MSL Technical Guide 12

Assuring the Quality of Weighing Results

Introduction

The weighing results from electronic balances and other weighing devices are often of critical importance. They may determine the acceptability of a product or the outcome of a test. Hence it is important to have procedures for assuring the quality of these weighing results.

In this technical guide we discuss the key factors that affect weighing accuracy and we present in-service checks that can be used to monitor the performance of a balance. While this guide focuses on electronic balances, the principles also apply to other weighing devices.

This guide assumes that you already have an appropriate balance, set up on a suitably sturdy weighing bench in a suitable clean environment at a steady temperature. See [1] for more detail on factors that can degrade the weighing performance of a balance.

Balance Characteristics

Electronic balances can be remarkably precise. The resolution of relatively inexpensive laboratory balances can be less than one-millionth of the maximum load. However, electronic balance readings can be in error by up to about 0.1 % without careful attention to factors such as scale adjustment, scale non-linearity, load centering on the pan and repeatability.

Electronic balances measure force. This means that the scale of an electronic balance is sensitive to the local value for gravity, which can vary by 0.1 % depending on where you are in New Zealand [2].

The scale of an electronic balance is also sensitive to variations in temperature typically amounting to about 0.002% (that is about 2 mg at 100 g).

Most modern balances have an automatic scale adjustment feature called Cal-Mode or Cal function or equivalent. When this feature is activated, the balance uses an in-built weight (or weights) to adjust its scale so that it correctly measures the mass of objects with a density of about 8000 kg/m^3.

Regular scale factor adjustment is important for assuring the quality of weighing results. As a guide, it is good practice to adjust the scale factor each day that the balance is used. You can assess how frequently the scale factor needs adjusting by periodically checking the balance accuracy without adjusting the scale factor. Note that some balances automatically re-adjust the scale factor if the balance temperature changes significantly.

Balance Calibration

The first requirement in assuring the quality of weighing results is regular calibration of your balance. For more details about balance calibration, see MSL Technical Guide 25 [2]. Normally this calibration will be performed by a balance calibration agent who is accredited by International Accreditation New Zealand (or equivalent) to ISO/IEC 17025.

Prior to calibration, the agent will usually service the balance and set it up at your location so that it complies with the manufacturer's specifications. This setup includes adjusting the balance scale factor.

An example of a balance calibration certificate is given in Figure 1 below. Balance calibration is discussed in detail in [2]. Normally a balance is calibrated at about 5 to 10 loads across its range. During a balance calibration, the parameters determined include; the repeatability near full capacity, corrections for scale linearity errors and the associated expanded uncertainties [3], best accuracy for different loads, and pan position errors.

Ballance & Waite Ltd.

Gracefield Rd PO Box 31-310 Lower Hutt   Tel: (04) 9313 536

ELECTRONIC BALANCE CALIBRATION CERTIFICATE

Customer: I. N. Hope Ltd	Address: 1 Nowhere Place, Erehwon
Balance Type: Electronic Analytical	Maximum Capacity: 200 g
Model No: XX200	Scale Range(s): 0 g to 200 g
Serial No: 1111	Resolution: 0.0001 g

Balance Calibrated at: Mass Laboratory at above address
Date of Calibration: 17 March 2017
Temperature at time of calibration: 20.4 ºC to 20.6 ºC

REPEATABILITY

Standard deviation (SD) of 10 repeat readings: 0.00012 g
Worst case repeatability error in any single reading: 0.00027 g
(greater of 2.26 x SD or resolution)

LINEARITY& BEST ACCURACY

The following table gives the measured correction (standard mass value - balance reading), the associated expanded uncertainty (for a 95 % level of confidence with a coverage factor of 2.2) and the best accuracy for different load ranges.

Nominal Load /g	Correction /g	Expanded uncertainty /g	Load range	Best Accuracy /g
50	0.00000	0.00013	0 - 50 g	0.00013
100	0.00001	0.00016	>50 g - 100 g	0.00017
150	0.00014	0.00021	>100 g - 150 g	0.00035
200	0.00041	0.00027	>150 g - 200 g	0.00068

The balance has been calibrated using weights of known mass and density, following MSL Technical Guide 25 v 5. The results are on the basis of weighings in air of density 1.2 kg/m^3.

PAN POSITION ERROR (to be taken into account if appropriate)

Maximum Error in reading due to off-centre loading of pan: 0.2 mg
Measured using a mass of 50 g at 25 mm from the centre of the pan.

COMMENTS ON BALANCE CONDITION AND LOCATION

In good condition. Located on a sturdy bench away from drafts.
Certificate No: BW/2017/0001   Dated: 17 March 2017
Signatory: *M. E. Trologist*   Checked: *A. U. Ditor*
The measurement results in this certificate are traceable to the national measurement standards of New Zealand.
This document shall not be reproduced except in full.

Figure 1. Balance calibration certificate.

The balance calibration certificate usually gives the best accuracy of the balance and how this varies with load. This best accuracy can be used as an estimate of the expanded uncertainty to associate with a single weighing on the balance. If the best accuracy is not given in the calibration certificate, it can be estimated for different loads as the sum of the expanded uncertainty in the correction and the measured correction (ignoring the sign).

In-Service Checks

The second requirement in assuring the quality of weighing results is in-service checks between calibrations. These checks are used to confirm that the balance is performing with the required accuracy and to identify any degradation in performance that might warrant action (such as servicing and re-calibration). The history of in-service checks can also be used to determine the re-calibration interval (up to a recommended maximum of three years).

As a minimum, we recommend:

- a repeatability check every six months at or near full load and near the most commonly used load, and
- an accuracy check every month at or near full load (or at several loads over the commonly used range, if the balance is used to its best accuracy).

The reference values for these checks are usually established (or re-confirmed) directly after the balance has been calibrated.

Both the repeatability and accuracy checks are performed using calibrated standard weights (see the section on check weights below). This is necessary to ensure that any changes in repeatability and accuracy that are apparent from the in-service checks are due to the balance and not to the check weights.

Other in-service checks may be necessary in some cases. For example, you may need to periodically check the pan position error if you are weighing samples that are hard to centre on the pan.

1. Repeatability check.

Repeatability is a measure of the random variations in a balance reading. The standard uncertainty u_R due to repeatability is normally evaluated as the sample standard deviation of the balance readings for n successive loadings of the same weight. That is

$$u_R = \sqrt{\sum_{i=1}^{n}(r_i - \bar{r})^2 \Big/ (n-1)} \qquad (1)$$

where r_i is the i^{th} balance reading, and $\bar{r}$ is the average of the n balance readings. The Excel function STDEV can be used to calculate u_R.

Normally 10 balance readings are recorded (that is, $n = 10$) with the weight un-loaded and loaded between each reading. The method used to record each reading should follow your normal weighing procedure. For example, if you normally tare the balance before each loading of the balance then tare the balance before each of the repeatability loadings.

2. Accuracy check.

The accuracy check should be performed following any normal setup procedure for the balance. For example, if you normally adjust the scale factor before using the balance, then do this before the accuracy check.

If you use your balance to an accuracy of about 0.001% or better then you must check the scale factor (and adjust it if necessary) before each weighing, or batch of weighings. The accuracy check normally consists of recording a single reading Q with a calibrated check weight, using your normal weighing procedure.

Acceptance Criteria

Acceptance criteria are defined here for each in-service check, along with the action that will be taken if these criteria are not met. The acceptance criteria are normally based on the performance of the balance directly after servicing and calibration (essentially on the manufacturer's specifications).

1. Repeatability criterion.

A reference value for the repeatability $u_{R(ref)}$ is measured directly after a calibration of the balance. For $u_{R(ref)}$, use the greater of the measured repeatability and $0.41a$ (the standard uncertainty due to the balance resolution a, see Section 6 in [2]). Each subsequent in-service check measurement of repeatability $u_{R(new)}$ is then compared with $u_{R(ref)}$. Here we use an F-test [4] which gives the acceptance criterion as

$$u_{R(new)} \le \sqrt{F}\ u_{R(ref)}. \qquad (2)$$

For example, when each repeatability value is determined from 10 readings and the F-test is based on a 5% probability, the criterion becomes

$$u_{R(new)} \le 1.8\, u_{R(ref)}. \qquad (3)$$

That is, the in-service repeatability check value must be no more than 1.8 times the reference value. If criterion (3) is met, you can be reasonably confident that the value of $u_{R(new)}$ does not indicate any deterioration in the performance of the balance.

If criterion (3) is not met, then there may be some deterioration in balance performance. In this case, re-measure the repeatability because there is a 5 % chance that this criterion will not be met when the balance is performing normally (and vice versa). If the new repeatability value also doesn't meet the criterion, then it is highly probable that there is a problem. An environmental factor (such as temperature changes, vibration, or drafts) may have degraded the repeatability or the balance may need servicing.

2. Accuracy criterion.

A reference value Q_{ref} for the accuracy check is determined directly after a calibration of the balance by taking the average of q readings. Each subsequent in-service accuracy check value Q (a single reading) is then compared with Q_{ref}. The acceptance criterion is a t-test [4], that is

$$|Q - Q_{ref}| \le t\sqrt{1 + \frac{1}{q}}\ u_{R(ref)}. \qquad (4)$$

For example, for $q = 10$ and a t-test based on a 5% probability, this criterion is

$$|Q - Q_{ref}| \le 2.4\, u_{R(ref)}. \qquad (5)$$

That is, the in-service accuracy check value must differ from the reference value by no more than 2.4 times the reference value for repeatability at that load.

If criterion (5) is not met, it is likely that something is wrong. If a repeat check does not meet the criterion, then start looking for a problem. Confirm that the balance was properly set up, that you are using the correct check weight, that the accuracy check was performed using the right procedure, that the environment has not changed and that the balance repeatability is still acceptable. At this point it may be necessary to have the balance serviced.

3. *Less stringent criteria.*

Less stringent criteria can be used when you are not using the balance to its best accuracy.

One option is to require more certainty that there has been a change in the balance performance by increasing the acceptance criteria values. For example, you may choose to set the criteria so that the chance of a failed test when the balance performance has not degraded is smaller than 5 %. For the repeatability criterion, the constant in (3) is 1.8, 2.3 and 3.2 for 5 %, 1 % and 0.1 % F-tests respectively. For the accuracy criterion with q = 10, the constant in (5) is 2.4, 3.4 and 5.0 for 5 %, 1 % and 0.1 % t-tests respectively. See reference [4] for other values of F and t.

Another option is to set the acceptance criteria according to the accuracy that you require. Suppose that you must meet regulatory requirements that specify an expanded uncertainty of 0.1 %. This corresponds to an expanded uncertainty of 0.01 g for 10 g samples. The balance available for the measurement has a best accuracy at 10 g of 0.0002 g. The purpose of the accuracy check in this case is to provide assurance that the balance is still able to meet the regulatory requirement. Here, you could simply allow a safety factor of 3 and use

$$|Q - Q_{ref}| \le 0.01\ \mathrm{g}/3 = 0.003\ \mathrm{g}. \qquad (6)$$

as the acceptance criterion for an accuracy check at 10 g. You will need a repeatability check to go with this accuracy check. Since the purpose of the repeatability check is to identify any degradation in the balance performance, the repeatability check should follow criterion (2) but perhaps with an F-test based on a 0.1 % probability.

Control Charts

It is a good idea to record the results of in-service checks on a control chart, along with the acceptance limit or limits, as this provides a good visual indication of balance performance and can reveal any shifts or trends in the data. An example is given in Figure 2 which shows a control chart for balance repeatability checks. In this case the repeatability never exceeded the limit.

Check Weights

As mentioned, the weights used for the in-service checks must be suitable for the purpose. A useful specification for standard weights is OIML R111-1 [5], which describes the characteristics that must be met for weights in each of nine different accuracy classes. These characteristics include; density, shape, construction, magnetism, material and surface finish. Standard weights that comply with the requirements of OIML R111-1 are available commercially.

Each check weight must be calibrated periodically by an accredited calibration laboratory to an uncertainty no greater than one-third of the uncertainty required of the balance. Also, the mass value of each check weight must change by less than this amount between successive calibrations.

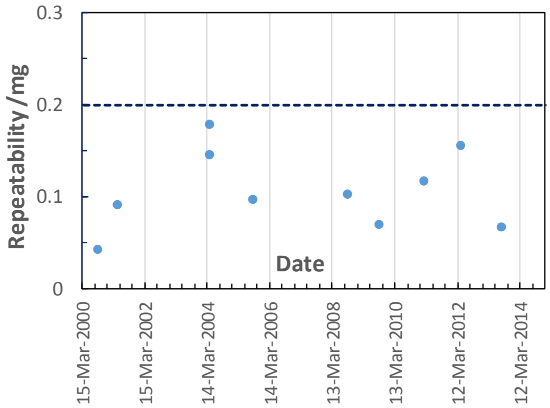

Figure 2. Control chart for balance repeatability. The acceptance limit is shown by the dashed line.

A control chart may be used to show any trends in the mass value of the check weight and to determine the re-calibration interval (typically three to five years).

Check weights must be treated with care if they are to remain stable in mass value. Don't let them get dirty. Avoid exposing them to extremes of temperature (moisture will condense on cold weights brought into a warmer place and can oxidise any lead adjustment plug). Keep check weights away from strong magnets. Lift and place weights, don't slide them. Be wary of weights of unknown specification and home-made weights – they may be too magnetic [6].

References and Bibliography

[1] C M Sutton, M T Clarkson and G F Reid, 2016, *Balances and Weighing Workshop Notes*, (Lower Hutt: MSL, IRL).

[2] C M Sutton and G F Reid, 2017, Calibrating Balances, MSL Technical Guide 25, www.measurement.govt.nz, Training and Resources, Technical Guides.

[3] JCGM 100:2008 *Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement*, available on the BIPM website at http://www.bipm.org/en/publications under Guides in Metrology.

[4] Appendix G of Morris E C and Fen K M T, 2002, *The Calibration of Weights and Balances*, Monograph 4: NML Technology Transfer Series, 2nd ed., (Sydney: CSIRO). See also the Excel functions FINV and TINV.

[5] OIML R 111-1: 2004, *Weights of classes E_1, E_2, F_1, F_2, M_1, M_{1-2}, M_2, M_{2-3} and M_3, Part 1: Metrological and technical requirements*, Organisation Internationale de Métrologie Légale.

[6] C M Sutton, 2004, *Magnetic Effects in Weighing*, MSL Technical Guide 6, www.measurement.govt.nz, Training and Resources, Technical Guides.

Further Information

If you want to know more about balances and weighing, contact MSL and book in for a Balances and Weighing Training Workshop. See the MSL website www.measurement.govt.nz.

Prepared by C M Sutton, G F Reid and M T Clarkson

Version 5, June 2017.