \left(\frac{1}{\rho_w} - \frac{1}{\rho_c}\right) + \frac{\rho_a - \rho_{a_{adj}}}{\rho_c}\right] \qquad (15)$$

Where BC, the buoyancy correction is equal to [8]:

$$BC = -L \cdot \left[(\rho_a - \rho_0) \cdot \left(\frac{1}{\rho_w} - \frac{1}{\rho_c}\right) + \frac{\rho_a - \rho_{a_{adj}}}{\rho_c}\right] \qquad (16)$$

where: ρ_w = density of the weight
ρ_a = density of the air during the calibration
ρ_0 = 1,2 kg/m^3 is the reference density of the air
ρ_c = reference (conventional) density of the adjustment weight equal to 8000 kg/m^3
$\rho_{a\ adj}$ = air density at the time of adjustment.

Provided

- the instrument has been adjusted immediately before the calibration , $\rho_{a\ adj} = \rho_a$, the buoyancy correction may be calculated as:

$$BC = -L \cdot (\rho_a - \rho_0) \cdot \left(\frac{1}{\rho_w} - \frac{1}{\rho_c}\right) \qquad (16')$$

- the instrument has been adjusted independent of calibration ($\rho_{a\ adj}$ is unknown) the buoyancy correction may be calculated as:

$$BC = -L \cdot \frac{\rho_a - \rho_0}{\rho_w} \qquad (16'')$$

with the next assumptions: $\rho_{a\ adj} = \rho_0$ and $\rho_w = \rho_c$

Starting from eq. (16') and (16''), the relative standard uncertainty associated to the buoyancy correction (u_{BC}) may be calculated as:

$$u_{BC}^2 = u_{\rho_a}^2 \cdot \left(\frac{1}{\rho_w} - \frac{1}{\rho_c}\right)^2 + (\rho_a - \rho_0)^2 \cdot \frac{u_{\rho_w}^2}{\rho_w^4} + u_{\rho_a}^2 \cdot \frac{u_{\rho_w}^2}{\rho_w^4} \qquad (17)$$

$$u_{BC}^2 = \frac{u_{\rho a}^2}{\rho_w^2} + (\rho_a - \rho_0)^2 \cdot \frac{u_{\rho_w}^2}{\rho_w^4} \qquad (18)$$

Uncertainty of air density $u_{\rho a}$ is determined according to [2]. When the air density is not measured and the average air density for the site is used instead, the uncertainty associated to the air density is estimated (according to chapter C.6.3.4 in [2]) as:

$$u(\rho_a) = \frac{0{,}12}{\sqrt{3}}\ [\text{kg/m}^3] \qquad (19)$$

The expression of uncertainty associated with indication error (when the buoyancy correction is applied) is:

$$u_{(EI)} = \sqrt{(u_w)^2 + (u_r)^2 + (u_{ref})^2 + (u_T)^2 \cdot L^2 + (u_H)^2 + (u_{BC})^2 \cdot L^2} \qquad (20)$$

The uncertainty $u_{(EI)}$ should be calculated for each value of the load used.
From eq. (20), the relative standard uncertainty can be calculated as:

$$u_{(EI)\,rel} = u_{(EI)} / L \qquad (21)$$

and the largest uncertainty $u_{(EI)\ rel\ max}$ is taken into account.

Uncertainty of measurement for the weighing instrument

The influences of the repeatability and of the rounding error are assumed to be independent from the load applied, while all the other components are proportional to the weight values. The standard uncertainties corresponding to the components that are proportional to the weight values are expressed as relative uncertainties. The combined standard uncertainty u_c is based on the parameters described above (which can be grouped to obtain a simplified expression that would better reflect the fact that some of the terms are independent from the applied load, while others are proportional to the weight value) [5]:

$$u_c = \alpha + \beta \cdot L \qquad (22)$$

- When corrections are applied to the error of indication of the weighing instrument, the expression for combined standard uncertainty u_c is:

$$u_c = \sqrt{u_w^2 + u_r^2} + \sqrt{L^2 \cdot (u_{exrel}^2 + u_{Trel}^2 + u_{(EI)rel\max}^2)}$$

$$= \sqrt{u_w^2 + u_r^2} + L \cdot \sqrt{u_{exrel}^2 + u_{Trel}^2 + u_{(EI)rel\max}^2} \qquad (23)$$

u_{Trel} from eq. (23) is calculated by replacing the temperature variation during calibration (from eq.7) with the actual temperature variation recorded during the use of the balance.

- When no corrections are applied to the error of indication of the weighing instrument, the largest relative indication error across the range that is measured $E_{I\ rel\ (Max)}$ should be added to u_c, in addition to $u_{(EI)rel(max)}$, as follows:

$$u_c = \sqrt{u_w{}^2 + u_r{}^2} + \sqrt{L^2 \cdot [u^2_{exrel} + u^2_{Trel} + (u_{(EI)_{rel\max}} + E_{I\,rel(Max)})^2]}$$

$$= \sqrt{u_w{}^2 + u_r{}^2} + L \cdot \sqrt{u^2_{exrel} + u^2_{Trel} + (u_{(EI)_{rel(Max)}} + E_{I\,rel(Max)})^2} \quad (24)$$

The expanded uncertainty for k=2 is

$$U = k \cdot u_c \quad (25)$$

B. Calibration of mechanical balances

***B1**. Two pan balances*: the balances with two pans and three knife edges are also known as equal-arm balances because the knife edges supporting the pans are nominally equidistant from the central knife edge. The three knife-edges are parallel and lie in the same horizontal plane.

Two-pan balances are generally undamped with a “rest point” being calculated from a series of “turning points”. Some balances incorporate a damping mechanism (usually mechanical or magnetic) to allow the direct reading of a “rest point”. In all cases, the reading in terms of scale units needs to be converted into a measured mass difference.

A two-pan balance undamped is used less frequently mainly due to the amount of time needed to make a weighing compared with electronic balances.

There are two methods to calculate the ”rest point” (the equilibrium positions) “P” for balances (the accuracy of the second is better than that of the first one):

$$P = (e_1 + 2e_2 + e_3)/4 \text{ or} \quad (26)$$

$$P = (e_1 + 3e_2 + 3e_3 + e_4)/8 \quad (27)$$

where $e_1 \ldots e_4$ are consecutive readings at the extremity of the swing of the pointer, i.e. where it changes its direction of motion.

A calibration procedure, [7], is shown in the table 1.

Table 1. Calibration procedure for two pan balances

No	Loads applied on receivers		Readings e_1	e_2	e_3	Equilibrium position div	div	Difference Δ_i div
	left	right						
1	0	0				P_1		
2	L_1	L_2					P_2	
3	L_2	L_1				P_3		
4	L_2	L_1+sw_1					P_4	
5	0	0				P_5		
6	L_3	L_4					P_6	
7	L_4	L_3				P_7		
8	L_4+sw_2	L_3					P_8	
9	0	0				P_9		
10	L_3	L_4					P_{10}	Δ_1= P_{10}-P_9
11	0	0				P_{11}		
12	L_3	L_4					P_{12}	Δ_2= P_{12}-P_{11}
13	0	0				P_{13}		
14	L_3	L_4					P_{14}	Δ_3= P_{14}-P_{13}
15	0	0				P_{15}		
16	L_3	L_4					P_{16}	Δ_4= P_{16}-P_{15}
17	0	0				P_{17}		
18	L_3	L_4					P_{18}	Δ_5= P_{18}-P_{17}
19	0	0				P_{19}		
20	L_3	L_4					P_{20}	Δ_6= P_{20}-P_{19}

where:

sw_1 and sw_2 are additional small weights (sensitivity weights) with mass m_{sw}, used to determine the scale interval of the balance. The sensitivity weights should be calibrated against suitable mass standards.

$L_1$and L_2 are weights with nominal masses equal to the minimum capacity of the balance.

L_3 and L_4 are weights with nominal masses equal to the maximum capacity of the balance.

The following tests and calculations should be carried out on a regular basis and are essential to the routine operation of the balance [7]:

1. Determining scale interval while the balance is loaded with minimum capacity.
$$d_{\min} = m_{sw1} / |P_4 - P_3| \quad (28)$$
2. Determining scale interval while the balance is loaded with maximum capacity:
$$d_{\max} = m_{sw2} / |P_8 - P_7| \quad (29)$$
3. Determining repeatability while the balance is no loaded and loaded with maximum capacity (by determining the experimental standard deviations):

$$R_0 = \sqrt{\frac{\sum_{i=1}^{n}(P_{oimed} - P_{oi})^2}{n-1}} \; ; R_{\max} = \sqrt{\frac{\sum_{i=1}^{n}(\Delta_{imed} - \Delta_i)^2}{n-1}} \quad (30)$$

where:

P_{0i} are the equilibrium positions while the balance is not loaded

$P_{0i\ med}$ are the mean of equilibrium positions while the balance is not loaded

Δ_i are the differences between equilibrium positions of the balance when it is not loaded and when it is loaded with maximum capacity

$\Delta_{i\ med}$ is the mean of Δ_i differences

4. Determining errors due to the fact that the two arms of the balance are not equal in length (this test is not applicable to balances with a single pan, case B2, section to be discussed in).

$$J_{\min} = \frac{P_2 + P_3}{2} - \frac{P_1 + P_5}{2} \quad (31)$$

$$J_{\max} = \frac{P_6 + P_7}{2} - \frac{P_5 + P_9}{2} \quad (32)$$

Uncertainty of measurement for the weighing instrument

The standard uncertainty is based on the described above parameters as following:

- uncertainty due to the sensitivity of the balance:

$$u_{s\ min} = d_{\min} \cdot \sqrt{\left(\frac{u_{sw1}}{m_{sw1}}\right)^2 + \left(\frac{u_{(P4-P3)}}{P_4 - P_3}\right)^2} \quad (33)$$

and

$$u_{s\ max} = d_{\max} \cdot \sqrt{\left(\frac{u_{sw2}}{m_{sw2}}\right)^2 + \left(\frac{u_{(P_8-P_7)}}{P_8 - P_7}\right)^2} \quad (34)$$

where: u_{sw} is the uncertainty of the additional small weights *sw* (sensitivity weights);

$(P_4 - P_3)$ or $(P_8 - P_7)$ is the change in the indication of the balance (due to the sensitivity weights) with the uncertainties $u_{(P4-P3)}$ or $u_{(P8-P7)}$, respectively;

d is the scale interval.

From eq. (33) and (34), the relative standard uncertainty can be calculated as:

$$u_{s\,rel} = u_{s\,(min,\,max)} / L \quad (35)$$

and the largest uncertainty $u_{s\,rel\,max}$ is taken into account

- the variance of repeatability :

$$u_w^{\,2} = s^2 = R^2 \quad (36)$$

- uncertainty due to the inequality of the two arms lengths

$$u_J = \sqrt{\frac{u_{P6}^2}{4} + \frac{u_{P7}^2}{4} + \frac{u_{P5}^2}{4} + \frac{u_{P9}^2}{4} + u_w^2} \quad \text{(in scale divisions)} \quad (37)$$

$$u_J = \sqrt{u_r^2 + (u_w \cdot d)^2} = \sqrt{\left(\frac{0{,}2 \cdot d}{2\sqrt{3}}\right)^2 + (u_w \cdot d)^2} = \quad \text{(in mg)} \quad (37')$$

$$= \sqrt{0.0033 \cdot d^2 + (u_w \cdot d)^2}$$

where: u_w^2 is the variance of the repeatability

u_r^2 is the variance of limited resolution.

The resolution is equal to 1/10 or 2/10 of the scale interval *d*, the standard uncertainty being calculated as:

$$u_r = \frac{\frac{0{,}2d}{2}}{\sqrt{3}} = \frac{0{,}2d}{2\sqrt{3}} \quad (38)$$

Then, the combined standard uncertainty u_c can be calculated as follows:

$$u_c = \sqrt{(u_w \cdot d)^2 + u_J^2} + \sqrt{u_{s_{rel\max}}^2 \cdot L^2} = \sqrt{(u_w \cdot d)^2 + u_J^2} + (u_{s_{rel\max}} \cdot L) \quad (39)$$

The expanded uncertainty is reporting by multiplying u_c with the coverage factor k=2

$$U = k \cdot u_c \quad (40)$$

B2. Single pan balances

Displays on these balances tend to be of the optical variety, the sensitivity of the balance being usually adjusted by a skilled person.

In the case of single pan, direct reading analytical balances, the following tests and calculations should be carried out: repeatability, calibration of the screen and calibration of built-in weights.

1. Repeatability: this test should be done at or near the nominal maximum capacity of the weighing instrument or using the largest load generally weighed in applications. Repeatability is determined in the same way as was described in section B1, eq. (30).

2. Calibration of the screen: on can determine the accuracy measurements for the entire screen by the application standard weights at various points in the range of the screen (1/4, 1/2, 3/4 and 4/4) according to the table 2:

Table 2. Calibration of the screen

No	Load applied mg	Equilibrium positions P_1 mg	P_2 mg	P_3 mg	P_{med} mg	P_{0imed} mg	Diff Δ_i mg	Mass of sensitivity weight mg
1	0				P_1			
2	sw_1 =1/4				P_2		Δ_1= P_2-P_{01}	m_{sw1}
3	0				P_3	P_{01}		
4	sw_2 =1/2				P_4		Δ_2= P_4-P_{02}	m_{sw2}
5	0				P_5	P_{02}		
6	sw_3 = 3/4				P_6		Δ_3= P_6-P_{03}	m_{sw3}
7	0				P_7	P_{03}		
8	sw_4= 4/4				P_8		Δ_4= P_8-P_{04}	m_{sw4}
9	0				P_9	P_{04}		

where: sw_1... sw_4 are sensitivity weights having nominal mass equal to 1/4...4/4 from the maximum capacity of the screen;

m_{swi} is the mass of the sensitivity weight applied;

$P_{oi\ med}$ are the average equilibrium positions (rest points) while the balance is not loaded.

The indication error of the screen will be calculated as follows:

$$E_I = \Delta_i - m_{swi} - \rho_a \cdot V_{swi} \quad (41)$$

where: ρ_a is the density of the air and V_{swi} is the volume of the sensitivity weight (with u_{Vsw} uncertainty).

3. Calibration of built-in weights: the built-in weights are used in combination during the operation of balance. First of all, it is necessary to identify the built-in weights as nominal values. Ideally the weights built into the balance should be removed and calibrated externally. If this is not possible they can be left in the balance and calibrated by dialing them upon combinations. A standard weight *S* of mass m_s and volume V_s is chosen for calibration, depending on the accuracy of the balance.

The steps for calibration of built-in weights are [9]:

- record screen reading at no load indication I_1;
- record screen reading I_2 when loading with standard weight *S*;
- record screen reading I_3 when loading with standard *S* (with volume V_s) and a sensitivity weight of mass m_{sw} (with volume V_{sw});
- record screen reading I_4 when the standard *S* is removed and on pan remains only the sensitivity weight.

To calculate the mass of the built in weight, the next formula can be applied:

$$BW = m_S - \rho_a \cdot V_S + \rho_a \cdot V_{BW} + K \cdot \left(\frac{I_1 + I_4}{2} - \frac{I_2 + I_3}{2}\right) \quad (42)$$

where K is a factor used to convert the reading in terms of scale units into a measured mass difference.

$$K = \frac{m_{sw} - \rho_a \cdot V_{sw}}{I_3 - I_2} \quad (43)$$

The formula (42) can be reduced to a simpler one if the accuracy of the weighing allows it and it is known that *K* is constant from the previous measurements:

$$BW = m_S - \rho_a \cdot V_S + \rho_a \cdot V_{BW} + K \cdot (I_1 - I_2) \quad (44)$$

The values for m_s, V_s, V_{sw}, m_{sw}, are given in the calibration certificate.

Measurement uncertainty for the weighing instrument

To estimate measurement uncertainty for the weighing instrument the following parameters need to be considered:

1. Uncertainty due to the repeatability of the weighing instrument, u_w, - given by standard deviation *s* of several weighing results obtained for the same load under the same conditions, calculated as in eq. (36).

2. Uncertainty associated with the indication error of the screen - calculated as follows:

$$u_{(EI)} = \sqrt{u_{sw}^{\;2} + u_{\rho_a}^2 \cdot V_{sw}^2 + \rho_a^2 \cdot u_{Vsw}^2 + u_w^2 + u_r^2} \quad (45)$$

The above expression includes the parameters described: u_w (repeatability), u_r (resolution), $u_{\rho a}$ (uncertainty of the air density), u_{sw} (uncertainty of the sensitivity weight), V_{swi} (volume of the sensitivity weight with u_{Vsw} uncertainty).
3. Uncertainty of the built-in weights - calculated starting from eq. (42) or (44):

$$u_{BW} = \sqrt{u_A^2 + u_S^2 + u_{\rho_a}^2 (V_{BW} - V_S)^2 + \rho_a^2 \cdot (u_{VBW}^2 + u_{V_S}^2) + u_K^2 \cdot (\frac{I_1 + I_4}{2} - \frac{I_2 + I_3}{2})^2 + \frac{1}{2} K^2 \cdot u^2_{[(I_2+I_3)-(I_1+I_4)]}} \quad (46)$$

$$u_{BW} = \sqrt{u_A^2 + u_S^2 + u_{\rho_a}^2 (V_{BW} - V_S)^2 + \rho_a^2 \cdot (u_{V_{BW}}^2 + u_{V_S}^2) + u_K^2 \cdot (I_1 - I_2)^2 + K^2 \cdot u^2_{(I_1 - I_2)}} \quad (47)$$

Since an experimental standard deviation cannot be calculated for a single measurement to estimate u_A, data obtained from previous repeatability evaluations can be used, thus resulting a pooled standard deviation.
Standard uncertainty of the reference weight, u_s is calculated according to eq. (9) from above.
The combined standard uncertainty u_c can be calculated as follows:

- when corrections are applied to the error of indication, the expression for combined standard uncertainty u_c is:

$$u_c = \sqrt{u_w{}^2 + u_r{}^2 + u_{BW}^2 + (u_{(EI)})^2} \quad (48)$$

- when no corrections are applied to the error of indication, the indication error across the partial screen range that is measured E_I should be added to u_c, in addition to $u_{(EI)}$, as follows:

$$u_c = \sqrt{u_w{}^2 + u_r{}^2 + u_{BW}^2 + (u_{(EI)} + E_I)^2} \quad (49)$$

The expanded uncertainty for k=2 will be:

$$U = k \cdot u_c \quad (50)$$

Conclusions

This paper established metrological requirements for the calibration of nonautomatic weighing instruments and provided useful information for operators working in accredited calibration laboratories in various fields, in order to determine the mass of products.

- A laboratory should not attempt to make measurements with an uncertainty of “x” using an instrument that has the readability “x”. If the user wishes to apply no corrections, to obtain an uncertainty of “x”, he should have a balance with a readability of “0.1x”, to be sure that are no gross errors present.

- The balance indications are closer to the conventional mass than to the true mass, on many occasions, the indication being directly used as the conventional mass. This is normally not valid for mass (true mass). In current use, it is necessary to convert the weighing result from the conventional mass to the true mass (in section B2 described above, the weighing result is transformed directly in true mass).

- When a calibrated instrument is used, the calibration uncertainty stated in the calibration certificate of that instrument has to be taken into account when reporting the measurement uncertainty associated with any measurement results, but it should be remembered that the calibration uncertainty represents only one part of the measurement uncertainty stated in current applications of the laboratory.
Other contributions to the measurement uncertainty that have to be taken into account are the influence of the buoyancy correction, the influence of the properties of the product that is weighed (evaporation, hygroscopic behavior, electrostatic charging, etc).

- Mechanical balances have generally been replaced by electronic balances, which often offer better resolution and are easier to use. The recalibration period for all of them (mechanical and electronic) can be different for each type, being influenced by such factors as the usage of the receives, operator skill and the environment in which the balance is located. As a general guideline, balance should be recalibrated yearly, until the stability of operation is established.

References

[1] International Recommendation OIML R76 -1 “Non-automatic weighing instruments”, Annex A. pp 68-73

[2] International Recommendation N°111 “Weights of classes E_1, E_2, F_1, F_2, M_1, M_2,M_3” ch. 6, pp. 70-74.

[3] “Guide to the expression of uncertainty in measurement” (ISO, Geneva, 1995), Annex F pp 54 .

[4] International Document OIML D 28 “Conventional value of the result of weighing in air “pp 7-9, 2004

[5] Document 2089, Edition 00 – October 2000 “Specific requirements relating to the calibration of non-automatic weighing instruments”, ch.8.5 - 8.6, pp 19-24.

[6] DKD –R-7-1, “Calibration of non-automatic weighing instruments”, issue 98, ch.5

[7] NTM 3-05-77 “Verificarea balanțelor cl. 3, 4 şi 5” ch.5, pp 25-31

[8] EA -10 /18 EA “Guidelines on the calibration of non-automatic weighing instruments” , (draft) July 2004, ch.4, pp 11 and 2.

[9] Randall M.Schoonover: “Air Buoyancy Correction in High-Accuracy Weighing on Analytical Balances”. Anal. Chem. 1981, 53 , 900-902