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Guidelines on the Calibration of Automatic Catchweighing Instruments

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APPENDICES

1 INTRODUCTION

Automatic catchweighing instruments (ACI) [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.

2 SCOPE

This document contains guidance for the calibration of automatic catchweighing instruments (hereafter called "instrument"), 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. contents of the calibration certificate.

The guide refers to automatic operation of the instrument [1]. The guide deals with the instruments that weigh dynamically [1], but it could be as well used for the instruments that weigh statically [1], i.e. for the instruments, 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].

The object of the calibration is the indication provided by the instrument in response to an applied 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 calibrating laboratory. This guideline does not specify lower or upper boundaries for the uncertainty of measurement. It is up to the calibrating 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.

While it is not intended to present one or few uniform procedures the use of which would be obligatory, this document gives general guidance for establishing of calibration procedures the results of which may be considered as equivalent within the EURAMET Member Organisations.

Any such procedure must include, for a limited number of test loads, the determination of the errors of indication and evaluation of the uncertainty of measurement 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.

The information presented in this guideline is intended to serve, and should be observed by

1. bodies accrediting laboratories for the calibration of automatic catchweighing instruments,
2. laboratories accredited for the calibration of automatic catchweighing instruments,
3. manufacturers and other users using calibrated automatic catchweighing instruments for measurements relevant for the quality of production subject to QM requirements (e.g. EN ISO 9000 series, EN ISO 10012).

3 TERMINOLOGY AND SYMBOLS

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

- OIML R51 [1] for terms related to the operation, construction and metrological characterization of automatic catchweighing instruments
- 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 mean error of the indications, and
4. 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 individual nominal values, which are defined by the selected test loads, and it is only valid for the specified test loads (with a small bandwidth for mass, volume and shape). It will usually not be possible to calibrate a "range" for such instruments, because of their dynamic behaviour.

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

The calibration is performed at speed(s) of load transport system and rate(s) of operation [1] requested and specified in advance by the client. Normally these conditions are the same as conditions during the actual weighing process.

The calibration it is only valid for these conditions.

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 normal conditions of use (air flow, vibrations, stability of the weighing site etc.) of the instrument. 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 prevail during the calibration. In this way disturbing effects such as air flow, vibrations, or inclination of the measuring platform will, so far as 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

The test loads should preferably be the type of article(s), which are normally weighed on the calibrated instrument. For the purpose of calibration, their traceability to the SI unit of mass shall be demonstrated.

In addition, a selection of the test loads requires due consideration of the following:

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 belt,

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 may be necessary throughout the period of use of the loads during the calibration.

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 the test load and its uncertainty are performed on the 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 are not used for calibration of the instrument.

The requirements for the standard weights, which are used for calibration of the control instrument or calibration 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 should 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.

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 automatic catchweighing instrument, only the test load indications I_{TL} are taken into account, and they are not corrected for the no load indications I_0.

$$I = I_{TL} \tag{4.4.1-1}$$

During calibration tests, the instrument indications should be recorded, not errors or variations of the indication.

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

4.4.2 Resolution

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

At the discretion of the calibration laboratory and with the consent of the client, means to obtain indications in higher resolution than in *d* may be applied, e.g. where compliance to a specification is checked and the smallest uncertainty is desired. Such means may be switching the indicating device to a smaller scale interval $d_T < d$ ("service mode"). In this case, the indications are obtained as integer multiple of d_T.

4.5 Reference value of mass of test loads

To determine the errors of indication of an instrument, test loads are applied. Their conventional value of mass m_{cTL} is a priori not known, their density ρ_{TL} is normally significantly different from the reference value ρ_c and the air density ρ_a at the time of calibration is normally different from reference air density ρ_0.

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

$$m_{ref} = m_{cTL} + \delta m_B + \delta m_D + \delta m_{conv} + \delta m \ldots \tag{4.5-1}$$

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 last 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 NAWI, 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 could be significant. If reference value of mass is determined at air density, which is different from air density at the time of calibration of catchweigher, the density of the test load need 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 there is no difference in the air density value. It will be shown that the density of the test load doesn't need to be known in such a case.

m_{ref} could be determined in various ways. Some of these methods are summarised in the table below, with further details given in subsections of Appendix B.

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 ACI.	No significant drift of test load. Small air buoyancy correction. No need to know density of test load.	B1
Test load weighed on the simultaneously calibrated control instrument	Control instrument calibrated at time and place of calibration of ACI. Test load weighed at the time and place of calibration of ACI.	No drift of test load. Small air buoyancy correction. No need to know density of test load.	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 ACI.	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 correction. No need to know density of test load.	B3
Test load with calibration certificate	Test load calibrated previously.	Drift of test load is relevant. Significant air buoyancy correction. Density of test load needs to be known.	/

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, $\delta m_D \approx 0$ and $\delta m_{conv} = 0$, respectively. In such a case, (4.5.1) is simplified to

$$m_{ref} = m_{cTL} + \delta m_B. \tag{4.5-2}$$

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

$$\delta m_B = -m_{cTL}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_s}\right)\right] \qquad (4.5\text{-}3)$$

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

Appendix B provides complete description of determination of reference value of mass m_{ref}, which results from determination of the conventional mass of test load m_{cTL} and the air buoyancy correction for test load δm_B, considering the principle and time of determination of the reference value of mass. Final results of Appendix B subsections are used in Section 7.1.2.

4.6 *Operating parameters*

Article dimensions, the length of the platform and load transport system speed (belt speed) must be determined, and the speed setting (indicated belt speed and/or rate of operation, or position of speed setting switch) recorded for each case.

Based on the belt speed v, and the distance between the centres of consecutive articles S, maximum rate c_{max} is calculated according to the following expression:

$$c_{max} = v/S \qquad (4.6\text{-}1)$$

The distance S is equal or larger than the length of the platform.

The dimensions of the article are given in the following standardized form *a* × *b* × *c*, being

- *a*, length in the forward direction of the belt,
- *b*, width, perpendicular to the length in the plane of the belt,
- *c*, height, perpendicular to the plane of the belt.

5 MEASUREMENT METHODS

Tests are normally performed to determine:

- the errors and repeatability of indications, and
- the effect of eccentric application of a load on the indication.

The calibration laboratory deciding on the number of measurements for its routine calibration procedure should consider that, in general, a larger number of measurements tends to reduce the uncertainty of measurement.

Details of the tests performed for an individual calibration may be fixed by agreement of the client and the calibration laboratory, in view of the normal use of the instrument. The parties may also agree on further tests or checks, which may assist in evaluating the performance of the instrument under special conditions of use. Any such agreement should be consistent with the minimum numbers of tests as specified in the following sections.

The general test procedure for the test specified in the following sections shall be as follows:

1) Select the test loads as specified in Section 4.3 with the test load values as specified in Sections 5.1 and 5.2 for the test for errors and repeatability of indication and eccentricity test, respectively. Determine the reference value of

mass of each test load on the control instrument as specified in Section 4.5 and Appendix B.

2) The instrument should be tested in its normal mode of automatic operation (with the consent of 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) The number of consecutive test weighings for each test load depends on the nominal mass of the test load as specified in Sections 5.1 and 5.2 for the test for errors and repeatability of indication and eccentricity test, respectively.

5) Where applicable, before commencing the tests select the corresponding dynamic setting factor, or carry out the dynamic setting for each test load value if the client regularly uses this facility.

6) Zero shall be set at the start of each test at a given load value and not readjusted at any time during the test. It has to be allowed that automatic adjustment of zero, if exists and used by user, is operational during the tests.

7) Enable the test loads 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 preferably using the load conveyor of the instrument.

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

5.1 Test for errors and repeatability of indication

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

The test is performed with k different test loads L_{Tj}, $1 \leq j \leq k$.

Examples for the test load target values:

- the minimum nominal load of weighed articles available on-site Min',
- the largest nominal load of weighed articles available on-site Max',
- one, two or more test points equally distributed between Min' and Max' according to use of the instrument and depending on articles available on-site.

Details about the test load target values need to be agreed with the client to represent usual use of the calibrated instrument.

The minimum number of consecutive test weighings shall be as specified in the following table:

Nominal mass m_N of the test load	Minimum number of repetitions, n
m_N ≤ 10 kg	30
10 kg < m_N ≤ 20 kg	20

20 kg < m_N	10

If the instrument is used to determine the net values of the weighed articles and one of available tare devices (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 during the test for errors and repeatability of indication. The (preset) tare value(s) shall 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).

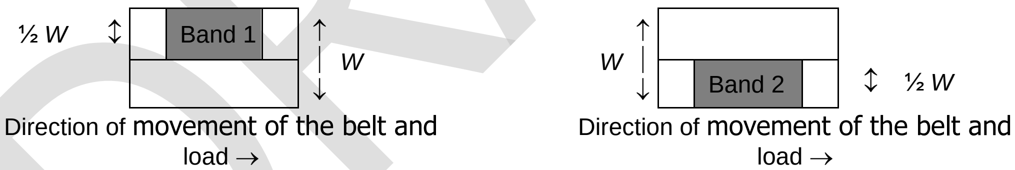
5.2 Eccentricity test

The effect of the eccentric application of the load on the indication is tested 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 test is performed with the same test loads and in the same test points as in the test for errors and repeatability of indication (Section 5.1), $L_{eccj} = L_{Tj}$.

The effect of eccentric loading shall be determined using the selected test load using the portion of the load transport system that is halfway between the centre and the back, and repeated with the same test load using the portion of the load transport system that is halfway between the centre and the front as shown in figure 5.2-1.

Figure 5.2-1: Positions of load for test of eccentricity.



In figure 5.2-1, W represents the width of the load transport system if there are no guides or width between guides where they exist.

The minimum number of consecutive test weighings on each test band shall be as specified in the following table:

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

5.3 Auxiliary measurements

The following additional measurements or recordings are recommended, in particular where a calibration is intended to be performed with the lowest possible uncertainty.

The air temperature in reasonable 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.

6 MEASUREMENT RESULTS

The procedures and formulae in sections 6 and 7 provide the basis for the evaluation of the results of the calibration tests 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 may need to be provided in the certificate.

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

6.1 Repeatability

From the n indications I_{ij} for a given test load L_{Tj}, the standard deviation $s(I_j)$ is calculated

$$s(I_j) = \sqrt{\frac{1}{n-1}\sum_{1=1}^{n}\left(I_{ij} - \bar{I}_j\right)^2} \tag{6.1-1}$$

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

$$\bar{I}_j = \frac{1}{n}\sum_{1=1}^{n} I_{ij}. \tag{6.1-2}$$

6.2 Mean error of indication

For each test load L_{Tj}, the mean error of indication E_j is calculated as follows

$$E_j = \bar{I}_j - m_{ref,j} \tag{6.2-1}$$

where the mean value of several indications, $\bar{I}_j$, is calculated as per (6.1-2) and $m_{ref,j}$ is the value obtained according to Section 4.5 and Appendix B.

6.3 Effect of eccentric loading

For each tested band b of the load transport system (cf. Figure 5.2-1) and for j-th test load $L_{ecc,j} = L_{Tj}$, the average difference $\Delta I_{ecc,bj}$ is calculated as follows:

$$\Delta I_{ecc,bj} = \bar{I}_{bj} - \bar{I}_j \tag{6.3-1}$$

$\bar{I}_{bj}$ being the average of the indications of the test load $L_{ecc,j} = L_{Tj}$, on b-th tested band, b being 1 or 2, and $\bar{I}_j$ the average of the indications of the test load L_{Tj} in the middle of the load transport system, cf. (6.1-2).

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 101 [6], 9.3.2.6).

7.1 Standard uncertainty of mean error

Taking into account (6.2-1) the basic formula for the calibration is

$$E = \bar{I} - m_{ref} \tag{7.1-1}$$

with standard uncertainty of the error

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

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

$$\bar{I} = \bar{I}_{TL} + \delta I_{digTL} + \delta I_{rep} + \delta I_{ecc} \tag{7.1.1-1}$$

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

For the purpose of calibration of automatic catchweighing instrument, the load indications I_{TL} are not corrected for the no load indications I_0.

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

7.1.1.1 δI_{digTL} accounts for the effect of the resolution of indication at load. Limits are $\pm d/2$ or $\pm d_T/2$ as applicable (explanation for d_T is given in Section 4.4.2); rectangular distribution to be assumed, therefore

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

or

$$u(\delta I_{digTL}) = d_T/2\sqrt{3} \tag{7.1.1-2b}$$

respectively.

Note: on a multi-interval instrument, d varies with I.

7.1.1.2 δI_{rep} accounts for the repeatability of the instrument; normal distribution is assumed, estimated as

$$u(\delta I_{rep}) = s(I_j)/\sqrt{n} \tag{7.1.1-3}$$

where $s(I_j)$ is determined in 6.1 and n is number of repeated weighings for the given test load.

$s(I_j)$ is determined for each given test load L_{Tj} and it is considered as representative only for the respective test load.

Note: For a standard deviation reported in a calibration certificate, it should be clear whether it is related to a single indication or to the mean of n indications.

7.1.1.3 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 belt. Where this effect cannot be neglected, an estimate of its magnitude may be based on these assumptions:

- the average differences ΔI_{ecc} determined by (6.3-1) are proportional to the distance of the load from the centre of the load receptor in a direction perpendicular to movement of the belt,
- the effective centre of gravity of the test loads during the test for errors of indication and repeatability of indication 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 belt (i.e. ¼ W), as per figure 5.2-1.

Based on the largest of the differences determined as per 6.3, δI_{ecc} is estimated to be

$$\delta I_{ecc} \leq \left|\Delta I_{ecc,b}\right|_{max}/2 \tag{7.1.1-4}$$

Rectangular distribution is assumed, so the standard uncertainty is

$$u(\delta I_{ecc}) \leq \left|\Delta I_{ecc,b}\right|_{max}/\left(2\sqrt{3}\right) \tag{7.1.1-5}$$

δI_{ecc} is determined for each given test load $L_{ecc,j} = L_{Tj}$ and it is considered as representative only for the respective test load.

7.1.1.4 The standard uncertainty of the indication for j-th test point is normally obtained by

$$u^2(\bar{I}) = d^2/12 + s^2(I)/n + \left(\left|\Delta I_{ecc,b}\right|_{max}/\left(2\sqrt{3}\right)\right)^2 \tag{7.1.1-7}$$

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)

$$m_{ref} = m_{cR} + \delta m_{BTot} + \overline{\Delta m}$$

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

$$m_{ref} = m_{cR} + \delta m_{BTot} + \overline{\Delta m} + \delta m_{ba} \quad (7.1.2\text{-}1)$$

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 $u(m_{cR})$ 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, equation (B1-4)

$$\delta m_{BTot} = -m_{cR}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_R} - \frac{1}{\rho_s}\right)\right]$$

Where a comparison of expected 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. δm_{BTot}=0. If conformity of the standard weights used for adjustment of the catchweigher and calibration of the test load to OIML R111 [3] is established and if the catchweigher is not adjusted before the calibration, the standard uncertainty is evaluated as given in [2]

$$u(\delta m_{BTot}) \approx (0{,}1\, \rho_0 m_N/\rho_c + mpe/4)/\sqrt{3} \quad (7.1.2\text{-}2)$$

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

For smaller uncertainties, e.g. if the air buoyancy correction is taken into account according to (B1-4) or the catchweigher is adjusted immediately before calibration, the standard uncertainties could be evaluated according to Section 7.1.2.2 of [2].

7.1.2.3 $\bar{\Delta}$ is the average difference in indication between the test load and standard weight(s) measurements on the control instrument as introduced in Annex B1, equation (B1-1). Its standard uncertainty $u(\bar{\Delta})$ 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 apllied, $\delta m_{ba} = 0$ and its standard uncertainty $u(\delta m_{ba})$ 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

$$u^2(m_{ref}) = u^2(m_{cTL}) + u^2(\delta m_B) + u^2(\overline{\Delta m_c}) + u^2(\delta m_{ba}) \quad (7.1.2\text{-}3)$$

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 (B2-12)

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

To account for sources of variability of the reference value of mass for this case, (B2-12) is amended by corrections terms δX_{xx} as follows

$$\begin{aligned} m_{ref} = {} & \left(R_{LCI} + \delta R_{digLCI} + \delta R_{repCI} + \delta R_{eccCI} - (R_{0CI} + \delta R_{0CI})\right) \\ & - \left(I_{LCI} + \delta I_{digLCI} + \delta I_{repCI} + \delta I_{eccCI} - \left(I_{0CI} + \delta I_{dig0CI}\right)\right) \\ & + (m_{NCalCI} + \delta m_{cCalCI} + \delta m_{DCalCI} + \delta m_{convCalCI}) + \delta m_{BTot} \end{aligned} \tag{7.1.2-4}$$

7.1.2.6 R_{CI} is the reading of the test load on the control instrument (cf. also (B2-3)). Its standard uncertainty $u(R_{CI})$ 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 $u(I_{CI})$ 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 $u(m_{CalCI})$ 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, equation (B2-11)

$$\delta m_{BTot} = -m_{cCalCI}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_s}\right)\right]$$

Where a simple comparison of expected 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. δm_{BTot}=0. If conformity of the standard weights used for adjustment of the catchweigher and calibration of the control instrument to OIML R111 [3] is established and if the catchweigher is not adjusted before calibration, the standard uncertainty is evaluated as given in [2] and by (7.1.2-2)

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

For smaller uncertainties, e.g. if the air buoyancy correction is taken into account according to (B2-11) or the catchweigher is adjusted immediately before calibration, the standard uncertainties could be evaluated according to Section 7.1.2.2 of [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

$$u^2(m_{ref}) = u^2(R_{CI}) + u^2(I_{CI}) + u^2(m_{CalCI}) + u^2(\delta m_{BTot}) \tag{7.1.2-5}$$

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 (B3-6)

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

7.1.2.11 W_{CI} is the weighing result of the control intrument. W_{CI} is determined according to Appendix B3. Its standard uncertainty $u(W_{CI})$ 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 $U_{gl}(W_{CI})$, respectively.

According to [2], the standard uncertainty for the weighing result under conditions of the calibration $u(W_{CI}^{*})$ could be used instead of $u(W_{CI})$ 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. If the certificate states uncertainty of the instrument in use, this is non-accredited value. 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)

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

Where a simple comparison of expected 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. δm_{BTot}=0. Where conformity of the standard weights used for adjustment of the catchweigher and control instrument to OIML R111 [3] is established and if the catchweigher is not adjusted before calibration, the standard uncertainty is evaluated as given in [2] and by (7.1.2-2)

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

For smaller uncertainties, e.g. if the air buoyancy correction is taken into account according to (B3-5) or the catchweigher is adjusted immediately before calibration, the standard uncertainties could be evaluated according to Section 7.1.2.2 of [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

$$u^2(m_{ref}) = u^2(W_{CI}) + u^2(\delta m_{BTot}) \qquad (7.1.2\text{-}6)$$

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 (4.5-1) the reference value of mass is

$$m_{ref} = m_{cTL} + \delta m_B + \delta m_D + \delta m_{conv}$$

The corrections and their standard uncertainties are

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

$$u(m_{cTL}) = U/k \qquad (7.1.2\text{-}7)$$

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

$$u(m_{cTL}) = Tol/\sqrt{3} \qquad (7.1.2\text{-}8)$$

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 (4.5-3)

$$\delta m_B = -m_{cTL}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_s}\right)\right]$$

with the standard uncertainty

$$u(\delta m_B) = m_{cTL}\sqrt{u^2(\rho_a)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_s}\right)^2 + (\rho_a - \rho_0)^2 u^2(\rho_s)/\rho_s^4 + (\rho_a - \rho_0)^2 u^2(\rho_{TL})/\rho_{TL}^4} \qquad (7.1.2\text{-}9)$$

As far as values for ρ_{TL}, $u(\rho_{TL})$, ρ_s, $u(\rho_s)$, ρ_a and $u(\rho_a)$, are known, these values should be used to determine $u_{rel}(\delta m_B)$.

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

$$u(\delta m_D) = D/\sqrt{3} \qquad (7.1.2\text{-}10)$$

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 $\pm\Delta m_{conv}$. The standard uncertainty is then

$$u(\delta m_{conv}) = \Delta m_{conv}/\sqrt{3} \qquad (7.1.2\text{-}11)$$

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 F_1 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

$$u^2(m_{ref}) = u^2(m_{cTL}) + u^2(\delta m_B) + u^2(\delta m_D) + u^2(\delta m_{conv}) \qquad (7.1.2\text{-}12)$$

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 $U(E)$ is

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

where standard uncertainty of the error $u(E)$ 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. Where a calibration laboratory offers to its clients such estimates which are based upon information that has not been measured by the laboratory, the estimates must not be presented as part of the calibration certificate. However, it is acceptable to provide such estimates as long as they are clearly separated from the calibration results.

The user of an 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. generally only one reading is taken for each load, not several readings to obtain a mean value,

b. it is not possible to make corrections to the instrument indication,

c. reading is to the scale interval d, of the instrument, not to a higher resolution,

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

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

The associated standard uncertainty is

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

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

$$R = R_L + \delta R_{digL} + \delta R_{rep} + \delta R_{ecc} + \delta R_0 \qquad (7.3.1\text{-}1)$$

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 $d_T < d$ is excluded, so

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

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

$$u(\delta R_{rep}) = s(I) \qquad (7.3.1\text{-}3)$$

Note: The standard deviation not the standard deviation of the mean should be used for the uncertainty calculation.

7.3.1.3 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

$$u(\delta R_{ecc}) = \left|\Delta I_{ecc,b}\right|_{max}/\sqrt{3} \tag{7.3.1-4}$$

7.3.1.4 δR_0 accounts for the stability 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.

$$u(\delta R_0) = pd/\sqrt{3} \tag{7.3.1-5}$$

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

7.3.1.5 The standard uncertainty of the reading is then obtained by

$$u^2(R) = d^2/12 + s^2(I) + \left(\left|\Delta I_{ecc,b}\right|_{max}\right)^2/3 + (pd)^2/3 \tag{7.3.1-6}$$

7.3.2 Uncertainty from environmental influences

The term δR_{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 $\delta R_{temp} = K_T \cdot \Delta T \cdot R$ 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 $K_T = [\partial I(Max)/\partial T]/Max$, in many cases quoted in 10^{-6}/K. By default, for instruments with type approval under OIML R 51 [1], it may be assumed $|K_T| \leq mpe(Max)/(Max \cdot \Delta T_{Approval})$, where $\Delta T_{Approval}$ 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.

Rectangular distribution is assumed, therefore the standard uncertainty is

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

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

$$u(\delta R_{buoy}) = 0{,}1\rho_0 R/(\rho_c\sqrt{3}) \tag{7.3.2-2}$$

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 $|\Delta E_{max}|$ 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 $\Delta E_{max} = mpe(R)$ 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.

Rectangular distribution is assumed, therefore the relative uncertainty is

$$u(\delta R_{adj}) = \Delta E_{max}(R)/\sqrt{3} \qquad (7.3.2\text{-}3)$$

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

$$u(\delta R_{instr}) = \sqrt{u^2(\delta R_{temp}) + u^2(\delta R_{buoy}) + u^2(\delta R_{adj})} \qquad (7.3.2\text{-}4)$$

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

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

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

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

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" $U_{gl}(W)$ which includes the errors of indication such that no corrections have to be applied to the readings in use

$$W = R \pm U_{gl}(W) \qquad (7.4.2\text{-}1)$$

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

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

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

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

8. CALIBRATION CERTIFICATE

This section contains advice what information 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

Identification of the calibration laboratory,
reference to the accreditation (accreditation body, number of the accreditation),
identification of the certificate (number, date of issue, number of pages),
signature(s) of authorised person(s).

Identification of the client.

Identification of the calibrated automatic catchweighing instrument,
information about the instrument (manufacturer, type, Max, d, (d_T), T).

Warning that the certificate may be reproduced only in full unless the calibration laboratory permits otherwise in writing.

8.2 Information about the calibration procedure

Date of measurements,
site of calibration - place of installation,
conditions of environment and/or use that may affect the results of the calibration.

Information about the instrument operation for each measurement/test (adjustment performed, dynamic setting performed, setting of software as far as relevant for the calibration, belt speed and/or rate of operation, or position of speed setting switch for specific measurements, maximum rate (cf. 4.6), zero settings, 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 d_T),.

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 (cf. 4.6), shape or other applicable information, including drawing or photo, if applicable).

Agreement with the client e.g. over metrological specifications to which conformity is declared.

Information about the traceability of the measuring results.

8.3 Results of measurement

Reference value of mass (gross or net), mean value of indications and mean errors of indication for applied test loads, as discrete values;
number of repetitions, for each measurement/test;
details of the loading procedure if relevant for the understanding of the above, referring to the feeding principle manually or by device;
standard deviation(s) determined, identified as related to the mean of indications, for each measurement/test;
information about the eccentricity test, indicating effect of eccentric loading, as well as position and direction of the belt (Band 1 or Band 2), where the max eccentricity was determined, for each measurement/test;
expanded uncertainty of measurement for the reported results.

Indication of the coverage factor, with comment on coverage probability.

Where the indications/errors have not been determined by normal readings - single readings with the normal resolution of the instrument - a warning should be given that the reported uncertainty is smaller than would be found with normal readings.

9 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 2, Directive 2009/23/EC: Common application non-automatic weighing instruments*, 2015

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

[6] *JCGM 101:2008, Evaluation of Measurement Data – Supplement 1 to the "Guide to the expression of uncertainty in measurement" – Propagation of Distributions using a Monte Carlo method,* 1st edition, 2008

[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 an indication)
I	indication of an instrument related to standard weights
L	load on an instrument
Max	maximum weighing capacity
R	indication (reading) of an instrument not related to a test load
U	expanded uncertainty
U_{gl}	global expanded uncertainty
Tol	specified tolerance value
W	weighing result
d	scale interval, the difference in mass between two consecutive indications of the indicating device
d_T	effective scale interval < d , used in calibration tests
k	coverage factor
m	mass of an object
m_c	conventional value of mass
m_N	nominal value of mass
m_{ref}	reference value of mass of a 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
N	nominal value
T	test
TL	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
rep	repeatability
s	used for adjustment
0	zero, no-load, initial

APPENDIX B: METHODS FOR DETERMINATION OF REFERENCE VALUE OF MASS

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 the conventional mass of the test load m_{cTL} is to that described in OIML R111 [3]

$$m_{cTL} = m_{cR}\left(1 + \left(\rho_{aCI} - \rho_0\right)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_R}\right)\right) + \overline{\Delta m} \qquad \text{(B1-1)}$$

with

$\overline{\Delta m}$ – average difference in indication between the test load and standard weight(s) measurements on the control instrument,

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 (4.5-2), taking into account (B1-1) for the conventional mass of the test load, (4.5-3) for the air buoyancy correction, and under the condition that $m_{cTL} \cong m_{cR}$, the reference value of mass m_{ref} is determined by

$$m_{ref} = m_{cR}\left[1 + (\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_R}\right)\right] + \overline{\Delta m_c} - m_{cR}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_s}\right)\right] \qquad \text{(B1-2)}$$

Since the reference value of mass is determined at the same time and place as the calibration of catchweigher, $\rho_{aCI} = \rho_a$, (B1-2) consequently simplifies to

$$m_{ref} = m_{cR} + m_{cR}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_s} - \frac{1}{\rho_R}\right)\right] + \overline{\Delta m_c} \qquad \text{(B1-3)}$$

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

$$\delta m_{BTot} = -m_{cR}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_R} - \frac{1}{\rho_s}\right)\right] \qquad \text{(B1-4)}$$

and

$$m_{ref} = m_{cR} + \delta m_{BTot} + \overline{\Delta m} \qquad \text{(B1-5)}$$

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 indication 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}:

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

where

$$W_{CI} = R_{CI} - E_{CI} \quad \text{(B2-2)}$$

$$R_{CI} = R_{LCI} - R_{0CI} \quad \text{(B2-3)}$$

$$E_{CI} = I_{CI} - m_{refCI} \quad \text{(B2-4)}$$

$$I_{CI} = I_{LCI} - I_{0CI} \quad \text{(B2-5)}$$

$$m_{refCI} = m_{cCalCI} + \delta m_{BCI} \quad \text{(B2-6)}$$

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

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} – eror 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 (4.5-3) for the air buoyancy correction we get the following general expression for m_{ref}:

(B2-8)

$$m_{ref} = \left\{(R_{LCI} - R_{0CI}) - (I_{LCI} - I_{0CI}) + m_{cCalCI} - m_{cCalCI}\left[(\rho_{aCalCI} - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_{sCI}}\right)\right]\right\}\left[1 + (\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_{sCI}}\right)\right] - m_{cTL}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_s}\right)\right]$$

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

$$m_{ref} = (R_{LCI} - R_{0CI}) - (I_{LCI} - I_{0CI}) + m_{cCalCI} - m_{cCalCI}\left[(\rho_{aCalCI} - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_{sCI}}\right)\right] + m_{cCalCI}\left[(\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_{sCI}}\right)\right] - m_{cCalCI}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_s}\right)\right] \quad \text{(B2-9)}$$

Since the reference value of mass is determined at the same time and place as the calibration of control instrument and catchweigher, then $\rho_{aCI} = \rho_{aCalCI} = \rho_a$, and

$$m_{ref} = (R_{LCI} - R_{0CI}) - (I_{LCI} - I_{0CI}) + m_{cCalCI}\left[1 - (\rho_a - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_s}\right)\right] \quad \text{(B2-10)}$$

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

$$\delta m_{BTot} = -m_{cCalCI}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_s}\right)\right] \quad \text{(B2-11)}$$

and

$$m_{ref} = (R_{LCI} - R_{0CI}) - (I_{LCI} - I_{0CI}) + m_{cCalCI} + \delta m_{BTot} \quad \text{(B2-12)}$$

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.

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

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

$$W_{CI} = R_{CI} \quad \text{(B3-1)}$$

but errors of the control instrument need to be included in an uncertainty (i.e. a "global uncertainty" $U_{gl}(W_{CI})$, which includes the errors of indication 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 (4.5-3) for the air buoyancy correction, we get the following general expression for m_{ref}:

$$m_{ref} = W_{CI}\left[1 + (\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_{sCI}}\right)\right] - m_{cTL}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_s}\right)\right] \qquad \text{(B3-2)}$$

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

$$m_{ref} = W_{CI}\left[1 + (\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_{sCI}}\right) - (\rho_a - \rho_0)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_s}\right)\right] \qquad \text{(B3-3)}$$

Since the reference value of mass is determined at the same time and place as calibration of the catchweigher, $\rho_{aCI} = \rho_a$, and (B3-3) consequently simplifies to

$$m_{ref} = W_{CI}\left[1 + (\rho_a - \rho_0)\left(\frac{1}{\rho_s} - \frac{1}{\rho_{sCI}}\right)\right] \qquad \text{(B3-4)}$$

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

$$\delta m_{BTot} = -W_{CI}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_{sCI}} - \frac{1}{\rho_s}\right)\right] \qquad \text{(B3-5)}$$

and

$$m_{ref} = W_{CI} + \delta m_{BTot} \qquad \text{(B3-6)}$$

APPENDIX C: CONTROL INSTRUMENT CALIBRATED TO SPECIFIED TOLERANCES

The standard global uncertainty of the weighing result $u_{gl}(W_{CI})$ 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:

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

with

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

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

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

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

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:

- $d_T \le mpe_{R76}/5$
- $R = 20000 mpe_{R76}$
- mpe_{R76} is taken at L_T

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