Calibration of automatic catchweighing instruments in
dynamic mode of operation

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Abstract. The article presents a method developed for calibration of automatic catchweighing instruments, which operates in the dynamic mode. The specifics of the calibration of the automatic catchweighing instruments in the dynamic mode of operation are highlighted and basic information about the measurement method, error model and measurement uncertainty contributions are given. The use of harmonized and validated methods will enable a traceable calibration of the catchweighing instrument in the dynamic mode of operation.

1. Introduction
Automatic catchweighing instruments (ACIs) are used to determine the mass value of pre-assembled discrete loads. They are extensively used in the preparation, production and quality assurance of pre-packed products as well as for products, whose content or composition is determined by weighing.

The calibration of ACI is not yet well defined, because there is a significant difference between the static mode of operation, typical for non-automatic weighing instruments and the dynamic measurement mode of operation, which is typical for the majority of automatic weighing instruments [1]. The need was identified to confirm their metrological quality by calibrations and the reliable estimation of their measurement uncertainty in order to judge the accuracy of the weighing result. The development of calibration method for dynamic measurements with the ACI is part of the EMPIR project 14RPT02 (AWICal) Traceable calibration of dynamic weighing instruments operating in the dynamic mode [2].

This paper focuses on the calibration method for the ACI, error model and uncertainty budget for the determination of the uncertainty of measurement in the dynamic mode of operation as well it presents the calibration example.

2. The calibration of automatic catchweighing instruments
The object of the calibration is the indication provided by the ACI in response to an applied load under the conditions of the calibration. The calibration consists of determining the mass of the test loads, applying the test loads to the ACI under specified conditions, determining the mean error of the indications, and evaluating the uncertainty of measurement to be attributed to the results. The actual value of the load indicated by the ACI is affected by dynamic effects, speed of the load transport system, the rate of operation, the load properties and dimensions.

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The calibration delivers a measurement error in comparison to a reference at the time of calibration and under the conditions of the calibration. The calibration is performed at the location where the ACI is being installed and normally at the same as conditions as that of the actual weighing process.

A control instrument is used to determine the reference value of mass of the test loads. It 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 ACI. The control instrument may be either separate or integral.

The calibration of ACI in the dynamic mode of operation cannot be performed directly with standard weights. The test loads should preferably be the type of article(s), which are normally weighed on the calibrated instrument. Their traceability to the SI unit of mass shall be demonstrated. Various methods could be used, e.g. determination of the mass of test load by comparison with standard weight on the control instrument used as a mass comparator, or by determination of the mass of test load by its weighing on control weighing instrument. In the latter situation, the control instrument could be calibrated at the same time as the ACI or earlier. In general, knowledge about density of the test load is not needed.

3. Measurement method
The tests are normally performed to determine the errors and repeatability of indications, and the effect of eccentric application of the load on the indication.

3.1. 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 constant test conditions. The purpose of this test is an evaluation of the accuracy and repeatability of the ACI in selected test points. The test is performed at least in points of usual application of the instrument and may refer to the net or gross values of the weighed articles. The minimum number of consecutive test weighings is specified in table 1:

| Nominal mass $m_N$ of the test load | $m_N \leq 10$ kg | $10 \text{ kg} < m_N \leq 20$ kg | $20 \text{ kg} < m_N$ |
|-----------------------------------|-----------------|-----------------|-----------------|
| Minimum number of repetitions $n$ | 30              | 20              | 10              |

For each test load $L_T$, the mean error of indication $E$ is calculated based on the mean value of several indications $\bar{I}$ and reference mass value $m_{ref}$

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

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

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

3.2. Eccentricity test
The effect of the eccentric application of the load on the indication may occur where the ACI does not have guides to centre the articles. The test is performed with the same test loads as the test for errors of indication. The effect is determined using two bands of the load transport system: a halfway between the centre and the back, and a halfway between the centre and the front. The minimum number of consecutive test weighings on each test band is specified in table 2:

| Nominal mass $m_N$ of the test load | $m_N \leq 10$ kg | $10 \text{ kg} < m_N \leq 20$ kg | $20 \text{ kg} < m_N$ |
|-----------------------------------|-----------------|-----------------|-----------------|
| Minimum number of repetitions $n$ | 6               | 5               | 3               |
For each tested band \( b \) the average difference \( \Delta I_{ecc,b} \) is calculated as difference between the average of the indications on individual band \( I_b \) and the result in the middle of the load receptor \( \bar{I} \)

\[
\Delta I_{ecc,b} = I_b - \bar{I}
\]

(3)

4. Evaluation of measurement results
The object of calibration for the ACI is the mean indication of the instrument \( \bar{I} \) in response to the applied test load with reference value of mass, \( m_{ref} \). The mean error of indication \( E \) equals

\[
E = \bar{I} - m_{ref}
\]

with the standard uncertainty of the error

\[
u(E) = \sqrt{u^2(\bar{I}) + u^2(m_{ref})}
\]

(5)

The expanded uncertainty of the error \( U(E) \) equals \( U(E) = 2u(E) \).

To account for sources of variability of the indication, i.e. the effect of the resolution \( d \) of indication \( \delta I_{digTL} \), repeatability of the instrument \( \delta I_{rep} \) and error due to off-centre position of the test load \( \delta I_{ecc} \), \( \bar{I} \) is amended by correction terms as follows. The corrections have the expectation value 0.

\[
\bar{I} = \bar{I}_{TL} + \delta I_{digTL} + \delta I_{rep} + \delta I_{ecc}
\]

(6)

Due to effects of air buoyancy and other minor effects, \( m_{ref} \) is not exactly equal to the conventional mass value of the test load. If \( m_{ref} \) is determined by weighing on the previously calibrated control instrument, \( m_{ref} \) equals to the result of weighing of the test load on the control instrument \( W_{CI} \), corrected for the overall air buoyancy correction \( \delta m_{BTot} \)

\[
m_{ref} = W_{CI} + \delta m_{BTot}
\]

(7)

It can be shown that it is usually not necessary to apply the buoyancy correction, i.e. \( \delta m_{BTot} = 0 \).

4.1. Standard uncertainty of indication
The standard uncertainty of the indication of the ACI \( u(\bar{I}) \) equals

\[
u^2(\bar{I}) = u^2(\delta I_{digTL}) + u^2(\delta I_{rep}) + u^2(\delta I_{ecc}) = d^2/12 + s^2(l)/n + \left( \frac{|\Delta I_{ecc,b}|_{max}}{2\sqrt{3}} \right)^2
\]

(8)

4.2. Standard uncertainty of reference value of mass
The standard uncertainty of the reference value of mass \( u(m_{ref}) \) equals

\[
u^2(m_{ref}) = u^2(W_{CI}) + u^2(\delta m_{BTot})
\]

(9)

The standard uncertainty of the weighing result \( u(W_{CI}) \) should be evaluated according to [4] either for the case when errors of the control instrument are accounted by correction or for the case they are included in the “global” uncertainty \( U_{gt}(W_{CI}) \). 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 or adjusted right before its use.

Even if no buoyancy correction is applied, the uncertainty of air buoyancy correction \( u(\delta m_{BTot}) \) could be significant. If conformity of weights used for adjustment of the ACI and control instrument to [5] is established and if the ACI is not adjusted before the calibration, the uncertainty is evaluated as

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

(10)

with \( m_N \) being the nominal value of the test load, \( \rho_0 = 1,2 \, kg/m^2 \), \( \rho_c = 8000 \, kg/m^2 \) and \( mpe \) the maximum permissible error of the standard weights used for adjustment.
5. Calibration example
The subject of calibration was the ACI with the maximum capacity 500 g and the scale interval 0,1 g, which was used to weigh plastic containers filled with powder with the nominal net value of 350 g. The speed of load transportation system was 45 m/min.

The reference weighing of the test load was done on the previously calibrated control instrument with Max = 610 g and d = 0,01 g, which was internally adjusted before use. In its calibration certificate was given for the test load 350 g the error of indication $E_{cI} = 0,03 g$ with corresponding standard uncertainty $u(E_{cI}) = 0,020 g$. The determined reference value of mass of the test load was 350,23 g.

The weighing of the test load on the ACI was repeated 30 times, resulting in the mean value of indications $\bar{I} = 350,41 g$ with the standard deviation 0,42 g. The eccentric effects were not applicable.

Table 3 summarizes the results of calibration of the ACI in the dynamic mode.

Table 3. Results of calibration and with corresponding uncertainties.

| $\bar{I}$ | $m_{ref}$ | E | $u(\delta_{digTL})$ | $u(\delta_{rep})$ | $u(W_{cI})$ | $u(\delta m_{TOT})$ | $u(E)$ | $U(E)$ |
|-------|---------|---|------------------|-----------------|-------------|-----------------|--------|--------|
| 350,41 | 350,23 | 0,18 | 0,029 | 0,028 | 0,041 | 0,006 | 0,077 | 0,16 |

6. Conclusion
The uncertainty of measurement depends significantly on properties of the calibrated ACI itself, the control instrument, the characteristics of the test loads and the equipment of the calibrating laboratory. Due to the dynamic behaviour of operation, functional relationship between the weighing result, parameters of operations such as rate of operation, dimensions of products and nominal value of the test load is very complex and currently out of the scope of the calibration procedure. Consequently, it will usually not be possible to calibrate a measurement range for such instruments.

The calibration is only valid for the specified test loads (with a small bandwidth for mass, volume and shape) and speed of operation. Each test point is characterized by its own repeatability.

The expected impacts of the EMPIR project 14RPT02 are to provide basis for traceable dynamic measurements on the ACIs based on the EURAMET calibration guide to and improved weighing process control in different industries. Consequently, the calibration laboratories for the calibration of ACIs could be accredited by accreditation bodies based on the harmonised guidance.

7. References
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[4] EURAMET Calibration Guide No. 18 Guidelines on the Calibration of Non-Automatic Weighing Instruments, version 4.0 (11/2015)
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