

Introduction

The weighing results from electronic balances and other weighing devices are often of critical importance. For example 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, non-linearity, pan position error and repeatability.

The scale of a balance itself is usually not perfectly linear. For example, the balance may read correctly at full load but may have small errors at other loads.

Also, the reading of an electronic balance may vary with the position of the weight on the pan. Reference [2] explains how to estimate the uncertainty due to pan position error. In most cases, this uncertainty can be made negligible by ensuring that the object being weighed is sufficiently centred on the pan.

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, with a sensitivity typically in the range from 1 ppm/°C to 5 ppm/°C (ppm is parts per million). For example, if a balance with a sensitivity drift of 4 ppm/°C experiences a temperature change of 5 °C since the last scale factor adjustment, the balance reading will change by 20 ppm. That is 2 mg or 0.002 % at 100 g.

For most electronic balances, the scale can be adjusted to compensate for local gravity, for drift in the electronics, and for variations in temperature. Most balances now 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 the scale of the balance. Some balances require an external weight to be loaded by the operator. The balance scale factor is adjusted so that the balance correctly measures the mass of objects with a density of about 8000 kg/m³.

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 (see below) without adjusting the scale factor. 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. 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 to comply with the manufacturer's specifications at your location. This setup includes adjusting the scale factor.

During a balance calibration, the parameters measured include the repeatability near full capacity, linearity (or scale) errors, and pan position errors. The calibration certificate for the balance gives values for the repeatability, the maximum pan position error, linearity errors (or corrections to the balance reading), uncertainty in the linearity errors, and the best accuracy (or limit of performance) of the balance [2].

The best accuracy and linearity corrections are usually presented in the calibration certificate as a function of load as shown in Figure 1.

Capacity: 200 g

Resolution: 0.0001 g

Repeatability:

Standard Deviation of 10 repeat readings at 200 g: 0.000 12 g

Linearity & Best Accuracy of Balance:

Nominal Load	Correction	Expanded Uncertainty	Best Accuracy
50 g	0.000 03 g	0.000 22 g	0.000 25 g
100 g	0.000 04 g	0.000 25 g	0.000 29 g
150 g	0.000 27 g	0.000 31 g	0.000 58 g
200 g	0.000 28 g	0.000 40 g	0.000 68 g

Pan Position Error

Maximum Error in reading due to off-centre loading: 0.000 1 g
Measured using a 50 g mass, 25 mm from the centre of the pan.

Figure 1: Part of a balance calibration certificate

Best accuracy includes resolution, repeatability, measured linearity error and uncertainties in the standard weights used in the calibration. You can use the best accuracy values to check that the balance meets your accuracy requirements.

For a weighing that consists of a single loading of the balance, you can use the best accuracy as the expanded uncertainty [3] in the weighing result. The best accuracy value may be interpolated from the results in the calibration certificate. If you require linearity corrections and they are not given in the calibration certificate, then contact your calibration agent who will be able to provide them.

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

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

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. Remember that 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 $u_{R(\text{ref})}$ is measured directly after a calibration of the balance. For $u_{R(\text{ref})}$, use the greater of the measured repeatability and $0.41a$ (the standard uncertainty due to the balance resolution a , see 6.1 in [2]). Each subsequent in-service check measurement of repeatability $u_{R(\text{new})}$ is then compared with $u_{R(\text{ref})}$. Here we use an F -test [4] which gives the acceptance criterion as

$$u_{R(\text{new})} \leq \sqrt{F} u_{R(\text{ref})}. \quad (2)$$

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

$$u_{R(\text{new})} \leq 1.8 u_{R(\text{ref})}. \quad (3)$$

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 $u_{R(\text{new})}$ 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

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

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

$$|Q - Q_{ref}| \leq 2.4 u_{R(ref)}. \quad (5)$$

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. This will increase 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 which specify an expanded uncertainty of 0.1%. For example, this corresponds to an expanded uncertainty of 0.01 g for the 10 g samples that you weigh. 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 three and use

$$|Q - Q_{ref}| \leq 0.003 \text{ g}. \quad (6)$$

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 each in-service check on a control chart, along with the acceptance limit or limits. A control chart 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 did exceed the acceptance limit. This was confirmed by two further measurements of the repeatability. After servicing and re-calibration, the repeatability returned to normal.

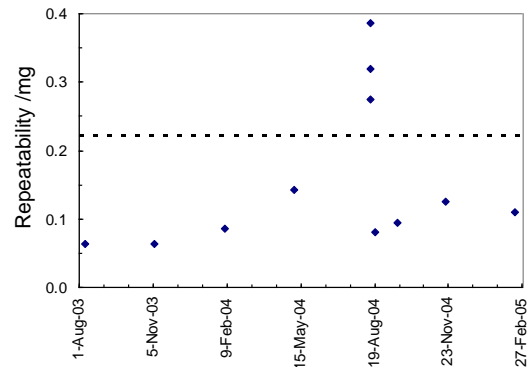


Figure 2: Control chart for balance repeatability. The acceptance limit is shown by the dashed line.

Check Weights

As mentioned, the weights used for the in-service checks must be suitable for the purpose. The most common 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. A control chart is used to show any trends in the mass value 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, J E Robinson, M T Clarkson and G F Reid, 2012, *Balances and Weighing Workshop Notes*, (Lower Hutt: MSL, IRL).
- [2] C M Sutton, J E Robinson and G F Reid, 2012, *Calibrating Balances*, MSL Technical Guide 25, <http://msl.irl.cri.nz/training-and-resources>.
- [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, <http://msl.irl.cri.nz/training-and-resources>.

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 <http://msl.irl.cri.nz/>.

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