Guidelines on the Calibration of Automatic Catchweighing Instruments

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Mass and Related Quantities

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This document gives guidance on measurement practices in in the specified fields of measurements. By applying the recommendations presented in this document laboratories can produce calibration results that can be recognised and accepted throughout Europe. The approaches taken are not mandatory and are for the guidance of calibration laboratories. The document has been produced as a means of promoting a consistent approach to good measurement practice leading to and supporting laboratory accreditation.

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Version (2.0/2024)

Calibration of Automatic Catchweighing Instruments

Purpose

This document has been produced to enhance the equivalence and mutual recognition of calibration results obtained by laboratories performing calibrations of automatic catchweighing instruments.

Content

1 INTRODUCTION

Automatic catchweighing instruments (hereafter called either „catchweigher“ or “instrument”) [1] are widely used to determine the value of pre-assembled discrete loads in terms of mass. There is a growing need for evaluation of their metrological characteristics by calibration, eg. where required by EN ISO 9001 standard.

A draft calibration guideline for catchweighers has been developed within EMPIR 14RPT02 AWICal project Traceable calibration of automatic weighing instruments operating in the dynamic mode and finalised by expert members is EURAMET TC-M project 1536 Finalisation of the draft Calibration Guideline on the Calibration of Automatic Catchweighing Instruments.

The document has been produced as a means of promoting a consistent approach to good measurement practice leading to and supporting laboratory accreditation.

The approaches taken are not mandatory and are for the guidance of calibration laboratories.

The guide may be used by third parties, e.g. National Accreditation Bodies, peer reviewers, witnesses to measurements, etc., as a reference only.

The guide is not applicable for evaluation of the instruments for the legal metrology purposes. For the legal metrology purposes international recommendation OIML R 51 could be used.

2 SCOPE

This document contains guidance for the calibration of catchweighers, in particular for

1. determination of the reference value of mass of test loads,
2. measurements to be performed,
3. calculation of the measuring results,
4. evaluation of the uncertainty of measurement,
5. specific contents of the calibration certificate.

The guide refers to automatic operation of the catchweigher [1]. The guide deals with the catchweighers that weigh dynamically [1], but it could be as well used for the catchweighers that weigh statically in automatic mode [1], i.e. for the catchweighers, which utilizes a so-called start-stop mode of operation.

The guide doesn’t cover calibration of vehicle incorporated instruments [1] and vehicle mounted instruments [1] (e.g. front-end loader, garbage weigher).

The object of the calibration is the indication provided by the catchweigher in response to an applied test load. The results are expressed in units of mass. The value of the load indicated by the instrument will be affected by dynamic effects, speed of the load transport system [1], the load dimensions, local gravity, the load temperature and density, and the temperature and density of the surrounding air.

The uncertainty of measurement depends significantly on properties of the calibrated instrument itself, the control instrument, the characteristics of the test loads, the equipment of the calibration laboratory. This guideline does not specify lower or upper boundaries for the uncertainty of measurement. It is up to the calibration laboratory and the client to agree on the anticipated value of the uncertainty of measurement, which is appropriate in view of the use of the instrument and in view of the cost of the calibration.

Any such procedure must include, for a limited number of test loads, the determination of the errors of measurement and evaluation of the uncertainty of measurements assigned to these errors. The calibration procedure should as closely as possible resemble the weighing operations that are routinely being performed by the user – e.g. using articles, which are actually weighed on the instrument by client, using the same speed of operation.

The calibration can only deliver a measurement error in comparison to a reference at the time of calibration and under the conditions of the calibration. Any transfer of this information to other conditions or an extrapolation of the results into the future requires additional succeeding calibrations or a priori information and the respective extrapolation of the uncertainty based on the knowledge about the behaviour of the instrument. This topic is not covered by this guide.

Calibration of a catchweigher as a non-automatic weighing instrument is out of the focus of this document but may be performed separately in the non-automatic mode and according to the respective calibration guideline for the non-automatic weighing instruments, EURAMET Calibration Guide No. 18 [2].

3 TERMINOLOGY AND SYMBOLS

The terminology used in this document is mainly based on existing documents

- OIML R 51 [1] for terms related to the operation, construction and metrological characterization of catchweighers,
- EURAMET Calibration Guide No. 18 [2] for terms related with the static weighing and calibration of control instrument.

Such terms are not explained in this document, but where they first appear, references will be indicated.

Symbols whose meanings are not self-evident, will be explained where they are first used. Those that are used in more than one section are collected in Appendix A.

4 GENERAL ASPECTS OF THE CALIBRATION

4.1 Elements of the calibration

Calibration consists of

1. determining the reference value of mass of the test loads,
2. applying the test loads to the instrument under specified conditions,
3. determining the error of measurement and variation of the indications
4. (evaluated by determination of repeatability, reproducibility and effect of eccentric loading), and
5. evaluating the uncertainty of measurement to be attributed to the results.

4.1.1 Range of calibration

In agreement with the client, the calibration is performed at set of calibration points, which are defined by the selected test loads, as well as by the load transport system speed setting and the orientation of the test loads on the load transport system.

The calibration is only valid for the above specified parameters. It will usually not be possible to calibrate a “range” for such instruments, because of their dynamic behaviour. The estimation of a calibration curve over parts or the whole range of the instrument is not covered by this guide.

On a multilane instrument (the instrument with several load receptors and a single terminal), the client shall identify which lane(s) need to be calibrated.

4.1.2 Place of calibration

Calibration is performed at the location where the instrument is being installed. The calibration is valid for the place of calibration.

4.1.3 Preconditions, preparations

The calibration should be performed under, as far as possible, normal conditions of use and operation of the catchweigher (type of weighed articles, their positioning and orientation, distance between the articles, speed of the load transport system, ambient temperature, air flow, vibrations, stability of the weighing site etc.). The calibration should not be performed unless

1. the instrument can be readily identified,
2. all functions of the instrument are free from effects of contamination or damage, and functions essential for the calibration operate as intended,
3. presentation of weight values is unambiguous and indications, where given, are easily readable,
4. the instrument is energized prior to calibration for an appropriate period, e.g. as long as the warm-up time specified for the instrument, or as set by the user,
5. the instrument is levelled, if applicable,
6. the instrument has been several times exercised in the automatic weighing mode with the largest test load.

If the instrument is fitted with the dynamic setting facility [1], which is regularly used by the user, the dynamic setting is executed for each test load value before commencing the calibration. Such setting should be made with the means normally used by the client and following the manufacturer's instructions when available.

If agreed with the client, the instrument could be statically adjusted before the calibration. Adjustment should be performed with the means that are normally applied by the client, and following the manufacturer’s instructions where available.

Instruments fitted with an automatic zero-setting device or a zero-tracking device [1] should be calibrated with the device operative or not, as used by the client.

The user of the instrument should be asked to ensure that the normal conditions of use as mentioned above prevail during the calibration. In this way influencing and disturbing effects will, as far as it is possible, be inherent in the measured values and will therefore be included in the determined uncertainty of measurement.

4.2 Control instrument

A control instrument [1] is used to determine the reference value of mass of the test loads.

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 reference value of mass of each test load to accuracy, which is appropriate to the expected uncertainty of calibration of the calibrated instrument.

As a recommendation it can be taken that the control instrument should have a resolution better than or equal to that of the calibrated instrument and, if applicable, ensure the determination of the reference value of mass of each test load to accuracy of at least one-third of appropriate tolerances for the calibrated instrument if they are defined by client.

Details on determination of the reference value of mass of the test load on the control instrument and corresponding uncertainty are given in Section 4.5 and Section 7.1.2, respectively.

4.3 Test loads and calibration points

As mentioned in Section 4.1.1, the calibration is performed at set of calibration points within the measurement range of the instrument. The calibration points correspond with the selected test loads, their orientation on the load transport system and the load transport system speed setting. Preferably, the test loads should be selected from types of articles that are normally weighed on the instrument to be calibrated. Thus the instrument is calibrated in k selected calibration points, corresponding with the test loads $L_{\mathrm{T}j}$, $1 \leq j \leq k$.

The calibration points and other conditions during the calibration should be defined in agreement with the customer in order to be as close as possible to the usual use of the instrument. If applicable, e.g. when only one type of article is weighed on the calibrated catchweigher, it can be calibrated in a single calibration point only.

For the purpose of calibrating the catchweigher, the reference value of mass of the test loads must be determined traceable to the SI unit of mass. Methods for this are given in Section 4.5.

Note 1: For the calibration of instruments with a high rate of operation (caused by e.g. high speeds of the load transport system and small distances between the loads), for each calibration point it could be considered to use a set of test loads. Such a set consists of a specified number of individual test loads of the same kind and with nearly the same mass. For further details see Note in Section 5.

In addition, when selecting the test loads, the following points must be taken into consideration:

1. appropriateness for the intended use of the instrument (if not exactly article(s), which are usually weighed on the calibrated instrument),
2. shape, material, composition should allow easy handling,
3. shape, material, composition should allow to easily estimate the position of centre of gravity in a direction perpendicular to movement of the load transport system,
4. their mass must remain constant throughout the period in which they are used for the calibration,
5. non-hygroscopic, non-electrostatic, non-magnetic material.

The reference value of mass of the test loads is normally determined at the time and place of calibration of the instrument. If it is not determined at the time and place of calibration of the instrument, but elsewhere (e.g. in a permanent laboratory):

6. their density should be easy to estimate and reported on the calibration report,
7. the test loads of low density may require special attention due to buoyancy. Monitoring of the temperature and the atmospheric pressure is necessary throughout the period of use of the loads during the calibration.

Note 2: Since the consideration of buoyancy effects is rather difficult in the latter case, this method should be avoided if possible.

4.3.1 Determination of the reference value of mass of the test load

The necessary measurements to determine the reference value of mass of each test load and its uncertainty are performed on the (static) control instrument (cf. 4.2). Recommended approaches are further discussed in Section 4.5.

4.3.2 Standard weights

Standard OIML weights [3] directly applied on the load transport system must not be used for calibration of the instrument.

The requirements for the standard weights, which are used for calibration of the control instrument or determination of the reference value of mass of the test loads using the control instrument as a comparator are given in [2] and [3], respectively.

4.3.3 Effects of convection

The test loads may not be at the same temperature as the instrument and its environment. The temperature difference ΔT is defined as the difference between the temperature of the test load and the temperature of the environment. Two phenomena should be noted in this case:

- An initial temperature difference ΔT_0 may be reduced to a smaller value ΔT by acclimatisation over a time Δt.
- When the test load is put on the load receptor, the actual difference ΔT will produce an air flow about the test load leading to parasitic forces which result in an apparent change Δm_{conv} on its mass. The sign of Δm_{conv} is normally opposite to the sign of ΔT, its value being greater for large test loads than for small ones.

The effect of convection could be minimized allowing the test loads to reach the temperature of the environment, i.e. to the extent that the remaining change Δm_{conv} is negligible in view of the uncertainty of the calibration required by the client.

Note: If a temperature difference between the instrument to be calibrated and the test loads is an “inherent” property of the weighing process (e.g. because frozen loads are checked), the resulting effect can be recognised in the calibration. In this case no temperature equilibration should be awaited, but the temperature difference shall be reported as a specific calibration condition.

4.4 Indications

4.4.1 General

An automatic weighing instrument is capable of performing consecutive weighing cycles without any intervention of an operator [4]. Unlike for non-automatic weighing instrument, the automatic weighing instrument operator is neither capable nor expected to make a correction of the indication under load with the indication at no load.

Consequently, for the purpose of calibration of catchweigher, generally only the test load indications I_{TL} are taken into account, and further called I. Since they are not corrected for the no load indications I_0 the following is valid

$$I = I_{\mathrm{TL}}. \qquad (4.4.1\text{-}1)$$

During the calibration, the instrument indications shall be recorded.

Instead of the visually observed indications, the indications stored electronically and displayed on demand or printed by the calibrated instrument may be preferably used by the calibration laboratory.

Note: The instrument can perform automatic zero-setting as part of every automatic weighing cycle, or after a programmable time interval. Due to this fact and at the discretion of the calibration laboratory, the correction for the no load indications I_0 as well as the corresponding uncertainty contribution can be taken into account

$$I = I_{\mathrm{TL}} - I_0. \qquad (4.4.1\text{-}2)$$

4.4.2 Resolution

Indications are normally obtained as integer multiples of the scale interval d.

If agreed with the client, means to obtain indications in higher resolution than d may be applied. Such means may be switching the indicating device to a smaller scale interval $d_\mathrm{s} < d$. In this case, the indications are obtained as integer multiple of d_s.

4.5 Reference value of mass of test loads

To calibrate the instrument, test loads are applied. Having Section 4.3 in mind, the conventional value of mass of the test load m_cTL is generally a priori not known, its density ρ_TL is normally significantly different from the reference value of density of standard weights ρ_c and the air density ρ_a at the time of calibration is normally different from the reference air density ρ_0.

However, in majority of cases it is not necessary to directly determine the conventional value of mass of the test load and know the density value of the test load (or its volume) as long as there is no significant difference in the air density value during the determination of the reference value of mass of the test load m_ref and the calibration of the catchweigher. Details are presented in Appendix B.

The reference value of mass of the test load, m_ref further called the reference value of mass, is the quantity, which will be used in connection with the test load to quantify performance of the catchweigher.

m_ref could be determined in various ways. Some of these methods are summarised in Table 4.5-1. Appendix B provides complete description of determination of reference value of mass m_ref, considering the methods and time of determination of the reference value of mass as given in the table. Final results of Appendix B subsections are used in Section 7.1.2.

Table 4.5-1: Methods of determination of reference value of mass of the test load.

Method of determination of reference value of mass	**Time of calibration**	**Remarks**	**Appendix**
Test load calibrated on the control instrument used as comparator	Test load calibrated at the time and place of calibration of catchweigher.	No significant drift of test load. Small air buoyancy correction.	B1
Test load weighed on the simultaneously calibrated control instrument	Control instrument calibrated at time and place of calibration of catchweigher. Test load weighed at the time and place of calibration of catchweigher.	No drift of test load. Small air buoyancy correction.	B2
Test load weighed on the previously calibrated control instrument	Control instrument calibrated previously. Test load weighed at the time and place of calibration of catchweigher.	Control instrument needs to have calibration certificate. Uncertainty of control instrument in use needs to be taken into account. No significant drift of test load. Small air buoyancy	B3
Test load with calibration certificate	Test load calibrated previously.	Drift of test load is relevant. Significant air buoyancy correction. Density/volume of test load needs to be known.	/

4.6 Operating parameters

Test load dimensions in terms of direction of the load transport system and the load transport system speed setting (the set/indicated speed, or the position of the speed setting switch) during the calibration should be determined and recorded for each test load.

The dimensions of the test load are given in the following form $a \times b \times c$, being

- a, length in the forward direction of the load transport system,
- b, width, perpendicular to the length in the plane of the load transport system,
- c, height, perpendicular to the plane of the load transport system.

Note: Maximum rate of operation is an important parameter for characterisation of operation of the instrument. Based on the load transport system speed v, and the length of the platform S, the maximum rate of operation c_{max} is calculated according to the following expression:

$$c_{\mathrm{max}} = v/S \tag{4.6-1}$$

5 MEASUREMENT METHOD

Measurements are normally performed to determine:

- the errors of measurement and the repeatability,

- the reproducibility and
- the effect of eccentric loading.

Details of the measurements performed for an individual calibration may be fixed by agreement of the client and the calibration laboratory, in view of the applied use of the instrument.

The general calibration procedure should be as follows:

1. Select the test loads as specified in Section 4.3. The reference value of mass of each test load is determined on the control instrument as specified in Section 4.5 and Appendix B.
2. Calibrate the instrument in its normal mode of automatic operation (if agreed with the client, indications in higher resolution may be obtained, see Section 4.4.2). Start the automatic weighing system, including the surrounding equipment, which is normally operational when the instrument is in use.
3. Set the load transport system to the speed agreed with the client. Normally this is the speed used for weighing articles by the client. The speed may vary depending on the mass of the test load.
4. Where applicable, before commencing the measurements select the corresponding dynamic setting factor, or carry out the dynamic setting for each test load value if the client regularly uses this facility.
5. Prior to the start of each test at the given load value, the indication is set to zero, and not manually set again at any time during the test. It has to be allowed that automatic zero setting, if exists and used by the user, is operational during the tests.
6. The number of consecutive measurements for each test load depends on its nominal mass as specified in Sections 5.1, 5.2 and 5.3.
7. Enable the same test load to be automatically weighed for the specified number of times and record each indication. The test load is introduced to the load transport system and the load receptor using the feeding system and the load conveyor of the instrument.

Note: For the calibration of instruments with a high rate of operation (see Note 1 in Section 4.3) the use of automatic feeding device could be considered. In this case the individual test loads of the same kind and with nearly the same mass are weighed once in the individual calibration point instead of the same test load being weighed several times. The number of the test loads used should equal the number of repetitions specified in Sections 5.1, 5.2 and 5.3. Then their reference value of mass is determined on the control instrument. The individual test loads must be individually characterised, identifiable and the order of use has to be clearly recorded. An automatic logging of the individual indications is presumed.

8. The status of dynamic adjustment and automatic zeroing facilities shall be recorded for each individual test, if applicable.

5.1 Determination of errors and repeatability

The purpose of this test is an appraisal of the errors and repeatability of the instrument in selected calibration points (represented by selected test loads). Each calibration point is characterized by its own repeatability.

The procedure consists of the passing repeatedly the selected test load over the load receptor, using the central portion of the load transport system, under identical conditions of handling of the load and the instrument, and under constant calibration conditions. For catchweighers where weighing is performed dynamically, the load transport system should not be stopped during the measurements.

The minimum number of consecutive repeated measurements with the same test load, n is selected as specified in Table 5.1-1.

Table 5.1-1: Minimum number of measurements in a relation to the nominal mass of the test load for determination of errors and repeatability of indication.

Nominal mass m_{N} of the test load	Minimum number of repetitions, n
m_{N} ≤ 10 kg	20
10 kg < m_{N} ≤ 20 kg	15
20 kg < m_{N}	10

The procedure described above is repeated in all selected calibration points, i.e. with the test loads (or sets of test loads) $L_{\mathrm{T}j}$, $1 \leq j \leq k$, that were selected according to Section 4.3 and their reference value of mass was determined according to Section 4.5.

If the instrument is used to determine the net values of the weighed articles and an available tare device (static or dynamic tare device, preset tare device) is used to take into account the tare value of the packing of weighed article, this may be taken into account. The (preset) tare value(s) need to be agreed with the client.

- For the static taring, place the tare load on the load receptor and allow the tare function to operate (refer to the manufacturer’s instructions).
- For the dynamic taring, pass the load to be tarred over the load receptor to allow the tare function to operate (refer to manufacturer’s instructions).
- For the preset tare, determine the tare value in the same way as the load value and introduce it into the instrument (refer to the manufacturer’s instructions).

5.2 Determination of reproducibility

The purpose of reproducibility measurements is to evaluate possible additional effects (such as adjustment of the belt, mechanical hysteresis, which could result from stopping and starting again operation of the load transport system), which influences the variation of calibration results, other than that already taken into account by Section 5.1. Each calibration point is characterized by its own reproducibility.

The measurement procedure consists of 5 cycles with at least 1 measurement of the test load in each cycle. In general, a larger number of measurements in the cycle could provide a better estimation of the reproducibility. The same test load is passed over the load receptor, using the central portion of the load transport system, under identical conditions of handling the load and the instrument, and under constant test conditions. For the test load heavier than 20 kg the number of cycles can be reduced to 3.

However, opposite to Section 5.1 it is essential that between the cycles the operation of the catchweigher is interrupted, e.g. by stopping and then starting again the load transport system.

The procedure described above is repeated in all selected calibration points, i.e. with the same test loads, $L_{\mathrm{T}j}$, $1 \leq j \leq k$, as mentioned in Section 5.1.

Note: The procedure described in this section may not be necessary for catchweighers where for the normal way of operation the weighing is performed statically (e.g. a start-stop operation) in automatic mode of operation.

5.3 Determination of effect of eccentric loading

The effect of the eccentric application of the load on the indication is measured when applicable. This effect may occur where the instrument does not have guides to centre the articles or where the guides are not suitable to this article. The test is not applicable when the test load cannot be applied eccentrically on the load receptor due to nature and shape of the article or the design of the load receptor, for example due to existence of mechanical guides, adapted to the width of the article.

The effect of eccentric loading is determined using the selected test load using the central portion of the load transport system, the portion of the load transport system that is halfway between the centre and the back, and the portion of the load transport system that is halfway between the centre and the front as shown in figure 5.3-1.

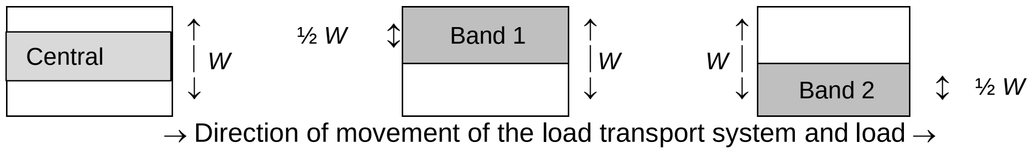

Figure 5.3-1. Positions of the test load for test of eccentricity.

In figure 5.3-1, W represents the width of the load transport system if there are no guides, or width between the guides where they exist.

The minimum number of consecutive measurements is selected as specified in Table 5.3-1.

Table 5.3-1: Minimum number of measurements on a portion of the load transport system in a relation to the nominal mass of the test load for determination of effect of eccentric loading.

Nominal mass m_{N} of the test load	Minimum number of repetitions n
m_{N} ≤ 10 kg	6
10 kg < m_{N} ≤ 20 kg	5
20 kg < m_{N}	3

The operation of the catchweigher should not be interrupted (e.g. by stopping and then starting again the load transport system) between the measurements on the central portion, the band 1 and the band 2, except for the safety reasons.

Note: When it is agreed with the client to carry out the determination of effect of eccentric loading even in a case of existence of mechanical guides, due to safety reasons stopping the load transport system may be necessary between the measurements on different portions of the load transport system in order to reposition the guides.

The procedure described above is repeated in all selected calibration points, i.e. with the same test loads, $L_{\mathrm{T}j}$, $1 \leq j \leq k$ as mentioned in Section 5.1.

The determination of the effect of the eccentric loading may be combined with the determination the errors of measurement. Measurement results from Section 5.1 can be used also as results for the central portion of the load transport system in this section if after measurements on the central portion of the load transport system the measurements are performed on the bands 1 and 2 for evaluation of the effect of the eccentric loading.

5.4 Auxiliary measurements

The air temperature in a vicinity to the instrument should be measured, at least once during the calibration. Where an instrument is used in a controlled environment, the span of the temperature variation should be noted, e.g. from a thermograph, from the settings of the control device etc.

Barometric pressure or the altitude above sea-level of the site may also be useful.

Special care should be taken to prevent excessive convection effects, by observing a limiting value for the temperature difference between the test loads and instrument, and/or recording an acclimatisation time that has been executed. However, if the test loads and the instrument have always the same temperature difference (e.g. frosted goods), the acclimatisation is not applicable and this condition should be noted.

The air flow level in a vicinity to the instrument should be also noted.

6 MEASUREMENT RESULTS

The procedures and formulae in Sections 6 and 7 provide the basis for the evaluation of the results of the calibration and therefore require no further description on a calibration certificate. If the procedures and formulae used deviate from those given in the guide, additional information should be provided in the certificate.

The definition of an indication I as given in 4.4.1 is used in this section.

Formulae in Sections 6 and 7 are applicable to all calibration points, corresponding with the test loads $L_{\mathrm{T}j}$, $1 \leq j \leq k$. The index "j " in formulae has been omitted hereafter.

6.1 General considerations

The instrument indication at calibration I is a function of several effects such as the reference mass of the test load m_{ref} and error of measurement E.

$$I = f(m_{\mathrm{ref}}, E) \tag{6.1-1}$$

I and m_{ref} are further influenced by many effects. We can only take into account the most important aspects (via uncertainties in Section 7).

The calibration allows the derivation of the error of measurement of the instrument as the difference between indicated values and reference value of mass.

6.2 Error of measurement

For each test load $L_{\mathrm{T}j}$, the error of measurement E is calculated as follows

$$E = \bar{I} - m_{\mathrm{ref}} \tag{6.2-1}$$

where the mean value of several indications, $\bar{I}$ is calculated as per (6.3-2) and m_{ref} is the value obtained according to Section 4.5 and Appendix B.

6.3 Repeatability

From the n indications I_i for a given test load $L_{\mathrm{T}j}$, the standard deviation $s(I)$ is calculated

$$s(I) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(I_i - \bar{I}\right)^2} \qquad (6.3\text{-}1)$$

with the mean value of indications $\bar{I}$

$$\bar{I} = \frac{1}{n}\sum_{i=1}^{n} I_i \qquad (6.3\text{-}2)$$

6.4 Reproducibility

From 5 indications I_i, $1 \leq i \leq 5$, for a given test load $L_{\mathrm{T}j}$, the maximum difference between the indications $\Delta I_{\mathrm{rpd,max}}$ is calculated

$$\Delta I_{\mathrm{rpd},max} = I_{i,\mathrm{max}} - I_{i,\mathrm{min}} \qquad (6.4\text{-}1)$$

If more than one measurement per cycle was executed, then the average indicated value per cycle is taken into account in (6.4-1).

6.5 Effect of eccentric loading

For each band b of the load transport system (cf. Figure 5.3-1) and for a given test load $L_{\mathrm{T}j}$, the average difference $\Delta I_{\mathrm{ecc},b}$ is calculated as follows:

$$\Delta I_{\mathrm{ecc},b} = \bar{I}_b - \bar{I}_{\mathrm{c}} \qquad (6.5\text{-}1)$$

$\bar{I}_b$ being the average of the indications of the test load on the band, b being 1 or 2, and $\bar{I}_{\mathrm{c}}$ the average of the indications of the test load on the central portion of the load transport system.

7 UNCERTAINTY OF MEASUREMENT

For the determination of uncertainty, second order terms have been considered negligible, but when first order contributions cancel out, second order contributions should be taken into account (see JCGM 100 [6], 5.1.2 note).

7.1 Standard uncertainty of error of measurement

Taking into account (6.2-1) the outcome of the calibration is the error of measurement of the instrument

$$E = \bar{I} - m_{\mathrm{ref}} \qquad (7.1\text{-}1)$$

with standard uncertainty of the error

$$u(E) = \sqrt{u^2(\bar{I}) + u^2(m_{\mathrm{ref}})} \qquad (7.1\text{-}2)$$

All input quantities are considered to be uncorrelated, therefore covariances are not considered.

The terms are further expanded hereafter.

7.1.1 Standard uncertainty of the indication of the catchweigher

To account for sources of variability of the indication, (4.4.1-1) is amended by correction terms δI_{xx} as follows

$$\bar{I} = \bar{I}_{\mathrm{TL}} + \delta I_{digTL} + \delta I_{\mathrm{rtp}} + \delta I_{\mathrm{rpd}} + \delta I_{\mathrm{ecc}} \quad (7.1.1\text{-}1)$$

Further correction terms may be applied in special conditions (temperature effects, drift of zero, ...), which are not considered hereafter.

All these corrections have the expectation value zero. Their standard uncertainties are:

7.1.1.1 $\delta I_{\mathrm{digTL}}$ accounts for the effect of the resolution of indication at load. Limits are $\pm d/2$ or $\pm d_{\mathrm{s}}/2$ as applicable (explanation for d_{s} is given in Section 4.4.2); rectangular distribution to be assumed, therefore the standard uncertainty due to the effect of the resolution $u(\delta I_{\mathrm{digTL}})$ is estimated as

$$u(\delta I_{\mathrm{digTL}}) = d/2\sqrt{3} \quad (7.1.1\text{-}2a)$$

or

$$u(\delta I_{\mathrm{digTL}}) = d_{\mathrm{s}}/2\sqrt{3} \quad (7.1.1\text{-}2b)$$

respectively.

Note: on a multi-interval instrument, d (or d_{s}) varies with I.

7.1.1.2 δI_{rpt} accounts for the repeatability of the catchweigher; the normal distribution is assumed, the standard uncertainty due to repeatability $u(\delta I_{\mathrm{rpt}})$ is estimated as

$$u(\delta I_{\mathrm{rpt}}) = s(I)/\sqrt{n} \quad (7.1.1\text{-}3)$$

where $s(I)$ is determined in 6.3 and n is number of repeated weighings for the given test load.

$s(I)$ is determined for each given test load $L_{\mathrm{T}j}$ and it is considered as representative only for the respective test load.

7.1.1.3 δI_{rpd} accounts for reproducibility of the instrument; the rectangular distribution is assumed, the standard uncertainty due to reproducibility $u(\delta I_{\mathrm{rpd}})$ is estimated as

$$u(\delta I_{\mathrm{rpd}}) = \Delta I_{\mathrm{rpd,max}}/\sqrt{12} \quad (7.1.1\text{-}4)$$

where $\Delta I_{\mathrm{rpd,max}}$ is determined in 6.4.

$\Delta I_{\mathrm{rpd,max}}$ is determined for each given test load $L_{\mathrm{T}j}$ and it is considered as representative only for the respective test load.

7.1.1.4 δI_{ecc} accounts for the error due to off-centre position of the centre of gravity of the test load in a direction perpendicular to movement of the load transport system. Where this effect cannot be neglected, an estimate of its magnitude may be based on these assumptions:

- the average differences ΔI_{ecc} determined by (6.5-1) are proportional to the distance of the load from the centre of the load receptor in a direction perpendicular to movement of the load transport system,

- the effective centre of gravity of the test loads during the determination of errors is not further from the centre of the load receptor than half the distance between the load receptor centre and the eccentricity load positions in a direction perpendicular to movement of the load transport system (i.e. ¼ *W*), as per figure 5.2-1.

Based on the largest of the differences determined as per 6.5, δI_{ecc} is estimated to be

$$\delta I_{\mathrm{ecc}} \leq \frac{1}{2}\left|\Delta I_{\mathrm{ecc},b}\right|_{\mathrm{max}} \tag{7.1.1-5}$$

Rectangular distribution is assumed, so the standard uncertainty due to eccentricity $u(\delta I_{\mathrm{ecc}})$ is estimated as

$$u(\delta I_{\mathrm{ecc}}) \leq \frac{1}{2}\left|\Delta I_{\mathrm{ecc},b}\right|_{\mathrm{max}} \cdot \frac{1}{\sqrt{3}} \tag{7.1.1-6}$$

$\left|\Delta I_{\mathrm{ecc},b}\right|_{\mathrm{max}}$ is determined for each given test load $L_{\mathrm{T}j}$ and it is considered as representative only for the respective test load.

7.1.1.5 The standard uncertainty of the indication for calibration point j is normally obtained by

$$u(\bar{I}) = \sqrt{u^2(\delta I_{\mathrm{digTL}}) + u^2(\delta I_{\mathrm{rpt}}) + u^2(\delta I_{\mathrm{rpd}}) + u^2(\delta I_{\mathrm{ecc}})} \tag{7.1.1-7}$$

Note: The first term on the right hand side may have to be modified in special cases as mentioned in 7.1.1.1.

7.1.2 Standard uncertainty of the reference value of mass

Taken into account the content of table in Section 4.5 and Appendix B, the following cases of determination of the reference value of mass are treated in this section:

A. Test load calibrated on the control instrument
B. Test load weighed on the simultaneously calibrated control instrument
C. Test load weighed on the previously calibrated control instrument
D. Test load with calibration certificate

In general, uncertainty of reference value of mass gets larger from procedure A to procedure C.

7.1.2.A Test load calibrated on the control instrument

The determination of the reference value of mass, when the test load is calibrated on the control instrument, which is used as the comparator, is dealt with in Appendix B1 by (B1-5)

$$m_{\mathrm{ref}} = m_{\mathrm{cR}} + \delta m_{\mathrm{BTot}} + \overline{\Delta I_{\mathrm{CI}}}$$

To account for sources of variability of the reference value of mass for this case, (B1-5) is amended by correction term δm_{ba} as follows

$$m_{\mathrm{ref}} = m_{\mathrm{cR}} + \delta m_{\mathrm{BTot}} + \overline{\Delta I_{\mathrm{CI}}} + \delta m_{\mathrm{ba}} \tag{7.1.2-1}$$

7.1.2.1 m_{cR} is the conventional mass of the standard weights used for calibration of the test load on the control instrument. Its standard uncertainty $u(m_{\mathrm{cR}})$ should be evaluated according to Section C.6.2 of OIML R111 [3].

7.1.2.2 δm_{BTot} is the correction for air buoyancy as introduced in Appendix B1, equations (B1-4), (B1-5) and (B1-6)

$$\delta m_{BTot} = V_{TL}(\rho_{aCI} - \rho_a) - m_{cR}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_R} - \frac{1}{\rho_S}\right)\right] = \delta m_{B1} + \delta m_{B2}$$

Where a comparison of estimated values of δm_{BTot} with the resolution of the instrument d shows that the air buoyancy correction is small enough, a more elaborate calculation of the correction and its uncertainty component based on actual data may be superfluous. Consequently, no correction is applied, i.e. $\delta m_{\mathrm{BTot}} = 0$. Some estimates of δm_{B1} in a relation to the densities/volumes of the test load and the air density differences are given in Table B1-1. It can be seen that small changes of the air density during the calibration or higher densities of the test load result in a very small value of δm_{B1}.

The standard uncertainty of the air buoyancy correction $u(\delta m_{\mathrm{BTot}})$ is evaluated as a combination of two contributions

$$u(\delta m_{\mathrm{BTot}}) = \sqrt{u^2(\delta m_{\mathrm{B1}}) + u^2(\delta m_{\mathrm{B2}})} \tag{7.1.2-2}$$

where $u(\delta m_{\mathrm{B1}})$ can be evaluated on a basis of the maximum measured (or estimated) air density variation during the calibration $|\delta m_{\mathrm{B1}}|_{\mathrm{max}}$ using (B1-5)

$$u(\delta m_{\mathrm{B1}}) \approx \frac{|\delta m_{\mathrm{B1}}|_{\mathrm{max}}}{\sqrt{3}} \tag{7.1.2-3}$$

and $u(\delta m_{\mathrm{B2}})$ can be evaluated as given in [2]

$$u(\delta m_{\mathrm{B2}}) \approx (0{,}1\,\rho_0 m_{\mathrm{N}}/\rho_{\mathrm{c}} + mpe/4)/\sqrt{3} \tag{7.1.2-4}$$

with m_{N} being the nominal mass of the test load and mpe the maximum permissible error of the standard weights according to [3] corresponding to the nominal mass of the test load. The lowest accuracy class of the standard weights used for adjustment is applicable.

However, for smaller uncertainties the air buoyancy correction needs to be taken into account according to (B1-4). In such a case $u(\delta m_{\mathrm{B1}})$ can be evaluated based on standard uncertainties of the volume of the test load $u(V_{\mathrm{TL}})$ and the air density difference $u(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}})$

$$u(\delta m_{\mathrm{B1}}) = \sqrt{\left(V_{\mathrm{TL}} u(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}})\right)^2 + \left((\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}})\, u(V_{\mathrm{TL}})\right)^2} \tag{7.1.2-5}$$

and $u(\delta m_{\mathrm{B2}})$ could be evaluated in the same way as in Section 7.1.2.2 of [2].

7.1.2.3 $\overline{\Delta I_{\mathrm{CI}}}$ is the average difference in indication between the test load and standard weight(s) measurements on the control instrument as introduced in Annex B1. Its standard uncertainty $u(\overline{\Delta I_{\mathrm{CI}}})$ should be evaluated according to Section C.6.1 of OIML R111 [3].

7.1.2.4 δm_{ba} corresponds to the influences of the control instrument used for calibration of the test load. No correction is applied, $\delta m_{\mathrm{ba}} = 0$ and its standard uncertainty $u(\delta m_{\mathrm{ba}})$ should be evaluated according to Section C.6.4 of OIML R111 [3].

7.1.2.5 When the test load calibrated on the control instrument is used, the standard uncertainty of the reference value of mass is obtained from

$$u(m_{ref}) = \sqrt{u^2(m_{\mathrm{cR}}) + u^2(\delta m_{\mathrm{BTot}}) + u^2(\overline{\Delta I_{\mathrm{CI}}}) + u^2(\delta m_{\mathrm{ba}})} \tag{7.1.2-6}$$

with the contributions from 7.1.2.1 to 7.1.2.4.

7.1.2.B Test load weighed on simultaneously calibrated control instrument

The determination of the reference value of mass, when the test load is determined by weighing on the control instrument, which was calibrated immediately before the weighing took place, is dealt with in Appendix B2 by (B2-14)

$$m_{\mathrm{ref}} = (R_{\mathrm{LCI}} - R_{\mathrm{0CI}}) - (I_{\mathrm{LCI}} - I_{\mathrm{0CI}}) + m_{\mathrm{cCalCI}} + \delta m_{\mathrm{BTot}}$$

To account for sources of variability of the reference value of mass for this case, (B2-14) is amended by corrections terms δX_{xx} as follows

$$\begin{aligned} m_{ref} = &\left(R_{\mathrm{LCI}} + \delta R_{\mathrm{digLCI}} + \delta R_{\mathrm{repCI}} + \delta R_{\mathrm{eccCI}} - (R_{\mathrm{0CI}} + \delta R_{\mathrm{0CI}})\right) \\ &- \left(I_{\mathrm{LCI}} + \delta I_{\mathrm{digLCI}} + \delta I_{\mathrm{repCI}} + \delta I_{\mathrm{eccCI}} - \left(I_{\mathrm{0CI}} + \delta I_{\mathrm{dig0CI}}\right)\right) \\ &+ (m_{\mathrm{NCalCI}} + \delta m_{\mathrm{cCalCI}} + \delta m_{\mathrm{DCalCI}} + \delta m_{\mathrm{convCalCI}}) \\ &+ \delta m_{\mathrm{BTot}} \end{aligned} \tag{7.1.2-7}$$

7.1.2.6 R_{CI} is the reading of the test load on the control instrument (cf. also (B2-3)). Its standard uncertainty $u(R_{\mathrm{CI}})$ should be evaluated according to Section 7.4.1 of [2].

7.1.2.7 I_{CI} is indication of the standard weights on the control instrument (cf. also (B2-5)). Its standard uncertainty $u(I_{\mathrm{CI}})$ should be evaluated according to Section 7.1.1 of [2].

7.1.2.8 m_{CalCI} is the reference value of mass of standard weights used for calibration of the control instrument, without taking into account the correction term for air buoyancy. Its standard uncertainty $u(m_{\mathrm{CalCI}})$ should be evaluated according to Section 7.1.2 of [2], but not taking into account the standard uncertainty of the air buoyancy correction. The standard uncertainty of the air buoyancy correction is treated separately according the following paragraph.

7.1.2.9 δm_{BTot} is the correction for air buoyancy as introduced in Appendix B2, equations (B2-11), (B2-12) and (B2-13)

$$\delta m_{\mathrm{BTot}} = V_{\mathrm{TL}}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) - m_{\mathrm{cCalCI}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{CalCI}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] = \delta m_{\mathrm{B1}} + \delta m_{\mathrm{B2}}$$

Application of the correction and the corresponding uncertainty is done in the same way as described in Section 7.1.2.2.

7.1.2.10 When the test load weighed on the simultaneously calibrated control instrument is used, the standard uncertainty of the reference value of mass is obtained from

$$u(m_{\mathrm{ref}}) = \sqrt{u^2(R_{\mathrm{CI}}) + u^2(I_{\mathrm{CI}}) + u^2(m_{\mathrm{CalCI}}) + u^2(\delta m_{\mathrm{BTot}})} \tag{7.1.2-8}$$

with the contributions from 7.1.2.6 to 7.1.2.9.

7.1.2.C Test load weighed on previously calibrated control instrument

The determination of the reference value of mass, when the test load is determined by weighing on the control instrument, which was calibrated previously and separately from the weighing of test load, is dealt with in Appendix B3 by (B3-8)

$$m_{\text{ref}} = W_{\text{CI}} + \delta m_{\text{BTot}}$$

7.1.2.11 W_{CI} is the weighing result of the control instrument. W_{CI} is determined according to Appendix B3. Its standard uncertainty $u(W_{\text{CI}})$ should be evaluated according to Sections 7.4.5 or 7.5.2 of [2] for the case when errors of the control instrument are accounted by correction or included in a "global" uncertainty $U_{\text{gl}}(W_{\text{CI}})$, respectively.

According to [2], the standard uncertainty for the weighing result under conditions of the calibration $u(W^{*}_{\text{CI}})$ could be used instead of $u(W_{\text{CI}})$ if the control instrument was calibrated right before its use. Similar can be assumed if the control instrument was adjusted right before its use and uncertainty contributions resulting from the operation of the control instrument (as defined in Section 7.4.4 of [2]) are negligible.

The control instruments needs to have the calibration certificate. On basis of [2] the laboratory needs to independently evaluate uncertainty in use based on actual conditions valid in a period since the last calibration of control instrument.

For a special case, where the control instrument is used, which conforms to [7,8] and where the tolerance specified by the client Tol equals maximum permissible error of the non-automatic weighing instrument mpe_{R76}[7,8], evaluation of the standard global uncertainty is provided in Appendix C.

7.1.2.12 δm_{BTot} is the correction for air buoyancy as introduced in Appendix B3, equation (B3-5), (B3-6) and (B3-7)

$$\delta m_{\text{BTot}} = V_{\text{TL}}(\rho_{\text{aCI}} - \rho_{\text{a}}) - W_{\text{CI}}\left[(\rho_{\text{a}} - \rho_0)\left(\frac{1}{\rho_{\text{sCI}}} - \frac{1}{\rho_{\text{s}}}\right)\right] = \delta m_{\text{B1}} + \delta m_{\text{B2}}$$

Application of the correction and the corresponding uncertainty is done in the same way as described in Section 7.1.2.2.

7.1.2.13 When the test load weighed on the previously calibrated control instrument is used, the standard uncertainty of the reference mass is obtained from

$$u(m_{\text{ref}}) = \sqrt{u^2(W_{\text{CI}}) + u^2(\delta m_{\text{BTot}})} \quad (7.1.2\text{-}9)$$

with the contributions from 7.1.2.11 and 7.1.2.12.

7.1.2.D Test load with calibration certificate

If it is justified that the test load is calibrated prior to the calibration of the instrument, then it is accompanied with calibration certificate, which states its conventional mass m_{cTL} with uncertainty and density with uncertainty. According to (B-1) the reference value of mass is

$$m_{\text{ref}} = m_{\text{cTL}} + \delta m_{\text{B}} + \delta m_{\text{D}} + \delta m_{\text{conv}}$$

7.1.2.14 m_{cTL} is the conventional mass of the test load given in the calibration certificate for the test load, together with the uncertainty of calibration U and the coverage factor k. The standard uncertainty is

$$u(m_{\text{cTL}}) = U/k \quad (7.1.2\text{-}10)$$

Where the test load has been calibrated to specified tolerances Tol, e.g. to the mpe given in OIML R111 [3], and where its nominal value m_{N} is used, rectangular distribution is assumed, therefore

$$u(m_{\mathrm{cTL}}) = Tol/\sqrt{3} \qquad (7.1.2\text{-}11)$$

Where a test load consists of more than one test piece, the standard uncertainties are summed arithmetically not by a sum of squares, to account for assumed correlation.

7.1.2.15 δm_{B} is the correction for air buoyancy for the test load used for calibration of the catchweigher as given by (B-3)

$$\delta m_{\mathrm{B}} = -m_{\mathrm{cTL}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] u(m_{\mathrm{cTL}}) = U/k$$

with the standard uncertainty

$$u(\delta m_{\mathrm{B}}) = m_{\mathrm{cTL}}\sqrt{u^2(\rho_{\mathrm{a}})\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{s}}}\right)^2 + (\rho_{\mathrm{a}} - \rho_0)^2 u^2\,(\rho_{\mathrm{s}})/\rho_{\mathrm{s}}^4 + (\rho_{\mathrm{a}} - \rho_0)^2 u^2\,(\rho_{\mathrm{TL}})/\rho_{\mathrm{TL}}^4} \qquad (7.1.2\text{-}12)$$

As far as values for ρ_{TL}, $u(\rho_{\mathrm{TL}})$, ρ_{s}, $u(\rho_{\mathrm{s}})$, ρ_{a} and $u(\rho_{\mathrm{a}})$, are known, these values should be used to determine $u_{\mathrm{rel}}(\delta m_{\mathrm{B}})$.

The calibration certificate for test load needs to provide information about the density of the test load with uncertainty or the density ρ_{TL} (as well as the density ρ_{s}) and its standard uncertainty may be estimated according to the state of the art or based on information available. Table B7 from [3] offers internationally recognized values only for common materials used for standard weights.

The air density ρ_{a} and its standard uncertainty can be calculated from temperature and barometric pressure if available (the relative humidity being of minor influence), or may be estimated from the altitude above sea-level. Appendix A in [2] gives further information on air density calculation.

Only if the density of test load equals to that of a certain accuracy class of the standard OIML weights, recourse may be taken to section 10 of OIML R111 [3]. No correction is applied, and the uncertainties can be determined according to Section 7.1.2.2 of [2].

7.1.2.16 δm_{D} corresponds to the possible drift of m_{cTL} since the last calibration. A limiting value D is best assumed, based on the difference in m_{cTL} evident from consecutive calibration certificates of the test load. D could be also estimated as the maximum allowed drift of the test load between its recalibrations, or the maximum drift expected in the medium term, when the calibration of test load has been performed for a particular use, but not immediately prior to the calibration of catchweigher.

It is not advised to apply a correction but to assume even distribution within $\pm D$ (rectangular distribution). The standard uncertainty is then

$$u(\delta m_{\mathrm{D}}) = D/\sqrt{3} \qquad (7.1.2\text{-}13)$$

7.1.2.17 δm_{conv} corresponds to the convection effects. It is not advised to apply a correction but to assume an even distribution within $\pm\Delta m_{\mathrm{conv}}$. The standard uncertainty is then

$$u(\delta m_{\mathrm{conv}}) = \Delta m_{\mathrm{conv}}/\sqrt{3} \qquad (7.1.2\text{-}14)$$

There are no studies available, which would give a simple elaboration of the convection effects for a general case. It appears that this effect is only relevant for uncertainties of calibration comparable to uncertainties for weights of class F1 or better [2]. In such a case, a suitable temperature equilibrium need to be reached between the test load and surrounding air at location of calibration of the catchweigher.

7.1.2.18 When the test load with calibration certificate is used, the standard uncertainty of the reference value of mass is obtained by

$$u(m_{\text{ref}}) = \sqrt{u^2(m_{\text{cTL}}) + u^2(\delta m_{\text{B}}) + u^2(\delta m_{\text{D}}) + u^2(\delta m_{\text{conv}})} \qquad (7.1.2\text{-}15)$$

with the contributions from 7.1.2.14 to 7.1.2.17.

7.2 Expanded uncertainty at calibration

The expanded uncertainty of the error of measurement $U(E)$ is

$$U(E) = ku(E) \qquad (7.2\text{-}1)$$

where standard uncertainty of the error of measurement $u(E)$ is defined by (7.1-2) and k is the coverage factor.

The coverage factor $k = 2$ is chosen such that the expanded uncertainty corresponds to a coverage probability of 95,45 %.

7.3 Standard uncertainty of a weighing result

Chapters 7.3 and 7.4 provide advice how the measurement uncertainty of an instrument could be estimated in normal usage, thereby taking into account the measurement uncertainty at calibration.

The user of the instrument should be aware of the fact that in normal usage, the situation is different from that at calibration in some if not all of these aspects

1. the indications obtained for weighed articles are not the ones at calibration,
2. the weighing process may be different from the procedure at calibration
    a. only one reading is taken for each load, not several readings to obtain a mean value; however, loads with the same nominal mass are usually weighted,
    b. it is not possible to make corrections to the single instrument indication; however, the corrections can be taken into account in assessment of average load,
    c. reading is to the scale interval d, of the instrument, not to a higher resolution d_{T},
    d. eccentric application of the load,
3. the environment (temperature, barometric pressure etc.) may be different,
4. the adjustment may have changed, due to drift or to wear and tear. This effect should therefore be considered in relation to a certain period of time.

In order to clearly distinguish from the indications I obtained during calibration, the symbol R is introduced for the weighing result obtained when weighing a load L on the calibrated instrument.

To take into account the remaining possible influences on the weighing result W, the correction δR_{instr}, which represents a correction term due to environmental influences, is added to the reading R resulting in the general weighing result

$$W = R + \delta R_{\text{instr}} - E \qquad (7.3\text{-}1)$$

The associated standard uncertainty is

$$u(W) = \sqrt{u^2(R) + u^2(\delta R_{\mathrm{instr}}) + u^2(E)} \quad (7.3\text{-}2)$$

The added terms and the corresponding standard uncertainties are discussed in 7.3.1 and 7.3.2.

Sections 7.3 and 7.4 are meant as advice to the user of the instrument on how to estimate the uncertainty of weighing results obtained under their normal conditions of use. They are not meant to be exhaustive or mandatory.

7.3.1 Standard uncertainty of a reading in use

To account for sources of variability of the reading, (7.1.1-1) applies, with $\bar{I}$ replaced by R and the test load replaced by the load L

$$R = R_{\mathrm{L}} + \delta R_{\mathrm{digL}} + \delta R_{\mathrm{rpt}} + \delta R_{\mathrm{rpd}} + \delta R_{\mathrm{ecc}} + \delta R_0 \quad (7.3.1\text{-}1)$$

No corrections are actually applied but the corresponding uncertainties are estimated:

7.3.1.1 δR_{digL} accounts for the rounding error at load reading. 7.1.1.1 applies with the exception that the variant $d_{\mathrm{s}} < d$ is excluded, so

$$u(\delta I_{\mathrm{digL}}) = d/2\sqrt{3} \quad (7.3.1\text{-}2)$$

7.3.1.2 δR_{rpt} accounts for the repeatability of the instrument. 7.1.1.2 applies, the relevant standard deviations $s(I)$ is to be taken from the calibration certificate, so

$$u(\delta R_{\mathrm{rpt}}) = s(I) \quad (7.3.1\text{-}3)$$

Note: δR_{rpt} is applied to a single reading of the instrument.

7.3.1.3 δR_{rpd} accounts for the reproducibility of the instrument. 7.1.1.3 applies, the relevant maximum difference $\Delta I_{rpd,max}/\sqrt{12}$ is to be taken from the calibration certificate, so

$$u(\delta R_{\mathrm{rpd}}) = \Delta I_{\mathrm{rpd,max}}/\sqrt{12} \quad (7.3.1\text{-}4)$$

7.3.1.4 Where this effect is not neglected, δR_{ecc} accounts for the error due to off-centre position of the centre of gravity of a load. (7.1.1-5) applies with the modification that the effect found during calibration should be considered in full, so

$$u(\delta R_{\mathrm{ecc}}) = |\Delta I_{\mathrm{ecc},b}|_{\mathrm{max}}/\sqrt{3} \quad (7.3.1\text{-}5)$$

7.3.1.5 δR_0 accounts for the effectivity of automatic zero-setting device. The automatic zero-setting device may operate at the start of automatic operation, as part of every automatic weighing cycle, or after a programmable time interval. A description of the operation of the automatic zero-setting device may be included in the type approval certificate or the instrument manual.

$$u(\delta R_0) = p \cdot d/\sqrt{3} \quad (7.3.1\text{-}6)$$

p representing a portion of d, within which the zero is maintained.

7.3.1.6 The standard uncertainty of the reading is then obtained by

$$u(R) = \sqrt{d^2/12 + s(I) + \Delta I_{\mathrm{rpd,max}}/\sqrt{12} + \left(\left|\Delta I_{\mathrm{ecc},b}\right|_{\mathrm{max}}\right)^2/3 + (pd)^2/3} \quad (7.3.1\text{-}7)$$

7.3.2 Standard uncertainty from environmental influences

The term $\delta R_{\mathrm{instr}}$ accounts for up to 3 effects δR_{temp}, δR_{buoy} and δR_{adj}, which are discussed hereafter. No corrections are actually applied, the corresponding uncertainties are estimated based on the user's knowledge of the properties of the instrument.

7.3.2.1 The term δR_{temp} accounts for a change in the characteristic of the instrument caused by a change in ambient temperature. A limiting value can be estimated to be $\delta R_{\mathrm{temp}} = K_{\mathrm{T}} \cdot \Delta T \cdot R$ where ΔT is the maximum temperature variation at the instrument location and K_{T} is the sensitivity of the instrument to temperature variation.

Normally there is a manufacturer's specification such as $K_{\mathrm{T}} = [\partial I(Max)/\partial T]/Max$, in many cases quoted in 10^{-6}/K. By default, for instruments with type approval under OIML R 51 [1], it may be assumed $|K_{\mathrm{T}}| \leq mpe(Max)/(Max \cdot \Delta T_{\mathrm{Approval}})$, where $\Delta T_{\mathrm{Approval}}$ is the temperature range of approval marked on the instrument; for other instruments, either a conservative assumption has to be made, leading to a multiple (3 to 10 times) of the comparable value for instruments with type approval, or no information can be given at all for a use of the instrument at other temperatures than that at calibration.

The range of variation of temperature ΔT (full width) should be estimated in view of the site where the instrument is being used, preferably on the basis of recordings of the conditions on-site, e.g. from quality assurance documentation.

Rectangular distribution is assumed, therefore the standard uncertainty is

$$u(\delta R_{\mathrm{temp}}) = K_T \cdot \Delta T \cdot R/\sqrt{12} \quad (7.3.2\text{-}1)$$

7.3.2.2 The term δR_{buoy} accounts for a change in the adjustment of the instrument due to the variation of the air density; no correction to be applied.

The most conservative approach would be

$$u(\delta R_{\mathrm{buoy}}) = 0{,}1\rho_0 R/(\rho_{\mathrm{c}}\sqrt{3}) \quad (7.3.2\text{-}2)$$

7.3.2.3 The term δR_{adj} accounts for a change in the characteristics of the instrument since the time of calibration due to drift, or wear and tear.

A limiting value may be taken from previous calibrations where they exist, as the largest difference $|\Delta E_{\mathrm{max}}|$ in the errors for the same test load between any two consecutive calibrations. By default, ΔE_{max} should be taken from the manufacturer's specification for the instrument, or may be estimated as $\Delta E_{\mathrm{max}} = mpe(R)$ for instruments conforming to a type approval under OIML R 51 [1]. Any such value can be considered in view of the expected time interval between calibrations, assuming fairly linear progress of the change with time. It is up to the user of the instrument to care for the respective information.

Rectangular distribution is assumed, therefore the relative uncertainty is

$$u(\delta R_{\mathrm{buoy}}) = 0{,}1\rho_0 R/(\rho_{\mathrm{c}}\sqrt{3}) \quad (7.3.2\text{-}3)$$

7.3.2.4 The standard uncertainty related to errors resulting from environmental effects is calculated by

$$u(\delta R_{\mathrm{instr}}) = \sqrt{u^2\left(\delta R_{\mathrm{temp}}\right) + u^2\left(\delta R_{\mathrm{buoy}}\right) + u^2\left(\delta R_{\mathrm{adj}}\right)} \tag{7.3.2-4}$$

7.4 Expanded uncertainty of a weighing result

7.4.1 Errors accounted for by correction

The complete formula for a weighing result, which is equal to the reading corrected for the error determined by calibration, is

$$W = R - E \pm U(W) \tag{7.4.1-1}$$

The expanded uncertainty $U(W)$ is to be determined as

$$U(W) = ku(W) \tag{7.4.1-2}$$

with $u(W)$ as applicable from (7.3-2) and the coverage factor $k = 2$.

7.4.2 Errors included in uncertainty

It may have been agreed by the calibration laboratory and the client to derive a “global uncertainty” $U_{\mathrm{gl}}(W)$ which includes the errors of indication such that no corrections have to be applied to the readings in use

$$W = R \pm U_{\mathrm{gl}}(W) \tag{7.4.2-1}$$

The error generally forms a one-sided contribution to the uncertainty, which can only be treated in an approximate manner. The combination with the uncertainties in use may then, in principle, take on one of these forms

$$U_{\mathrm{gl}}(W) = k\sqrt{u^2(W) + E^2} \tag{7.4.2-2}$$

$$U_{\mathrm{gl}}(W) = ku(W) + |E| \tag{7.4.2-3}$$

with $u(W)$ as applicable from (7.3-2) and the coverage factor $k = 2$.

8 CALIBRATION CERTIFICATE

This section contains advice what specific information applicable to calibration of the catchweigher may be useful to be given in a calibration certificate. It is intended to be consistent with the requirements of ISO/IEC 17025, which take precedence.

8.1 General information

Description of the calibrated instrument (manufacturer, type, Max, d).

Description of the load transport system (belt/chain/slide plate, gripper, pusher...), the mode of operation (dynamic automatic, static automatic), the guides used to centre the articles.

8.2 Specific information about the calibration procedure

Conditions of environment as specified in Section 5.4.

Information about the instrument operation during the calibration (e.g. adjustment performed, dynamic setting performed, setting of software as far as relevant for the calibration, the load transport system speed setting (the set/indicated speed, or the position of the speed setting switch), status of automatic zero setting facilities, tare settings), any anomalies of functions, purpose of use of the instrument as far as relevant for the calibration etc..

Information if the indications were obtained as integer multiple of the scale interval d_s.

Reference to, or description of the applied procedure for calibration of the instrument.

Reference to, or description of the applied procedure for determination of the reference mass of the test load(s).

Description of the test load(s) (e.g. material, dimensions in terms of direction of the load transport system as specified in Section 4.6, shape or other applicable information, including drawing or photo, if applicable).

Details of the loading procedure if relevant for the understanding of the above, referring to the feeding principle manually or by device.

For multilane instruments – information which lane(s) was calibrated (see 4.1.1).

8.3 Results of measurement

For each calibration point it is necessary to report:

- Information about the repeatability, e.g. the standard deviation of the repeatability measurements related to a single indication;
- Information about the reproducibility, e.g. the maximum difference between results of the reproducibility measurements;
- Information about the effect of eccentric loading, e.g. maximum effect of the eccentric loading, if performed;
- The reference value of mass, mean value of indication and error of measurement for the applied test load(s), as discrete values;
- Expanded uncertainty of measurement for the reported results.
- Indication of the coverage factor, with comment on coverage probability.

Where the indications have not been determined with the normal resolution of the instrument - a warning shall be given that the reported uncertainty is smaller than would be found with normal resolution.

9 VALUE OF MASS OR CONVENTIONAL VALUE OF MASS

The quantity W is an estimate of the conventional value of mass m_{c} of the article weighed. For certain applications it could be necessary to derive from W the value of mass m, or a more accurate value for m_{c}. Details about this procedure are given in Section 9 of [2].

The density or the volume V of the article, together with an estimate of their standard uncertainty, must be known from other sources.

10 REFERENCES

[1] OIML R 51-1: Automatic catchweighing instruments. Part 1: Metrological and technical requirements – Tests, Edition 2006 (E)

[2] EURAMET Calibration Guide No. 18: Guidelines on the Calibration of Non-Automatic Weighing Instruments, Version 4.0 (1/2015)

[3] OIML R111, Weights of Classes E1, E2, F1, F2, M1, M1-2, M2, M2-3, M3, Edition 2004 (E)

[4] WELMEC Guide No. 2, Directives 2014/31/EU and 2014/32/EU: Common Application Non-Automatic Weighing Instruments (NAWI), Automatic Weighing Instruments (AWI), Multi-dimensional Measuring Instruments (MDMI), 2023

[5] OIML D 28: Conventional value of the result of weighing in air, Edition 2004 (E)

[6] BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, and OIML. Evaluation of measurement data | Guide to the expression of uncertainty in measurement. Joint Committee for Guides in Metrology, JCGM 100:2008. URL: https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6

[7] OIML R 761-1: Non-automatic weighing instruments. Part 1: Metrological and technical requirements – Tests, Edition 2006 (E)

[8] EN 45501:2015 Metrological aspects of non-automatic weighing instruments

APPENDIX A: Symbols

Symbols that are used in more than in one section of the main document are listed and explained hereafter.

Symbol	Definition
D	drift, variation of a value with time
E	error (of measurement)
I	indication of an instrument related to a test load
L	load on an instrument
Max	maximum weighing capacity
R	indication (reading) of an instrument in use
U	expanded uncertainty
U_{gl}	global expanded uncertainty
Tol	specified tolerance value
V	volume
W	weighing result
d	scale interval, the difference in mass between two consecutive indications of the indicating device
d_{s}	effective scale interval < d, used during the calibration
k	coverage factor, number of calibration points/test loads
m	mass of an article
m_{c}	conventional value of mass
m_{N}	nominal value of mass
m_{ref}	reference value of mass of the test load
mpe	maximum permissible error (of an indication, a standard weight etc.) in a given context
n	number of items, as indicated in each case
s	standard deviation
u	standard uncertainty
ρ	density
ρ_0	reference density of air, ρ_0 = 1,2 kg/m³
ρ_{a}	air density
ρ_{c}	reference density of a standard weight, ρ_{c} = 8 000 kg/m³

Suffix	related to
B	air buoyancy
Cal	calibration
CI	control instrument
D	drift
L	at load
T	test
TL	at test load
Tot	total contribution
a	air
ba	balance
conv	convection
dig	digitalisation
ecc	eccentric loading
gl	global, overall
i, j, b	numbering
max	maximum value from a given population
ref, R	reference
rpt	repeatability
rpd	reproducibility
s	used for adjustment
0	zero, at no-load, initial

APPENDIX B: Methods for determination of reference value of mass

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

$$m_{\mathrm{ref}} = m_{\mathrm{cTL}} + \delta m_{\mathrm{B}} + \delta m_{\mathrm{D}} + \delta m_{\mathrm{conv}} + \delta m \ldots \qquad \text{(B-1)}$$

with

δm_{B} – air buoyancy correction for the test load used for calibration of the catchweigher,
δm_{D} – correction due to possible drift of the test load of since its calibration,
δm_{conv} – correction due to convection effects on the test load,
δm – further corrections that it may be necessary to apply under special conditions, these are not considered hereafter.

Opposite to calibration of non-automatic weighing instruments, density of the test load used for calibration of the catchweigher may significantly differ from the reference density of standard weights ρ_{s}, i.e. 8000 kg/m^3 [5]. Consequently, air buoyancy correction should be examined in more detail. If m_{ref} is determined at air density, which is different from air density at the time of calibration of catchweigher, the density of the test load needs to be known with relevant accuracy/uncertainty. On the other hand, if reference value of mass is determined at the time and place of calibration of the catchweigher, usually there is no significant difference in the air density value.

For the cases, where the test loads are calibrated at the time and place of calibration of the catchweigher, and if the test loads are kept at the temperature conditions prevailed during the calibration for longer time before the calibration, it can be with negligible uncertainty assumed that the corrections due to possible drift and convection effects are not necessary, $\delta m_{\mathrm{D}} \approx 0$ and $\delta m_{\mathrm{conv}} = 0$, respectively. In such a case, (B-1) is simplified to

$$m_{\mathrm{ref}} = m_{\mathrm{cTL}} + \delta m_{\mathrm{B}} \qquad \text{(B-2)}$$

The air buoyancy correction δm_{B} for the test load used for calibration of the catchweigher is evaluated based on [2]. It is affected by air density at the time of calibration of the catchweigher ρ_{a}, density of the test load ρ_{TL} and density of standard weights used for adjustment of the catchweigher ρ_{s}

$$\delta m_{\mathrm{B}} = -m_{\mathrm{cTL}} \left[(\rho_{\mathrm{a}} - \rho_0) \left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{s}}} \right) \right] \qquad \text{(B-3)}$$

with reference air density $\rho_0 = 1{,}2\ kg/m^3$.

B1 Test load calibrated on the control instrument used as comparator

This section deals with the case where the control instrument is used as a mass comparator and the reference value of mass of the test load is obtained by its calibration with a reference standard weight(s) with conventional mass m_{cR}. The reference value of mass of the test load is determined at the same time and place as the calibration of catchweigher.

The procedure for determination of m_{ref} is derived from a determination of the conventional mass of the test load m_{cTL} as described in Section C of OIML R111 [3]

$$m_{\mathrm{cTL}} = m_{\mathrm{cR}}\left(1 + (\rho_{\mathrm{aCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{R}}}\right)\right) + \overline{\Delta I_{\mathrm{CI}}} \tag{B1-1}$$

with

$\overline{\Delta I_{\mathrm{CI}}}$ – average difference in indication between the test load and the standard weight(s) measurements on the control instrument, an appropriate number of weighing cycles should be applied,
ρ_{aCI} - air density at the time of calibration of the test load on the control instrument,
ρ_0 - reference air density, 1,2 kg/m^3,
ρ_{TL} - density of the test load,
ρ_{R} - density of standard weights used for calibration of the test load on the control instrument

Based on (B-2), taking into account (B1-1) for the conventional mass of the test load, (B-3) for the air buoyancy correction, and under the condition that $m_{\mathrm{cTL}} \cong m_{\mathrm{cR}}$, the reference value of mass m_{ref} is determined by

$$\begin{aligned} m_{\mathrm{ref}} = m_{\mathrm{cR}}\left[1 + (\rho_{\mathrm{aCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{R}}}\right)\right] + \overline{\Delta I_{\mathrm{CI}}} \\ - m_{\mathrm{cR}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \end{aligned} \tag{B1-2}$$

Without introducing a significant error (B1-2) can be rewritten as

$$m_{\mathrm{ref}} = m_{\mathrm{cR}} + V_{\mathrm{TL}}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) + m_{\mathrm{cR}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{s}}} - \frac{1}{\rho_{\mathrm{R}}}\right)\right] + \overline{\Delta I_{\mathrm{CI}}} \tag{B1-3}$$

If the total contribution of the correction for air buoyancy to m_{ref} in (B1-3) is called δm_{BTot} then

$$\delta m_{\mathrm{BTot}} = V_{\mathrm{TL}}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) - m_{\mathrm{cR}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{R}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \tag{B1-4}$$

with

V_{TL} – volume of the test load,

$$\delta m_{\mathrm{B1}} = V_{TL}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) \tag{B1-5}$$

$$\delta m_{\mathrm{B2}} = -m_{\mathrm{cR}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{R}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \tag{B1-6}$$

and

$$m_{\mathrm{ref}} = m_{\mathrm{cR}} + \delta m_{\mathrm{BTot}} + \overline{\Delta I_{\mathrm{CI}}} \tag{B1-7}$$

Further analyses of (B1-4) shows, that the contribution δm_{B1} could be relevant only when the test loads with low density are used and there is a significant change of air density during the calibration at the same time. Table B1-1 gives absolute and relative values of δm_{B1} for a test load with a nominal mass of 100 g under various densities/volumes of the test load at various air density differences $\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}$. The air density change is mostly caused by a change of the air temperature (a change of the temperature for 1 K changes the air density for approximately 0,0044 m^3/kg) and the air pressure (a change of the temperature for 1 hPa changes the air density for approximately 0,0012 m^3/kg). Appendix A of [2] gives advice for estimation of the air density.

Table B1-1: Quantified relationship between the input parameters (densities/volumes of the test load, air density differences), and absolute and relative values of δm_{B1} for a test load with the nominal mass m_{N} =100 g.

		δm_{B1} [mg] ($\delta m_{\mathrm{B1}}/m_{\mathrm{N}}$)					
		$\rho_{\mathrm{aCI}}-\rho_{\mathrm{a}}$ [kg/m^3]					
ρ_{TL} [kg/m^3]	V_{TL} @100 g [dm^3]	0,0010	0,0025	0,005	0,01	0,02	0,05
8000	0,0125	0,0125 ($1{,}3\cdot10^{-7}$)	0,03125 ($3{,}1\cdot10^{-7}$)	0,0625 ($6{,}3\cdot10^{-7}$)	0,125 ($1{,}3\cdot10^{-6}$)	0,25 ($2{,}5\cdot10^{-6}$)	0,625 ($6{,}3\cdot10^{-6}$)
2000	0,05	0,05 ($5{,}0\cdot10^{-7}$)	0,125 ($1{,}3\cdot10^{-6}$)	0,25 ($2{,}5\cdot10^{-6}$)	0,5 ($5{,}0\cdot10^{-6}$)	1 ($1{,}0\cdot10^{-5}$)	2,5 ($2{,}5\cdot10^{-5}$)
1000	0,1	0,1 ($1{,}0\cdot10^{-6}$)	0,25 ($2{,}5\cdot10^{-6}$)	0,5 ($5{,}0\cdot10^{-6}$)	1 ($1{,}0\cdot10^{-5}$)	2 ($2{,}0\cdot10^{-5}$)	5 ($5{,}0\cdot10^{-5}$)
500	0,2	0,2 ($2{,}0\cdot10^{-6}$)	0,5 ($5{,}0\cdot10^{-6}$)	1 ($1{,}0\cdot10^{-5}$)	2 ($2{,}0\cdot10^{-5}$)	4 ($4{,}0\cdot10^{-5}$)	10 ($1{,}0\cdot10^{-5}$)
200	0,5	0,5 ($5{,}0\cdot10^{-6}$)	1,25 ($1{,}3\cdot10^{-5}$)	2,5 ($2{,}0\cdot10^{-5}$)	5 ($5{,}0\cdot10^{-4}$)	10 ($1{,}0\cdot10^{-4}$)	25 ($2{,}5\cdot10^{-4}$)
100	1	1 ($1{,}0\cdot10^{-5}$)	2,5 ($2{,}5\cdot10^{-5}$)	5 ($5{,}0\cdot10^{-5}$)	10 ($1{,}0\cdot10^{-4}$)	20 ($2{,}0\cdot10^{-4}$)	50 ($5{,}0\cdot10^{-4}$)

A relevancy of the contribution δm_{B2} can be analysed in a comparable way as the buoyancy correction for the reference value of mass is treated in [2].

B2 Test load weighed on simultaneously calibrated control instrument

This section deals with the case where the reference value of mass is determined by weighing of the test loads on the calibrated control instrument. The control instrument is calibrated at time and place of calibration of the catchweigher and also the test load is weighed at the time and place of calibration of the catchweigher. The control instrument should be calibrated in calibration points close to nominal masses of the test loads and the error of the control instrument is taken into account.

Taking into account [2], the conventional mass of the test load m_{cTL} is proportional to the weighing result of the control instrument W_{CI}:

$$m_{\mathrm{cTL}} = W_{\mathrm{CI}}\left[1 + (\rho_{\mathrm{aCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right)\right] \tag{B2-1}$$

where

$$W_{\mathrm{CI}} = R_{\mathrm{CI}} - E_{\mathrm{CI}} \tag{B2-2}$$

$$R_{\mathrm{CI}} = R_{\mathrm{LCI}} - R_{\mathrm{0CI}} \tag{B2-3}$$

$$E_{\mathrm{CI}} = I_{\mathrm{CI}} - m_{\mathrm{refCI}} \tag{B2-4}$$

$$I_{\mathrm{CI}} = I_{\mathrm{LCI}} - I_{\mathrm{0CI}} \tag{B2-5}$$

$$m_{\mathrm{refCI}} = m_{\mathrm{cCalCI}} + \delta m_{\mathrm{BCI}} \tag{B2-6}$$

$$\delta m_{\mathrm{BCI}} = -m_{\mathrm{cCalCI}}\left[(\rho_{\mathrm{aCalCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{CalCI}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right)\right] \tag{B2-7}$$

with

R_{CI} – reading of the test load on the control instrument corrected for zero reading
R_{LCI} – reading of the test load on the control instrument (loaded)
R_{0CI} - reading of the test load on the control instrument (unloaded)
E_{CI} – error of the control instrument
I_{CI} – indication of the standard weights on the control instrument corrected for zero indication
I_{LCI} – indication of the standard weights on the control instrument (loaded)
I_{0CI} - indication of the standard weights on the control instrument (unloaded)
m_{refCI} – reference value of mass of standard weights used for calibration of the control instrument,
m_{cCalCI} - conventional mass of the standard weights used for calibration of the control instrument,
δm_{BCI} – air buoyancy correction for the standard weights used for calibration of the control instrument,
ρ_{aCI} - air density at the time of weighing of the test load on the control instrument,
ρ_{aCalCI} - air density at the time of calibration of the control instrument,
ρ_{sCI} - density of standard weights used for adjustment of the control instrument,
ρ_{CalCI} - density of standard weights used for calibration of the control instrument

Based on (B2-1) to (B2-7) for the conventional mass of the test load and (B-3) for the air buoyancy correction we get the following general expression for m_{ref}:

$$\begin{aligned} m_{\mathrm{ref}} = \Big\{ & (R_{\mathrm{LCI}} - R_{\mathrm{0CI}}) - (I_{\mathrm{LCI}} - I_{\mathrm{0CI}}) + m_{\mathrm{cCalCI}} \\ & - m_{\mathrm{cCalCI}}\left[(\rho_{\mathrm{aCalCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{CalCI}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right)\right]\Big\}\Big[1 \\ & + (\rho_{\mathrm{aCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right)\Big] \\ & - m_{\mathrm{cTL}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \end{aligned} \tag{B2-8}$$

It is necessary that $(R_{\mathrm{LCI}} - R_{\mathrm{0CI}}) - (I_{\mathrm{LCI}} - I_{\mathrm{0CI}}) - m_{\mathrm{cCalCI}}\left[(\rho_{\mathrm{aCalCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{CalCI}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right)\right] \ll m_{\mathrm{cCalCI}}$ and $m_{\mathrm{cTL}} \approx m_{\mathrm{cCalCI}}$, then (B2-8) simplifies to

$$\begin{aligned} m_{\mathrm{ref}} = & (R_{\mathrm{LCI}} - R_{\mathrm{0CI}}) - (I_{\mathrm{LCI}} - I_{\mathrm{0CI}}) + m_{\mathrm{cCalCI}} \\ & - m_{\mathrm{cCalCI}}\left[(\rho_{\mathrm{aCalCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{CalCI}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right)\right] \\ & + m_{\mathrm{cCalCI}}\left[(\rho_{\mathrm{aCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right)\right] \\ & - m_{\mathrm{cCalCI}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \end{aligned} \tag{B2-9}$$

Assuming $\rho_{\mathrm{aCI}} = \rho_{\mathrm{aCalCI}}$ and without introducing a significant error (B2-9) can be rewritten as

$$\begin{aligned} m_{\mathrm{ref}} = & (R_{\mathrm{LCI}} - R_{\mathrm{0CI}}) - (I_{\mathrm{LCI}} - I_{\mathrm{0CI}}) + V_{\mathrm{TL}}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) \\ & + m_{\mathrm{cCalCI}}\left[1 - (\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{CalCI}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \end{aligned} \tag{B2-10}$$

The total contribution of the air buoyancy correction δm_{BTot} to m_{ref} in (B2-10) equals

$$\delta m_{\mathrm{BTot}} = V_{\mathrm{TL}}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) - m_{\mathrm{cCalCI}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{CalCI}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \tag{B2-11}$$

with V_{TL} – volume of the test load,

$$\delta m_{\mathrm{B1}} = V_{\mathrm{TL}}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) \tag{B2-12}$$

$$\delta m_{\mathrm{B2}} = -m_{\mathrm{cCalCI}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{CalCI}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \tag{B2-13}$$

and

$$m_{\mathrm{ref}} = (R_{\mathrm{LCI}} - R_{0\mathrm{CI}}) - (I_{\mathrm{LCI}} - I_{0\mathrm{CI}}) + m_{\mathrm{cCalCI}} + \delta m_{\mathrm{BTot}} \tag{B2-14}$$

For evaluation of the contributions δm_{B1} and δm_{B2} and their relevancy the analysis given at the end of Section B1 is applicable.

B3 Test load weighed on previously calibrated control instrument

This section deals with the case where the reference value of mass is determined by weighing of the test load on the control instrument. The test load is weighed at the time and place of calibration of the catchweigher, but the control instrument has been calibrated previously. The calibration certificate for the control instrument is on a disposal. However, the same approach could be used in a case when the control instrument is calibrated immediately prior to determination of the reference value of mass.

If the mass of test load is close to the calibration point in which the error of control instrument was determined, then the weighing result W_{CI} could be determined based on the reading of the test load R_{CI} corrected for the error of the control instrument E_{CI} as given by (B2-2). The error of the control instrument is reported in its calibration certificate.

$$W_{\mathrm{CI}} = R_{\mathrm{CI}} - E_{\mathrm{CI}}$$

If this is not the case (e.g. when the mass of test load is not close to the calibration point in which the error of control instrument was determined, or if so decided by the calibration laboratory), no correction is applied to the reading

$$W_{\mathrm{CI}} = R_{\mathrm{CI}} \tag{B3-1}$$

but errors of the control instrument need to be included in an uncertainty (i.e. a “global uncertainty” $U_{\mathrm{gl}}(W_{\mathrm{CI}})$, which includes the errors of measurement such that no corrections have to be applied to the readings in use).

For a reading taken under the same conditions as those prevailing at calibration of the control instrument (e.g. immediately after its adjustment), the result may be denominated as the weighing result under conditions of the calibration W^*_{CI}.

Based on (B2-1) for the conventional mass of the test load and (B-3) for the air buoyancy correction, we get the following general expression for m_{ref}:

$$m_{\mathrm{ref}} = W_{\mathrm{CI}}\left[1 + (\rho_{\mathrm{aCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right)\right] - m_{\mathrm{cTL}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \tag{B3-2}$$

Under the condition that $m_{\mathrm{cTL}} \cong W_{\mathrm{CI}}$, then

$$m_{\mathrm{ref}} = W_{\mathrm{CI}}\left[1 + (\rho_{\mathrm{aCI}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right) - (\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{TL}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \quad \text{(B3-3)}$$

Without introducing a significant error (B3-3) can be rewritten as

$$m_{\mathrm{ref}} = W_{\mathrm{CI}}\left[1 + (\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{s}}} - \frac{1}{\rho_{\mathrm{sCI}}}\right)\right] + V_{\mathrm{TL}}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) \quad \text{(B3-4)}$$

The total contribution of the air buoyancy correction δm_{BTot} to m_{ref} in (B3-4) equals

$$\delta m_{\mathrm{BTot}} = V_{\mathrm{TL}}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) - W_{\mathrm{CI}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{sCI}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \quad \text{(B3-5)}$$

with

V_{TL} – volume of the test load,

$$\delta m_{\mathrm{B1}} = V_{\mathrm{TL}}(\rho_{\mathrm{aCI}} - \rho_{\mathrm{a}}) \quad \text{(B3-6)}$$

$$\delta m_{\mathrm{B2}} = -W_{\mathrm{CI}}\left[(\rho_{\mathrm{a}} - \rho_0)\left(\frac{1}{\rho_{\mathrm{sCI}}} - \frac{1}{\rho_{\mathrm{s}}}\right)\right] \quad \text{(B3-7)}$$

and

$$m_{\mathrm{ref}} = W_{\mathrm{CI}} + \delta m_{\mathrm{BTot}} \quad \text{(B3-8)}$$

For evaluation of the contributions δm_{B1} and δm_{B2} and their relevancy the analysis given at the end of Section B1 is applicable.

APPENDIX C: Control instrument calibrated to specified tolerances

The standard global uncertainty of the weighing result $u_{\mathrm{gl}}(W_{\mathrm{CI}})$ for the control instrument, which has been previously calibrated to specified tolerance Tol, which equals to the maximum permissible error of the non-automatic weighing instrument mpe_{R76} [7,8], can be conservatively estimated by:

$$u_{\mathrm{gl}}^2(W_{\mathrm{CI}}) = u^2(W_{\mathrm{CI}}) + mpe_{\mathrm{R76}}^2 \quad \text{(C-1)}$$

with

$$u(W_{\mathrm{CI}}) = \sqrt{u^2(W_{\mathrm{CI}}^*) + u^2(\delta R_{\mathrm{inst}}) + u^2(\delta R_{\mathrm{proc}})} \quad \text{(C-2)}$$

$$u^2(W_{\mathrm{CI}}^*) = u^2(E) + u^2(\delta R_{\mathrm{dig0}}) + u^2(\delta R_{\mathrm{digL}}) + u^2(\delta R_{\mathrm{rep}}) + u^2(\delta R_{\mathrm{ecc}}) \quad \text{(C-3)}$$

$$u^2(\delta R_{\mathrm{inst}}) = u^2(\delta R_{\mathrm{temp}}) + u^2(\delta R_{\mathrm{bouy}}) \quad \text{(C-4)}$$

$$u^2(\delta R_{\mathrm{proc}}) = u^2(\delta R_{\mathrm{Tare}}) + u^2(\delta R_{\mathrm{time}}) \quad \text{(C-5)}$$

Approximate relation between standard uncertainties of above mentioned influencing parameters and mpe_{R76} is summarised in the table below. The following assumptions are taken into account:

- $d_{\mathrm{T}} \le mpe_{\mathrm{R76}}/5$
- $R = 20000\, mpe_{\mathrm{R76}}$
- mpe_{R76} is taken at L_{T}

$u(W_{\mathrm{CI}}^*)$	$u(E)$	$u(\delta I_{\mathrm{dig0}})$	$d_{\mathrm{T}}/(2\sqrt{3}) \cong mpe_{\mathrm{R76}}/(10\sqrt{3}) \cong 0$
		$u(\delta I_{\mathrm{digL}})$	$d_{\mathrm{T}}/(2\sqrt{3}) \cong mpe_{\mathrm{R76}}/(10\sqrt{3}) \cong 0$
		$u(\delta I_{\mathrm{rep}})$	$mpe_{\mathrm{R76}}/(2\sqrt{3})$
		$u(\delta I_{\mathrm{ecc}})$	0
		$u(\delta m_{\mathrm{c}})$	$(mpe_{\mathrm{R76}}/3)/\sqrt{3}$
		$u(\delta m_{\mathrm{B}})$	$(0{,}000015/\sqrt{3})R + (mpe_{\mathrm{R76}}/3)/(4\sqrt{3}) \le mpe_{\mathrm{R76}}/5$
		$u(\delta m_{\mathrm{D}})$	$(mpe_{\mathrm{R76}}/3)/\sqrt{3}$
		$u(\delta m_{\mathrm{conv}})$	0
	$u(\delta R_{\mathrm{dig0}})$		$d/(2\sqrt{3}) \le mpe_{\mathrm{R76}}/(2\sqrt{3})$
	$u(\delta R_{\mathrm{digL}})$		$d/(2\sqrt{3}) \le mpe_{\mathrm{R76}}/(2\sqrt{3})$
	$u(\delta R_{\mathrm{rep}})$		$mpe_{\mathrm{R76}}/(2\sqrt{3})$
	$u(\delta R_{\mathrm{ecc}})$		$mpe_{\mathrm{R76}}/(2\sqrt{3})$
$u(\delta R_{\mathrm{inst}})$	$u(\delta R_{\mathrm{temp}})$		$mpe_{\mathrm{R76}}/\sqrt{12}$
	$u(\delta R_{\mathrm{bouy}})$		$(0{,}000015/\sqrt{3})R \le mpe_{\mathrm{R76}}/5$
	$u(\delta R_{\mathrm{adj}})$		$mpe_{\mathrm{R76}}/\sqrt{3}$
$u(\delta R_{\mathrm{proc}})$	$u(\delta R_{\mathrm{Tare}})$		0
	$u(\delta R_{\mathrm{time}})$		0
	$u(\delta R_{\mathrm{ecc}})$		evaluated and taken into account above
$u(W_{\mathrm{CI}})$			mpe_{R76}

$$u_{gl}(W_{CI}) \cong \sqrt{{mpe_{R76}}^2 + {mpe_{R76}}^2} = mpe_{R76}\sqrt{2} \qquad \text{(C-6)}$$

APPENDIX D: EXAMPLE

D1 Automatic Catchweighing Instrument (checkweigher, category X), *Max* = 2000 g

Note: The calculation is demonstrated on one sample test load in this example.

D1.1 Conditions specific for the calibration

Instrument:	**Automatic Catchweighing Instrument**
Max	200 g / 2000 g
Min	10 g
d	0,1 g / 0,2 g
d_s	0,01 g
Installation	In packaging workroom; 20 °C ≤ T ≤ 25 °C, reported by client
Temperature coefficient	$K_T \leq 4 \times 10^{-6}$ /K (estimated value)
Set load transport system speed	20 m/min
Temperature during calibration	23,0 °C to 24,5 °C
Barometric pressure during calibration:	1 002 hPa ± 5 hPa
Test load	A bag of pasta; volume 1,55 L, dimensions length x width x height, being the length in the direction of the load transport system, (16 × 21 × 4) cm.
Change of air density	$\rho_{aCI} - \rho_a$ = 0,0077 kg/m^3
Control instrument	Separate Max = 600 g, d = 0,001 g

D1.2 Tests and results

Reference mass	Test load calibrated on the control instrument used as comparator. 500 g standard weight was used, calibrated to OIML R 111 F1 accuracy class. m_{ref} = 493,492 g
Determination of errors and repeatability	**Test load of nominal value 500 g, applied 20 times over the central portion of the load transport system** Indications recorded (in g): 493,60 493,46 493,63 493,68 493,55 493,57 493,52 493,60 493,62 493,70 493,65 493,72 493,66 493,71 493,42 493,78 493,67 493,50 493,70 493,62 Mean value of 20 indications $\bar{I} = \frac{1}{20}\sum_{i=1}^{20} I_i$ = 493,618 g and corresponding standard deviation $s(I) = \sqrt{\frac{1}{20-1}\sum_{i=1}^{20}\left(I_i - \bar{I}\right)^2}$ = 0,093 g
Determination of reproducibility	**Test load of nominal value 500 g, applied 5 times over the central portion of the load transport system. The instrument was interrupted between measurements by stopping and then starting again the load transport system.** Indications recorded (in g): 493,60 493,47 493,68 493,65 493,50 The maximum difference between the indications $\Delta I_{\mathrm{rpd,max}} = I_{i,\mathrm{max}} - I_{i,\mathrm{min}}$ = 0,210 g
Eccentricity test	**Test load of nominal value 500 g, applied 6 times using the halfway portion of the load transport system** (centre, band 1 and band 2) Indications recorded (in g):

	Centre: The results of the determination of errors and repeatability taken into account; Band 1: 493,34, 493,50, 493,65, 493,59, 493,65, 493,47; Band 2: 493,72, 493,58, 493,61, 493,66, 493,71, 493,70; $\bar{I}_{\mathrm{c}}$= 493,618 g $\Delta I_{ecc,b} = \bar{I}_b - \bar{I}_{\mathrm{c}}$ $\bar{I}_1$= 493,533 g; $\Delta I_{\mathrm{ecc},1}$ = -0,085 g $\bar{I}_2$= 493,663 g; $\Delta I_{\mathrm{ecc},2}$= 0,045 g $\left\|\Delta I_{\mathrm{ecc},b}\right\|_{\max}$= 0,085 g
Error of measurement	$E = \bar{I} - m_{\mathrm{ref}}$ **$\boldsymbol{E}$ = 0,126 g**

D1.3 Uncertainty of measurement

Standard uncertainty of error of measurement	$E = \bar{I} - m_{\text{ref}}$ $u(E) = \sqrt{u^2(\bar{I}) + u^2(m_{\text{ref}})}$
Standard uncertainty of the indication of the catchweigher	$u(\bar{I}) = \sqrt{u^2(\delta I_{\text{digTL}}) + u^2(\delta I_{\text{rpt}}) + u^2(\delta I_{\text{rpd}}) + u^2(\delta I_{\text{ecc}})}$ $u(\delta I_{\text{digTL}}) = d_{\text{s}}/2\sqrt{3}$ $u(\delta I_{\text{digTL}})$ = 0,003 g $(\delta I_{\text{rpt}}) = s(I)/\sqrt{20}$ $u(\delta I_{\text{rpt}})$ = 0,021 g $u(\delta I_{\text{rpd}}) = \Delta I_{rpd,max}/\sqrt{12}$ $u(\delta I_{\text{rpd}})$= 0,061 g $u(\delta I_{\text{ecc}}) \leq \lvert \Delta I_{\text{ecc,b}} \rvert_{\text{max}}/(2\sqrt{3})$ $u(\delta I_{\text{ecc}})$ = 0,025 g $\boldsymbol{u(\bar{I})}$ = **0,069 g**
Standard uncertainty of the reference value of mass	$u(m_{\text{ref}}) = \sqrt{u^2(m_{\text{cR}}) + u^2(\delta m_{\text{BTot}}) + u^2(\overline{\Delta I_{\text{CI}}}) + u^2(\delta m_{\text{ba}})}$ $u(m_{\text{cR}})$ = 0,002 g $u(\delta m_{\text{B1}})$ = $\lvert V_{\text{TL}}(\rho_{\text{aCI}} - \rho_{\text{a}}) \rvert_{max}/\sqrt{3}$ = 0,007 g $u(\delta m_{\text{B2}}) = (0{,}1\, \rho_0 m_{\text{N}}/\rho_{\text{c}} + mpe/4)/\sqrt{3}$ = 0,005 g $u(\overline{\Delta I_{\text{CI}}})$ = 0,002 g $u(\delta m_{\text{ba}})$ = 0,002 g $\boldsymbol{u(m_{\text{ref}})}$ = **0,009 g**
Standard uncertainty of error of measurement	$u(E) = \sqrt{u^2(\bar{I}) + u^2(m_{\text{ref}})}$ $\boldsymbol{u(E)}$ = **0,070 g**
Expanded uncertainty at calibration	$U(E) = ku(E)$ $\boldsymbol{U(E)}$ = **0,140 g** The coverage factor $k = 2$ is chosen such that the expanded uncertainty corresponds to a coverage probability of 95,45 %.

D1.4 Standard uncertainty of weighing result

Standard uncertainty of reading in use	$R = R_L + \delta R_{digL} + \delta R_{rep} + \delta R_{rpd} + \delta R_{ecc} + \delta R_0$ $u(\delta R_{digL}) = d/2\sqrt{3}$ = 0,058 g $u(\delta R_{rpt}) = s(I)$ = 0,093 g $u(\delta R_{rpd}) = \Delta I_{rpd,max}/\sqrt{12}$ = 0,061 g $u(\delta R_{ecc}) = \lvert\Delta I_{ecc,b}\rvert_{max}/\sqrt{3}$ = 0,050 g $u(\delta R_0) = pd/\sqrt{3}$ = 0,058 g *Note: zero maintained within 0,5 d* $u(R)$ **= 0,147 g**
Standard uncertainty from environmental influences	$u(\delta R_{instr}) = \sqrt{u^2(\delta R_{temp}) + u^2(\delta R_{buoy}) + u^2(\delta R_{adj})}$ $u(\delta R_{temp}) = K_T \cdot \Delta T \cdot R/\sqrt{12}$ = 0,006 g *Note: ΔT is taken as 10 K.* $u(\delta R_{buoy}) = 0{,}1\rho_0 R/(\rho_c\sqrt{3})$ = 0,005 g $u(\delta R_{adj}) = \Delta E_{max}(R)/\sqrt{3}$ = 0,173 g *Note: $\Delta E_{max}(R)$ is taken as 0,3 g.* $u(\delta R_{instr})$ **= 0,173 g**
Standard uncertainty of a weighing result	$u(W) = \sqrt{u^2(R) + u^2(\delta R_{instr}) + u^2(E)}$ = **0,238 g**
Expanded uncertainty of a weighing result	$U(W) = ku(W)$ = **0,48 g** The coverage factor $k = 2$
"Global uncertainty"	$U_{gl}(W) = ku(W) + \lvert E\rvert$ = **0,67 g**

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