Traceable calibration of automatic weighing instruments in dynamic operation

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Abstract. The article aims to present progress in the development of methods for calibration of automatic weighing instruments (AWIs), which operates in dynamic mode. The specificities of the calibration of the AWIs in the dynamic mode of operation are highlighted. For automatic catchweighing instruments and automatic gravimetric filling instruments, basic information about the measurement method, error model and measurement uncertainty contributions are given. Several approaches are presented for determining the reference mass of the test loads on the control weighing instrument, including the related analysis of the air buoyancy correction and influence of the density of the test loads. The use of harmonized and validated methods will, when finalised, enable a traceable calibration of the AWIs in a dynamic mode of operation.

1 Introduction

Automatic weighing instruments (AWIs), which perform measurements in a dynamic mode, are extensively used in the preparation, production and quality assurance of pre-packed products as well as for products, whose content or composition is determined by weighing.

While NAWIs are routinely calibrated by accredited calibration laboratories according to EURAMET Calibration Guide for NAWIs [1], the calibration of AWIs is not as well defined, because there is a significant difference between the static measurement mode of operation of NAWIs and the dynamic measurement mode of operation, which is typical for the majority of AWI applications. The growing dissemination of AWIs emphasises the need to confirm their metrological quality by calibrations and the reliable estimation of their measurement uncertainty in order to judge the accuracy of the weighing result. Thus, the development of calibration methods for dynamic measurements with AWIs is the scope of the EMPIR project 14RPT02 "Traceable calibration of dynamic weighing instruments operating in the dynamic mode", with a short name AWICal, funded by EURAMET [2]. This project will develop harmonised calibration methods and uncertainty evaluation models for the three selected categories of AWIs, i.e. automatic catchweighers, automatic instruments for weighing road vehicles in motion and automatic gravimetric filling instruments, selected to represent the most commonly used instruments.

2. Calibration method

The first step in the process is the establishment of the measurement model, which is a mathematical relation between the measurand and all quantities, which are involved in the measurement. The actual value of weighing is affected by various dynamic effects of instrument operation, the load type and its properties, and the rate of operation of the instrument. Due to the dynamic behaviour of their operation, functional relationship between weighing result, parameters of operations such as rate of operation, type of material and nominal value of the test load is very complex and currently out of the scope of the calibration procedure.

Because of the dynamic behaviour, it will usually not be possible to calibrate a measurement range for such instruments. The calibration will deliver a measurement error of the instrument in comparison to a reference mass value under the conditions of the calibration such as speed of the load transport system and the load properties.

In agreement with the client, the calibration is performed at individual nominal values, which are defined by mass of the test loads, and it is only valid for the specified test loads (with a small bandwidth for mass, volume and shape).

Calibration is performed at the location where the instrument is being installed. Test loads are made of the type of product, which is normally weighed on the calibrated instrument. A calibration is performed at the rate of operation requested and specified in advance by the client. Normally these conditions are the same as conditions during the actual weighing process.

The documents for the calibration of automatic instruments should include at least guidance on:

- determination the mass of test loads,
- measurements to be performed,
- calculation of the measuring results,
- evaluation of the uncertainty of measurement,
- contents of the calibration certificates.

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In the following two subsections basic details are given about calibration procedures for the automatic catchweighing instruments and the automatic gravimetric filling instruments.

2.1 Automatic catchweighing instruments

The object of calibration for the automatic catchweighing instrument, which is symbolically shown on Figure 1, is the indication of the instrument I in response to an applied load with reference value of mass of the test load, m_{ref}. The error of indication E is

$$E = I - m_{ref} \tag{1}$$

Fig. 1. Automatic catchweighing instrument.

Due to effects of air buoyancy and other effects such as convection, drift and others which may lead to minor correction terms δm_x, m_{ref} is not exactly equal to m_{cTL}, the conventional mass value of the load

$$m_{ref} = m_{cTL} + \delta m_B + \delta m \ldots \tag{2}$$

δm_B is air buoyancy correction for the test load used for calibration, and δm further corrections that it may be necessary to apply under special conditions.

Tests are performed to determine the errors of indications, repeatability of indications, and the effect of eccentric application of a load on the indication.

2.1.1 Test for errors and repeatability of indication

The test consists of the passing repeatedly the same load over the middle of the load receptor, under identical conditions of handling the load and the instrument, and under constant test conditions. The purpose of this test is an appraisal of the accuracy and repeatability of the instrument at least in points of usual application of the instrument. Each test point is characterized by its own repeatability.

For the test load L_T, the mean error of indication E is calculated as follows

$$E = \bar{I} - m_{ref} \tag{3}$$

where $\bar{I}$ is the mean of several indications. Section 3 provides further information how m_{ref} could be obtained.

From the n indications I_i for a given test load, the standard deviation $s(I_i)$ is calculated

$$s(I) = \sqrt{\frac{1}{n-1}\sum_{1=1}^{n}\left(I_i - \bar{I}_{TL}\right)^2} \tag{4}$$

with

$$\bar{I}_{TL} = \frac{1}{n}\sum_{1=1}^{n} I_i. \tag{5}$$

2.1.2 Test for effect of eccentric loading

The effect of the eccentric application of the load on the indication is tested when applicable. The effect of eccentric loading shall be determined using the selected test load L_{ecc} using the middle of load transport system, the portion of the load transport system that is halfway between the centre and the back, and repeated with the same test load using the portion of the load transport system that is halfway between the centre and the front

For each tested band k of the load transport system, the average difference $\Delta I_{ecc,k}$ is calculated as follows:

$$\Delta I_{ecc,k} = \bar{I}_k - \bar{I}_m \tag{6}$$

2.1.3 Standard uncertainty of the error of indication

To account for sources of variability of the indication, i.e. the effect of the resolution of indication, the repeatability of the instrument and the error due to off-centre position of the test load, $\bar{I}$ is amended by correction terms as follows

$$\bar{I} = \bar{I}_{TL} + \delta I_{digTL} + \delta I_{rep} + \delta I_{ecc} \tag{7}$$

The standard uncertainty of the indication of the catchweigher $u(\bar{I})$ then equals

$$u^2(\bar{I}) = \frac{d^2}{12} + \frac{s^2(I)}{n} + \frac{|\Delta I_{ecc,k}|_{max}}{2L_{ecc}\sqrt{3}} I^2, \tag{8}$$

where d is resolution of the instrument.

The standard uncertainty of the indication and the standard uncertainty the reference value of mass $u(m_{ref})$ contribute to the standard uncertainty of the error of indication $u(E)$

$$u(E) = \sqrt{u^2(\bar{I}) + u^2(m_{ref})} \tag{9}$$

Section 3 provides further information about the standard uncertainty the reference value of mass.

2.2 Automatic gravimetric filling instruments

The object of the calibration the automatic gravimetric filling instruments, which is symbolically shown on Figure 2, is the preset value error of the instrument, E_P determined at different preset values, F_P, i.e. values, expressed in units of mass, preset by the operator, in order to define the nominal value of the fills. The preset value error for the i-th test fill equals:

$$E_{P,i} = m_{ref,i} - F_P \tag{10}$$

Due to effects of air buoyancy and other effects, which may lead to minor correction terms δm_x, the reference values of mass of test fill, $m_{ref,i}$ is not exactly equal to $m_{cF,i}$, the conventional mass the test fill. The conventional mass of the test fill cannot be determined directly, but trough determination of conventional mass of the filled container m_{cB} (gross value) and conventional mass of the empty container m_{cT} (tare value)

$$m_{ref,i} = m_{cB,i} - m_{cT,i} + \delta m_{B,F} + \delta m \ldots \tag{11}$$

δm_B is air buoyancy correction for the test fill (refers to net value of test fill), and δm further corrections that it may be necessary to apply under special conditions.

Fig. 2. Automatic gravimetric filling instrument.

2.2.1 Test for preset value error and repeatability

The test consists of repeated filling the fills with the same nominal value, and under constant test conditions. The purpose of this test is an evaluation of the accuracy and repeatability of the instrument at least in points of usual application of the instrument. Each test point is characterized by its own repeatability.

For the preset value F_P, the preset value error E_P is calculated based on measurement of n test fills as follows

$$E_P = \frac{1}{n}\sum_{i=1}^{n} m_{ref,i} - F_P \tag{12}$$

When the test fills are weighed on calibrated control instrument (cf. section 3), (12) can be modified by introduction of the mass of a single fill F_i in the equation, which is determined based on the weighing results for filled and empty containers, W_B and W_T, respecitvely.

$$F_i = W_{Bi} - W_{Ti} \tag{13}$$

Finally

$$E_P = \overline{F} + \delta m_{BTot} - F_P \tag{14}$$

where $\overline{F}$ is average mass of fills

$$\overline{F} = \frac{1}{n}\sum_{i=1}^{n} F_i \tag{15}$$

and δm_{BTot} is the total contribution of the air buoyancy correction. Section 3 provides more information how δm_{BTot} is obtained.

From the n fills F_i for a given preset value, the standard deviation $s(F)$ is calculated

$$s(F) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(F_i - \overline{F}\right)^2} \tag{16}$$

2.2.3 Standard uncertainty of the preset value error

To account for sources of variability of the preset value error, i.e. the repeatability of the instrument and the air buoyancy correction, (14) is amended by correction terms as follows

$$E_P = \overline{F} + \delta F_{rep} + \delta m_{BTot} - F_P \tag{17}$$

The standard uncertainty of the preset error $u(E_P)$ equals

$$u(E_P) = \sqrt{u^2(W_B) + u^2(W_T) + u^2(\delta F_{rep}) + u^2(\delta m_{BTot})} \tag{18}$$

where $u(W_B)$ and $u(W_T)$ account for the standard uncertainty of the weighing result for filled and empty container, respectively, $u(\delta m_{BTot})$ for the air buoyancy correction, and $u(\delta F_{rep})$ accounts for the repeatability of test fills, which is estimated as

$$u(\delta F_{rep}) = s(F)/\sqrt{n} \tag{19}$$

Further information about the standard uncertainty the air buoyancy correction is provided in Section 3.

3 Test loads, control instrument and air buoyancy correction

Calibration of AWIs in a dynamic mode of operation can not be performed directly with standard weights. To determine the errors of an instrument, test loads are applied. The test loads should preferably be the type of articles, which are normally weighed on the calibrated instrument. For the purpose of calibration, the traceability of test loads to the SI unit of mass shall be demonstrated using a control weighing instrument. The control instrument may be either separate (a weighing instrument other than the instrument being calibrated) or integral (when a static weighing mode is provided by the instrument being calibrated). The control instrument should ensure the determination of the mass of each test load to accuracy, which is appropriate to the expected uncertainty of calibration of the calibrated instrument.

The process of determination of the reference mass value of the test load and its associated measurement uncertainty is one part of the whole process of AWI calibration. An appropriate method of determining the test load reference mass value needs to be selected in a view of required measurement uncertainty and complexity of the method. Some of possible approaches are summarised below:

A. Test load is calibrated prior to calibration of AWI. Its conventional mass is reported together with uncertainty, e.g. in a calibration certificate.

B. Mass of test load is determined by comparison with standard weight at the time and place of calibration of AWI on a weighing instrument, which is used as a mass comparator.

C. Mass of test load is determined by weighing on control weighing instrument at the time and place of calibration of AWI and the control instrument is calibrated at the same time as the calibrated AWI, too.

D. Mass of test load is determined at the time and place of calibration of AWI by weighing on control weighing instrument, which had been calibrated prior to calibration of AWI. Results of calibration the control instrument had been reported in the certificate.

E. Mass of test load is determined at the time and place of calibration of AWI by weighing on the calibrated control instrument, which satisfy a given specification, e.g. tolerances of [3].

The conventional value of mass of the test load m_{cTL} is a priori not known, its density ρ_{TL} normally significantly differs from the conventional value $8000\, kg/m^3$ and the air density ρ_a at the time of calibration is normally different from ρ_0 ($1{,}2\, kg/m^3$). The reference value of mass of the test load m_{ref} therefore depends on the air buoyancy correction δm_B and δm_{BTot}, respectively

$$m_{ref} = m_{cTL} + \delta m_B = W_{CI} + \delta m_{BTot} \qquad (20)$$

where W_{CI} is the result of weighing of the test load on the control instrument and

$$\delta m_{BTot} = -m_c \left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{CI}} - \frac{1}{\rho_s}\right)\right] \qquad (21)$$

ρ_s and ρ_{CI} is the density of standard weights used for adjustment of the control and calibrated instrument, respectively.

It can be seen that the correction is very small and that usually it is not necessary to apply the correction, i.e. $\delta m_{BTot} = 0$. If conformity of the standard weights used for adjustment of the AWI and calibration of the test load to [4] is established and if the AWI is not adjusted before the calibration, the relative uncertainty is evaluated as [1]

$$u_{rel}(\delta m_{BTot}) \approx (0{,}1\, \rho_0/\rho_c + mpe/(4m_N))/\sqrt{3} \qquad (17)$$

Case A could be applicable only in a case when comparable dynamic behaviour of pre-prepared test loads with loads normally weighed on the instruments is achieved. In this case a drift mass of the test load within a time is relevant. A density of the test load needs to be known. Since it is expected that the density considerably differs from $8000\, kg/m^3$, air buoyancy correction in not negligible.

In Cases B to E the mass of test loads is determined at the time and place of calibration of AWI. Consequently no significant drift of the test load is expected. A density of the test load does not need to be known. The air buoyancy correction is very small or negligible and does not depend on a density of the test load.

A critical point of Cases D and E is evaluation of uncertainty of the control instrument in use.

In general, if the same control instrument is used, uncertainty of the reference mass value increases from Case B to Case E.

4 Validation

Finally, it is necessary to experimentally and on-site validate the measurement methods, error models and measurement uncertainty budgets developed and also check the reproducibility of the draft calibration methods and uncertainty budgets developed for the calibration of the selected categories of AWIs with the interlaboratory comparisons.

For this purpose the validation plans were prepared for each group of AWI concerned. The plans take into account instrument selection, test loads selection, determination of the test load mass, preparation and execution of measurements, monitoring environmental condition, calculation of measurement results and reporting.

The results obtained using the calibration methods developed for automatic instruments operating in the dynamic mode will be compared to the reference values obtained by static measurements of test loads on non-automatic weighing instrument and to the measurements obtained using the automatic instrument calibrated in the static mode of operation, each time taking into account the uncertainty of measurement.

5 Conclusion

The expected impacts of the EMPIR AWICal project are to provide basis for traceable dynamic measurements on three groups of AWIs based on the draft guides submitted to EURAMET and improved weighing process control in different industries such as production pre-packed products and transport. Consequently, the calibration laboratories for the calibration of AWIs could be accredited by accreditation bodies based on the harmonised guidance. Supporting information on measurement uncertainty will be available to conformity assessment bodies for AWIs.

For AWIs the uncertainty of measurement depends significantly on properties of the calibrated instrument itself, the characteristics of the test loads, the control instrument, and not only on other capabilities of the calibration laboratory. The reference mass of the test load is usually determined on situ. Several methods for determination of the reference mass are available however, it is necessary to look for a suitable compromise between the accuracy and simplicity of the selected method. Additionally, a density of the test load does not need to be known without significant influence to the measurement uncertainty.

Finally, the capabilities developed in emerging EURAMET members during the project will support their local industry and weighing sector and developed conformity assessment competence of these members in order to support the implementation of the MID and the Pre-packages Directives.

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References

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3 OIML Recommendation R 76, “Non-automatic weighing instruments” (2006)

4 OIML Recommendation R 111, “Weights of classes E1, E2, F1, F2, M1, M2, M3” (1994)