IMEKO 23rd TC3, 13th TC5 and 4th TC22 International Conference
30 May to 1 June, 2017, Helsinki, Finland

TWO MODEL FUNCTIONS FOR CALIBRATION OF AUTOMATIC GRAVIMETRIC FILLING INSTRUMENTS

M. Grum, G. Grgić

Metrology Institute of the Republic of Slovenia, Ljubljana, Slovenia, matej.grum@gov.si

Abstract: The article discusses basics of procedure for the calibration of automatic gravimetric filling instruments. It deals with the definition of the model function of measurement procedure, determination of the reference mass of test fills and estimation of measurement uncertainty. Depending on whether the calibrated instrument is able or not to record its results and on this basis adjust the filling process, two options for the selection of the calibration model function are addressed. Contributions to the measurement uncertainty are presented with an emphasis on the differences arising from the application of one or another model function.

Keywords: automatic gravimetric filling instruments, calibration procedure, measurement uncertainty budget.

1. INTRODUCTION

Automatic weighing instruments are capable of performing consecutive weighing cycles without any intervention of an operator. Automatic gravimetric filling instruments (AGFIs) are automatic weighing instruments, which fill containers with predetermined and virtually constant mass of product from bulk by automatic weighing.

There is the growing need to confirm metrological quality of AGFIs by calibrations and the determination of their measurement uncertainty [1, 2]. Users of AGFIs require a reliable estimation of the measurement uncertainty in order to judge the accuracy of the weighing result. At the moment there is no widely recognized procedure for calibration of AGFIs.

Due to the dynamic behaviour of their operation, functional relationship between weighing result and parameters of operations such as rate of operation, type of material and preset value of fills is very complex and currently out of the scope of the calibration procedure. The actual value of the fill is affected by various dynamic effects of instrument operation, the load type and its properties, the container properties, and the temperature and density of the surrounding air.

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

Consequently, it is not possible to calibrate a “measuring range” for such instruments. In agreement with the client, the calibration could be performed at individual calibration points, which are defined by preset value test fills, and it is only valid for the specified preset values and under other above mentioned conditions of operation of the instrument.

In a common case, object of the calibration is information on agreement between the actual mass of fills and the preset value, i.e. value, expressed in units of mass, preset by the operator, in order to define the nominal value of the fills. Information on a difference between the mass of a single fill and the preset value is not the main object of interest, but, due to nature of the production process, it is the average value of this difference. So far, this approach is similar to procedure of conformity assessment of the AGFI as defined in [3], where the preset value error needs to be determined, too.

In the case when AGFI also automatically records weighing and on this basis controls and adjusts the filling process in order to minimize the deviation between calculated average of fills and the preset value, it is relevant to apply a different approach to the calibration. A subject of calibration in this case is the difference between the recorded mass value of the fills and the reference mass of the same fills. Again, the subject of interest is the average value of the difference, and not just a difference of a particular fill.

The model functions for both above mentioned approaches to the calibration of AGFI are discussed in Chapter 2.

For the purpose of calibration, traceability of test fills mass vale to the SI unit of mass shall be demonstrated. This is normally achieved by a control instrument, which is used to determine the mass of test fills in containers and the mass of empty containers. Basic information concerning the determination of the reference mass value of each test fill are given in Chapter 3.

For a complete presentation of calibration results it is necessary to evaluate the measurement uncertainty. Contributions to uncertainty for both model functions are presented in Chapter 4.

2. MODEL FUNCTIONS FOR CALIBRATION

The user of the AGFI is interested to know the average error of the product in a respect of the preset value in order to optimise the adjustments of production process. AGFIs generally do not record weighing results for fills produced. However, certain AGFIs do have this functionality. These instruments have the possibility to adapt the filling process in order to optimally achieve the preset value. In such a case, the subject of calibration could be the average difference between the recorded mass value of the fills and the reference mass value of the same fills. For this kind of AGFIs it is also expected that the difference between the average mass of fills and the preset value is not constant over time.

2.1 Preset value error calibration model function

Users of the AGFI are in general interested in information on a deviation between average mass of the fills and preset value. In this case for the purpose of calibration of the AGFI the preset value of fill F_P is taken into account. The indications of calibrated instrument, if available at all, are not recorded.

The preset value error E_P is calculated based on measurement of n test fills as follows. Reference mass value of test fills $m_{ref,i}$ are determined with a help of control instrument. E_P is calculated as a difference between average reference mass value of test fills and the preset value.

$$E_P = \frac{1}{n}\sum_{i=1}^{n} m_{ref,i} - F_P \qquad (1)$$

In Figure 1, reference mass values of test fills are represented by blue filled circles and their average with a blue dotted line. The preset value is represented by a red line.

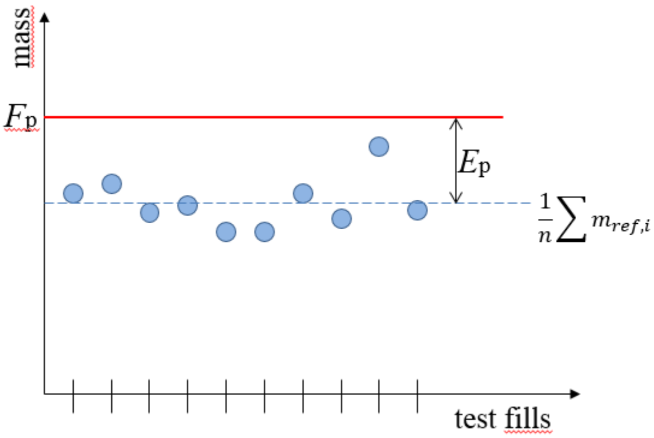

Figure 1: Schematic presentation of determination of preset value error of the AGFI.

2.2 Error of indication calibration model function

Many AGFIs internally record mass of each fill. Consequently they can calculate some statistical parameters from this information, and are also able to control their internal settings in order to better follow the preset value. This would also mean that in this case the preset error could change with time and that the model (1) is not the best one.

In such a case a user of AGFI can monitor difference between the preset value and average of indication, but information on accuracy of indication of AGFI is missing.

For such instruments an alternative approach to the measurement model defined by (1) is suggested. The measurand could be an average error of (internal) indication of the AGFI $E(I)$ defined as average difference between recorded masses (indications) of particular fills I_i and their reference masses determined by help of the control instrument.

$$E(I) = \frac{1}{n}\sum_{i=1}^{n}\left(I_i - m_{ref,i}\right) \qquad (2)$$

With this model it is expected that AGFI can on longer term apparently meet the preset value based on its own internal information on indication of mass of fill measured. However, there can be a significant difference between instrument indication and reference value of mass of each fill.

In Figure 2, reference mass values of test fills are represented by blue filled-in circles and their average with a blue dotted line, indicated values of test fills are represented by blank blue circles and their average with a blue solid line. The preset value is represented by a red line.

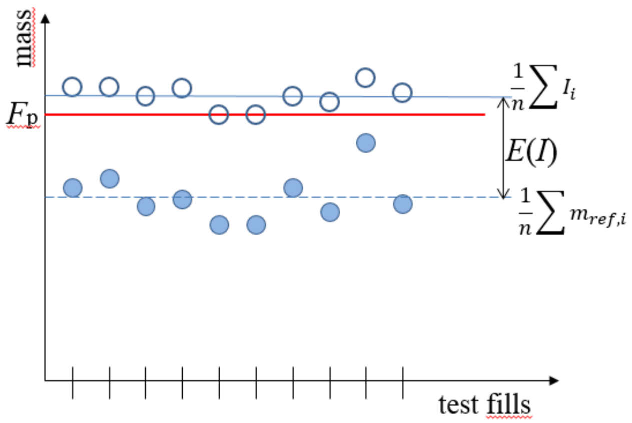

Figure 2: Schematic presentation of determination of error of indication of the AGFI.

3. REFERENCE MASS VALUE

In order to properly determine either preset value error according to (1) or error of indication of AGFI according to (2), the reference mass value of test fills need to be determined as well. The conventional mass of the test fills is normally determined at the time and place of calibration of the instrument.

The necessary measurements to determine the mass of the test fills are performed on the control instrument. The procedure requires measurements of empty containers (i.e. a tare value) and measurements of filled containers (i.e. a gross value).

There are several possible approaches how to determine the reference mass value of test fills. An approach is presented here, where a calibrated non-automatic weighing instrument is used to make weighing of the test fills, and the weighing results of control instrument W_{CI} are not corrected for instrument's errors of indication.

For calculation of $m_{ref,i}$ it is necessary to weigh filled-in containers as well as empty containers.

3.1 Virtually constant mass of containers

If the mass of containers is virtually constant, e.g. the mass difference between individual containers is smaller then e.g. a half of the scale interval value of preset value device, it is sufficient to determine average conventional mass of empty containers. The average mass of empty containers could be determined by simultaneous weighing of a sample of m empty containers (e.g. $m = 10$ or more). In this case (Case A)

$$m_{ref,i} = W_{CI,Bi} - \frac{1}{m}\sum_{z=1}^{m} W_{CI,Tz} + \delta m_{BTot} \quad (3)$$

$W_{CI,Bi}$ is weighing result on the control instrument for i-th filled container (gross value), $W_{CI,Tz}$ is weighing result for z -th container in the sample of m empty containers, δm_{BTot} is the total contribution of the air buoyancy correction.

Since the mass of the test load is determined at the same time and place as calibration of the AGFI takes place, air density during weighing of the test fills on the control instrument ρ_{aCI} equals air density during calibration of the instrument ρ_a. Consequently the total contribution of the air buoyancy correction δm_{BTot} to m_{ref} in (3) equals

$$\delta m_{BTot} = -m_{n,F}(\rho_a - \rho_0)\left(\frac{1}{\rho_{sCI}} - \frac{1}{\rho_s}\right) \quad (4)$$

ρ_0 is reference air density, 1,2 kg/m3, ρ_{sCI} and ρ_s is density of standard weights used for adjustment of the control instrument and the AGFI, respectively.

From (4) it can be seen that no information is necessary about density of material, which if filled-in by the AGFI. A difference between ρ_{sCI} and ρ_s is relatively very small, consequently a detailed elaboration of the air buoyancy correction is not necessary.

3.2 Significant difference between mass of containers

If the mass difference between individual empty containers is significant, e.g. equal or larger then 0,5 d of the calibrated AGFI, then it is necessary to determine the mass of each empty container $W_{CI,Ti}$, which will be used. In this case (Case B) $m_{ref,i}$ equals

$$m_{ref,i} = W_{CI,Bi} - W_{CI,Ti} + \delta m_{BTot} \quad (5)$$

4. UNCERTAINTY EVALUATION

From (3) for the Case A, net value of a single fill F_{ij} is defined as

$$F_i = W_{CI,Bi} - \frac{1}{m}\sum_{z=1}^{m} W_{CI,Tz} \quad (6)$$

and from (5) for the Case B as

$$F_i = W_{CI,Bi} - W_{CI,Ti} \quad (7)$$

(6) and (7) are used to slightly modify (1) and (2), which represent models for the preset value error and error of indication, respectively. For (1) we get

$$E_P = \overline{F} + \delta m_{BTot} - F_P \quad (8)$$

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

$$\overline{F} = \frac{1}{n}\sum_{i=1}^{n} F_i \quad (9)$$

and for (2) we get

$$E(I) = \bar{E} + \delta m_{BTot} \quad (10)$$

where $\overline{E}$ is average error of indication not yet corrected for the air buoyancy influence

$$\bar{E} = \frac{1}{n}\sum_{i=1}^{n}(I_i - F_i) = \frac{1}{n}\sum_{i=1}^{n} E_i \quad (11)$$

4.1 Standard uncertainty of the preset value error

To account for sources of variability of the preset value error, (8) is amended by additional correction terms δX_{xx} as follows

$$E_P = \overline{F} + \delta F_{rep} + \delta F_{repT} + \delta m_{BTot} + \delta I_0 - F_P \quad (12)$$

All input quantities are considered to be uncorrelated, the standard uncertainty of the preset error $u(E_P)$

$$u^2(E_P) = u^2(W_{CI,B}) + u^2(W_{CI,T}) + u^2(F_{rep}) + u^2(F_{repT})^2 + u^2(m_{BTot}) + u^2(\delta I_0) \quad (13)$$

Standard uncertainties of weighing result on the control instrument for filled container (gross value) and empty container $u(W_{CI,B})$ and $u(W_{CI,BT})$, respectively, can be estimated in the same way as it is presented in [4]. If the average mass of empty containers is determined by simultaneous weighing of a sample of m empty containers, uncertainty is in the first step estimated for the complete sample $u(W_{CI,mT})$, and then divided by m.

δF_{rep} accounts for the variability of test fills; normal distribution is assumed, and standard uncertainty of the mean of several fills $u(\delta F_{rep})$ is estimated as

$$u(\delta F_{rep}) = s(F)/\sqrt{n} \quad (14)$$

The standard deviation $s(F)$ is for a given preset value F_P calculated from the n fills F_i (as defined in (6) or (7))

$$s(F) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(F_i - \bar{F})^2} \quad (15)$$

δF_{repT} accounts for the variability of mass of empty containers, its expectation value is zero. For the Case A from Section 3.1, the standard uncertainty of variability of mass of empty containers $u(\delta F_{repT})$ can be estimated based on maximum mass difference between empty containers assuming rectangular distribution. This contribution is not applicable in the case, where tare value of each container is determined and taken into account (cf. Case B in Section 3.2).

A difference between ρ_{sCI} and ρ_s is relatively small, consequently a more elaborate calculation of the correction δm_{BTot} and its uncertainty component based on actual data may be superfluous. In such a case, no correction is applied, i.e. δm_{BTot}=0. If conformity of the standard weights used for adjustment of the control instrument and AGFI to OIML R111 [5] is established, $u(\delta m_{BTot})$ can be estimated in the same way as it is presented in [4].

δI_0 accounts for the instability and drift of zero value of the AGFI. The expectation value of correction is zero. For the standard uncertainty of the instability and drift of zero value $u(\delta I_0)$ rectangular distribution is to be assumed. It can be estimated based on maximum deviation of instrument indication from zero in unloaded position before zero-setting takes place.

4.2 Standard uncertainty of the error of indication

To account for sources of variability of the error of indication, (10) is amended by additional correction terms δX_{xx} as follows

$$E(I) = \bar{E} + \delta E_{rep} + \delta F_{repT} + \delta m_{BTot} + \delta I_0 + \delta I_F \quad (16)$$

All input quantities are considered to be uncorrelated, the standard uncertainty of the error of indication $u(E(I))$

$$u^2(E(I)) = u^2(W_{CI,B}) + u^2(W_{CI,T}) + u^2(E_{rep}) + u^2(F_{repT})^2 + u^2(m_{BTot}) + u^2(\delta I_0) + u^2(\delta I_F) \quad (17)$$

Contributions $u(W_{CI,B})$, $u(W_{CI,BT})$, $u(\delta F_{repT})$, $u(\delta I_0)$ and $u(\delta m_{BTot})$ in (17) are estimated in the same way as presented in the Section 4.1. In addition, two uncertainty contributions from (17), i.e. δE_{rep} and δI_F, are not part of (13).

δE_{rep} accounts for the variability of difference between recorded masses (indications) of particular fills and their reference masses; normal distribution is assumed, and standard uncertainty of the mean of several differences $u(\delta E_{rep})$ is estimated as

$$u(\delta E_{rep}) = s(E)/\sqrt{n} \quad (18)$$

The standard deviation $s(E)$ is calculated from the n differences E_i (as defined in (11))

$$s(E) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(E_i - \bar{E})^2} \quad (19)$$

δI_F accounts for the effect of resolution of indicated value of test fill. Its expectation value of correction is zero. Limits of δI_F are $\pm d/2$; the standard uncertainty of the effect of resolution $u(\delta I_F)$ is estimated based on assumed rectangular distribution.

5. CONCLUSION

Two model functions for the calibration of AGFI were developed. The first model can be used to determine the preset value error of calibrated instrument and its uncertainty, and the other to determine the error of indication of calibrated instrument and its uncertainty. It can be seen that calibration methods for both model could be almost identical, in the second case only records of instrument results are necessary to be collected in addition.

The first model provides information on agreement between the test fills and the preset value, and the second provides information on accuracy on instruments results, which are used by the instrument for adjustment of the filling process.

Most of the contributions to the measurement uncertainty is common and the same for the two models, the essential difference is in the method of evaluation of uncertainty due to imperfect repeatability of the results of the instrument.

The uncertainty of calibration depends significantly on properties of the calibrated instrument itself and the characteristics of the material which is filled, uncertainty of the reference mass values depends on properties of the control instrument and its traceability. The density of the material, which is filled, is not necessary to be known and does not influence the measurement uncertainty.

Practical application of the presented procedures on various full operational AGFIs is planned in order to evaluate significance of individual uncertainty contributions.

6. ACKNOWLEDGEMENTS

This work was part-funded through the European Metrology Programme for Innovation and Research (EMPIR) Project 14RPT02 (AWICal). The EMPIR is jointly funded by the EMPIR participating countries within EURAMET and the European Union.

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