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IMPROVED CALIBRATION METHOD FOR AUTOMATIC CATCHWEIGHING INSTRUMENTS

M. Grum[1], G. Grgić[2], D. Knopf[3], F. Buendia[4]

Metrology Institute of the Republic of Slovenia, Ljubljana, Slovenia
[1] matej.grum@gov.si, [2] goran.grgic@gov.si
Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, [3] dorothea.knopf@ptb.de
Mettler-Toledo S.A.E., Madrid, Spain, [4] fulgencio.buendia@mt.com

Abstract:
The paper presents recent developments related to the establishment of a calibration procedure for automatic catchweighing instruments (catchweighers). The main purpose of the proposed calibration method is to provide a basis for traceable measurements of the catchweighers in the dynamic mode of operation outside of the legal metrology framework. The specifics of the instruments' operation in the dynamic mode are highlighted, the recent modifications in the calibration method and the uncertainty budget are outlined and the results of validation of the proposed method are presented. A good agreement of the performed validation experiments is shown, which could lead to the successful implementation of the procedure in practice.

Keywords: automatic catchweighing instruments; dynamic mode of operation; calibration; traceability; measurement uncertainty

1. INTRODUCTION

Catchweighers are automatic weighing instruments mostly used to weigh discrete loads following a pre-determined programme and, in the general case, motorised conveyers are used to place and remove the load on the load receptor. While non-automatic weighing instruments are routinely calibrated based on an existing EURAMET calibration guide [1], no harmonised calibration procedure is available for automatic weighing instruments, including the catchweighers.

However, the need was identified to confirm their metrological quality by calibration including a reliable estimation of the measurement uncertainty and thus, the traceability of the respective results to national standards.

The proposed calibration method and the included uncertainty evaluation model were developed within the EMPIR AWICal project [2]. The outcomes of additional validation experiments were used to improve the calibration method and the included uncertainty evaluation as presented in this paper.

This paper focuses on some specifics of the dynamic weighing process of catchweighers, which are important for the interpretation of calibration results, a basic description of the calibration method and the discussion of uncertainty contributions. The motivation to change the procedure will be presented on the basis of the validation results before and after improvement of the calibration method.

2. GENERAL ASPECTS OF THE CALIBRATION METHOD

The calibration method was developed with the goal to cover the metrological specifics of the automatic operation of catchweighers as good as possible on one hand and to reasonably take into account practical aspects on the other hand. It focusses on catchweighers that weigh dynamically, but it could be as well used for catchweighers that weigh statically in automatic mode, i.e. in a so-called "start-stop mode". However, the method is not intended for the calibration of vehicle incorporated or vehicle mounted catchweighers.

The calibration method consists of selecting the test loads and determination of their reference value of mass, applying the test loads according to the steps specified in the method and under local conditions of operation, recording indications, and evaluation of measurements results, i.e. the determination of the error of measurement together with the corresponding uncertainty.

The calibration should be performed under, as far as possible, normal conditions of use and operation of the catchweigher, including type of weighed articles, their positioning and orientation, distance between the articles, speed of the load transportation system, ambient temperature, air flow, vibrations, stability of the weighing site etc.

The calibration in the dynamic mode of operation cannot be performed directly with standard weights. As mentioned above, the test loads should be of the type of article(s), which are normally weighed on the calibrated instrument. Their mass should be determined traceable to the SI unit of mass by the use of a static control weighing instrument, either separate or integral and appropriate reference weights [3]. As usually the density of the weighed articles is not properly known, and thus could not be taken into account, it is requested to determine the mass of the test loads onsite for a proper recognition of buoyancy effects.

3. MEASUREMENT METHOD

The developed calibration method suggests the performance of several sets of measurements to determine the errors of measurement, the repeatability, the effect of the eccentric loading and the reproducibility.

The main difference to the calibration procedure proposed so far in [4] is the introduction of reproducibility measurements to evaluate additional effects (such as adjustment of the belt, mechanical hysteresis, which could e.g. result from stopping and starting again operation of the load transport system), which may influence the variation of measurement results additionally to the repeatability.

Of course, the repeatability and eccentricity effects have to be recognised by separate measurements too.

The errors of measurement, the repeatability, the effect of the eccentric loading and the reproducibility are determined for each selected test load and they are considered as representative only for the respective test load. Because of a dynamic behaviour of the instrument, the estimation of a calibration curve over parts or the whole range of the instrument is not covered by this method.

3.1. Error of Measurement and Repeatability

The procedure for evaluation of the errors and repeatability of the instrument consists of repeatedly passing the same test load over the load receptor for defined number of times, using the central portion of the load transport system, which should not be stopped during the measurements.

For each test load, the error of measurement E is calculated as a difference between the mean of the indications $\bar{I}$ and the predetermined reference value of mass of the test load m_{ref}.

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

The uncertainty due to repeatability u_{rpt} is evaluated as the standard deviation of the mean of the indications.

$$u_{\mathrm{rpt}} = s(I)/\sqrt{n} \tag{2}$$

where n is the number of repeated weighings for the given test load and $s(I)$ the corresponding standard deviation. A normal distribution is assumed.

3.2. Effect of Eccentric Loading

The effect of the eccentric application of the load on the indication may occur where the instrument does not have mechanical guides to centre the articles. The effect is determined passing repeatedly the same test load over the load receptor for a defined number of times using the central portion of the load transport system, the middle of the left and the middle of the right portion of the load transport system. The operation of the catchweigher should not be interrupted (e.g. by stopping and then starting again the load transport system) between the measurements on the different portions.

The standard uncertainty due to eccentricity u_{ecc} is based on the largest difference of the mean indications $|\Delta I_{\mathrm{ecc}}|_{\max}$ between the central and the left/right portions of the load transport system. Since it is expected that the centre of gravity of the test load during a determination of the error of measurement is closer to the load receptor centre than the eccentric load positions, only a half of the maximum measured difference is taken into account. A rectangular distribution is assumed.

$$u_{\mathrm{ecc}} \leq \frac{1}{2}\left|\Delta I_{\mathrm{ecc(left,right)}}\right|_{\max} \cdot \frac{1}{\sqrt{3}} \tag{3}$$

3.3. Reproducibility

A pragmatic approach was chosen for a feasible determination of the uncertainty contribution due to reproducibility. The same test load as for the repeatability and eccentricity measurements is again passed over the load receptor, using the central portion of the load transport system. However, opposite to the procedure for evaluation of the repeatability, it is essential that between the measurement cycles the operation of the catchweigher is interrupted, e.g. by stopping and then starting again the load transport system. The procedure consists of five cycles (or three cycles for heavier test loads) of measurements and at least one measurement of the test load is performed in each cycle.

If the number of measurements in the cycle is increased, a better estimation of the reproducibility could be provided.

It is proposed to determine the uncertainty due to reproducibility based on the maximum difference Δ of the indications I_i between the measurement cycles in the case when the operation of the instrument is interrupted.

$$\Delta = I_{i,\max} - I_{i,\min} \tag{4}$$

If more than one measurement per cycle was executed, then the average of the indicated values per cycle are taken into account.

Assuming a rectangular probability distribution of the indications, the standard uncertainty due to reproducibility u_{rpd} is estimated as

$$u_{\mathrm{rpd}} = \Delta/\sqrt{12} \tag{5}$$

3.4. Instruments with High Rate of Operation

As it is stated in the subsections above, the calibration procedure is usually based on passing the same test load repeatedly over the load receptor for a defined number of times. However, for the calibration of instruments with a high rate of operation (caused by e.g. high belt speeds and small distances between the loads), the use of automatic feeding device could be considered.

In such a case, a repeated weighing of a single test load could be replaced by a procedure, where a set of required number of individual test loads of the same kind and with nearly the same mass is weighed once.

Again, the masses of all test loads in the set are determined individually by a comparison with reference weights or a calibrated static weighing instrument. The individual test loads must be individually characterised, identifiable and the order of use has to be clearly recorded. An automatic logging of the individual indications is presumed.

4. CALIBRATION PROCEDURE VALIDATION

The experimental validation of the proposed calibration procedure was carried out to check an agreement between the calibration results. A part of measurements, which were carried out during the investigation are presented below.

4.1. Validation Case 1

In Table 1 and in Figure 1 the first example of results of measurements is presented. The measurements were carried out on a high resolution checkweigher with a maximum capacity of 2 kg, a resolution of 0.01 g and a speed of load transport system of 20 m/min.

The results refer to four separate series of measurements of a test load with a statically-determined mass of about 115 g. In each series, five cycles of n measurements were carried out. Within the cycle the load transportation system was not interrupted, however it was interrupted (stopped/started) between the cycles.

Each cycle of measurements is characterised with its own error of measurement E, a standard

Table 1: A summary of part of the validation results for the validation case 1. All mass values are in grams

Cycle	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
E	0.04	0.03	-0.07	-0.03	-0.08	-0.02	-0.06	-0.01	-0.05	-0.02	0.03	0.00	-0.06	-0.04	-0.04	0.01	-0.01	-0.05	0.06	-0.03
$s(I)$	0.030	0.025	0.023	0.018	0.030	0.021	0.013	0.013	0.011	0.011	0.023	0.014	0.015	0.020	0.019	0.010	0.022	0.020	0.018	0.016
n	10					20					30					10				
Δ	0.10					0.05					0.10					0.10				
u_{rpt}	0.009	0.008	0.007	0.006	0.010	0.005	0.003	0.003	0.002	0.002	0.004	0.002	0.003	0.004	0.004	0.003	0.007	0.006	0.006	0.005
u_{rpd}	0.029					0.014					0.029					0.029				
U'	0.020	0.017	0.016	0.013	0.020	0.011	0.008	0.008	0.007	0.007	0.010	0.008	0.008	0.009	0.009	0.008	0.015	0.014	0.013	0.012
U	0.061	0.060	0.060	0.059	0.061	0.031	0.030	0.030	0.030	0.030	0.059	0.058	0.058	0.058	0.058	0.058	0.060	0.059	0.059	0.059

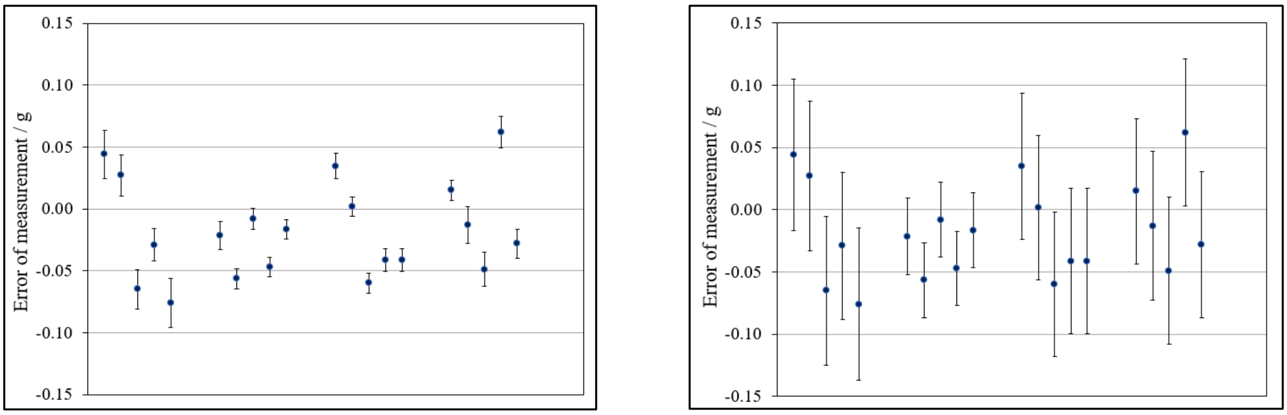

Figure 1: Errors of measurement with corresponding expanded uncertainty as an example of validation results for the validation case 1. *Left*: Only repeatability contribution taken into account as the statistical contribution to the uncertainty. *Right*: Both repeatability and reproducibility contributions taken into account as the statistical contribution to the uncertainty

deviation $s(I)$ and the standard uncertainty due to repeatability u_{rpt}.

However, the maximum difference of the indications between the measurement cycles Δ and the standard uncertainty due to reproducibility u_{rpd} are properties of one series of several cycles of measurements and not a single cycle, because they are calculated taking into account every first measurement result in the cycle.

Finally, the reported expanded uncertainty U' is given by:

$$U' = 2 \cdot u_{\mathrm{rpt}} \tag{6}$$

and U is calculated from:

$$U = 2\sqrt{u_{\mathrm{rpt}}^2 + u_{\mathrm{rpd}}^2} \tag{7}$$

Other uncertainty contributions are not taken into account in the presentation. The measurements were made with the same test load, so the uncertainty of m_{ref} does not influence the reported differences between the errors of measurement. Nevertheless, it would be easy to determine the reference mass with the standard uncertainty significantly smaller than 0.001 g at 100 g nominal mass. Furthermore, the standard uncertainty resulting from the resolution of the instrument of 0.01 g is less than 0.003 g and, all measurements were carefully done over the central portion of the load receptor in order to avoid any significant eccentric effect.

4.2. Validation Case 2

In Table 2 and in Figure 2 an example of results of measurements is presented, which were carried out on another high resolution checkweigher with a maximum capacity of 1.5 kg, a resolution of 0.01 g and a speed of load transport system of 50 m/min.

The results refer to two separate series of measurements of a test load with a statically-determined mass of about 52 g.

Table 2: A summary of part of the validation results for the validation case 2. All mass values are in grams

Cycle	1	2	3	4	5	1	2	3	4	5
E	-0.07	0.00	0.06	-0.02	-0.01	0.14	0.02	0.13	0.02	0.03
$s(I)$	0.09	0.07	0.05	0.09	0.05	0.06	0.11	0.07	0.07	0.06
n	20					20				
$\Delta(1)$	0.35					0.23				
$\Delta(2)$	0.16					0.19				
u_{rpt}	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.01
$u_{\mathrm{rpd}}(1)$	0.10					0.07				
$u_{\mathrm{rpd}}(2)$	0.05					0.05				
U'	0.04	0.03	0.02	0.04	0.02	0.03	0.05	0.03	0.03	0.03
$U(1)$	0.21	0.20	0.20	0.21	0.20	0.14	0.14	0.14	0.14	0.14
$U(2)$	0.10	0.10	0.09	0.10	0.09	0.12	0.12	0.12	0.12	0.12

The measurements were executed in the same way as in the validation case 1. Also the results of measurements were processed in the same way.

However, an alternative evaluation is additionally presented, where the maximum difference of the indications between the measurement cycles Δ was determined based on the mean value of the first two measurement results in the cycle. Consequently, $\Delta(1)$, $u_{\mathrm{rpd}}(1)$, $U(1)$ and $\Delta(2)$, $u_{\mathrm{rpd}}(2)$, $U(2)$ refer to the evaluation based on the first one and the evaluation based on the first two measurement results in the cycle, respectively.

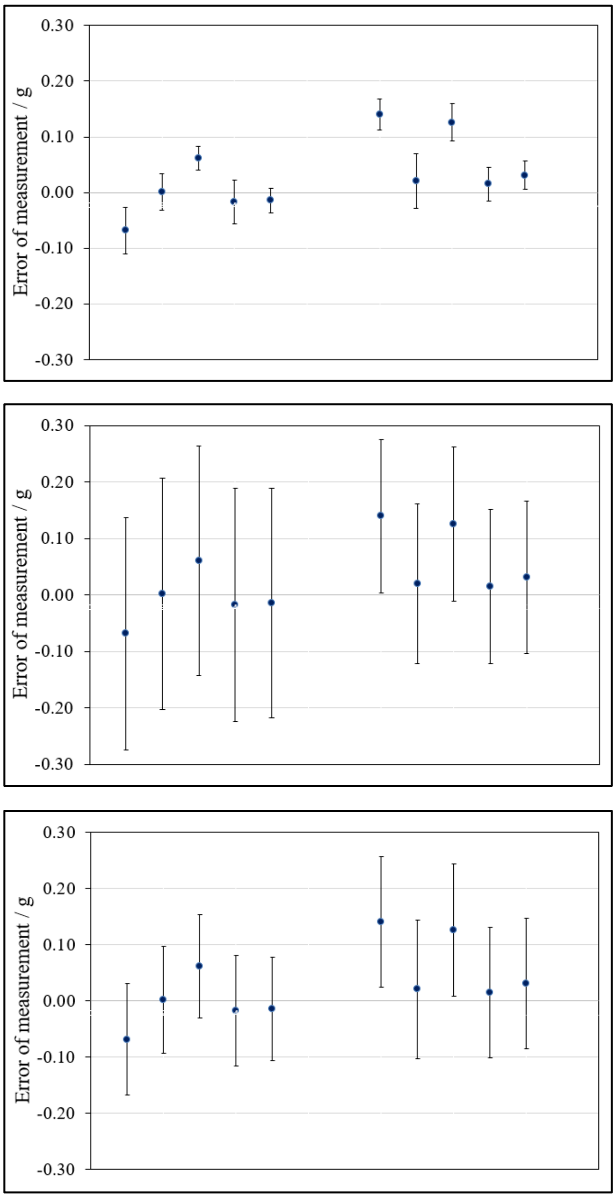

Figure 2: Errors of measurement with corresponding expanded uncertainty as an example of validation results for the validation case 2. *Top*: Only the repeatability contribution taken into account. *Middle*: Both repeatability and reproducibility contributions taken into account, reproducibility based on the first measurement of each cycle. *Bottom*: Both repeatability and reproducibility contributions taken into account, reproducibility based on the first two measurements of each cycle

5. SUMMARY

The calibration according to the developed method delivers information of the measurement error of the catchweigher with the corresponding measurement uncertainty at the time of calibration and under the conditions of the calibration. The calibration needs to be performed under conditions as far as possible close to that of the actual weighing process. The validity of calibration results is particularly limited to the measuring points defined by selected test loads, their orientation and the speed of the load transportation system. Each calibration point is characterised by its own repeatability, reproducibility and effect of the eccentric application of the load.

The initial validation experiments suggested that there were previously unconsidered effects. From the left-hand side graph in Figure 1 and the top graph in Figure 2 it can be recognised that there was a poor agreement between measurement cycles taking into account the measurement errors and corresponding uncertainties. The effect of reproducibility was not taken into account in the uncertainty.

After the introduction of additional measurements for the recognition of reproducibility and the corresponding uncertainty contribution, practical experimental results showed a suitable agreement between a larger set of measurement results. This can be seen well from the right-hand side graph in Figure 1 and the middle and bottom graph in Figure 2. The validation measurements also showed that the reproducibility effect may in specific cases be the determining effect.

However, a comparison of the uncertainties presented in the middle and bottom graph in Figure 2 shows that the evaluation of reproducibility based on a larger number of measurements in the cycle (as per bottom graph in Figure 2) could provide a better estimation of the reproducibility.

The presented calibration method provides feasible and suitable information to ensure traceable dynamic measurements on catchweighers and can help to monitor, control and improve weighing processes.

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