MSL Technical Guide 25

Calibrating Balances

Introduction

Regular calibration and servicing are essential for ensuring that a balance (or other weighing device) performs within its specifications. Calibration and servicing, along with in-service checks, are key requirements for reliable weighing results. In-service checks and other aspects of assuring the quality of weighing results are covered in a separate technical guide [1].

A method for calibrating balances is described in this technical guide. It includes pre-calibration steps, the measurements to be recorded and their analysis, the evaluation of measurement uncertainties and the reporting of results. This method, which is taught in the MSL Balances & Weighing workshop, focuses on electronic top-loading balances but applies to almost all weighing devices. One exception is older-style mechanical balances with in-built dial weights, which require additional measurements (see Chapter 7 of [2]).

This technical guide is intended for balance users and laboratory managers who are responsible for ensuring that balances are regularly calibrated and for balance calibration and servicing agents who are in the business of calibrating balances. It is also intended for balance users in general to give them a better understanding of the purpose and significance of a balance calibration.

Calibrating Balances - overview

Balances are calibrated to establish the accuracy with which they can be used to measure mass and (usually) to confirm that they are performing to the manufacturer's specifications. The key parameters determined in a balance calibration are repeatability of reading, pan position error, scale linearity and best accuracy. These are defined in subsequent sections.

A balance shall be calibrated when first commissioned, after servicing, and at regular intervals but no more than three years apart. Regular in-service checks, such as those suggested in [1], may be used to determine the re-calibration interval or to identify any degradation in balance performance that warrants action (such as servicing and re-calibration).

Balances should be calibrated in their installed position for two main reasons; one, moving a balance may change the balance characteristics, and two, electronic balances respond to force and hence the balance reading depends on the value for local gravity. As Figure 1 shows, local gravity in New Zealand varies by 0.1 % from 9.808 N/kg in Bluff to 9.798 N/kg in Kaitaia.

The exception is weighing devices that are designed to be portable and that have a best accuracy value ≥ 0.1 % of reading. These weighing devices may be used up to about 500 km from the site of calibration. This limit is set by variations in local gravity.

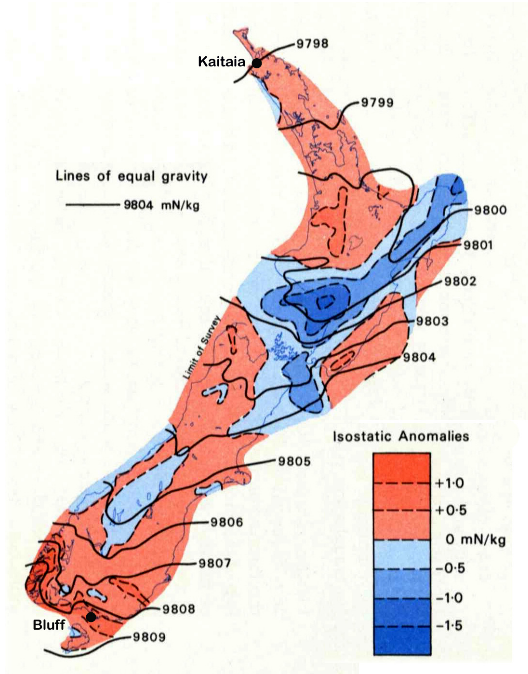

Figure 1. Variation in local gravity in New Zealand.

Normally balance calibrations will be performed by a balance calibration agent who is accredited to ISO/IEC 17025 *General requirements for the competence of testing and calibration laboratories* by International Accreditation New Zealand (or equivalent) for this purpose. If you wish to perform balance calibrations for internal use as part of your laboratory accreditation, then contact your accreditation body for their requirements.

Equipment and Standard Weights

Balances are calibrated using standard weights with a density of about 8000 kg/m^3. Suitable weights are described in OIML R111-1 [3], which gives the characteristics that must be met for weights in each of nine different accuracy classes. The standard weights shall be calibrated periodically by a laboratory accredited for mass calibration and with measurement traceability directly or indirectly to MSL. Alternatively, this traceability may be to another National Metrology Institute with suitable calibration and measurement capabilities (CMCs) in the CIPM MRA [4].

A thermometer with a calibrated accuracy of about 0.2 °C is used to measure the ambient temperature during the balance calibration as the sensitivity of a balance depends to some extent on temperature.

Calibrating Balances – step by step

The following sequence of steps is performed for a balance calibration. For dual range balances, perform separate calibration measurements for each range.

1. Talk to the client

Talk to the client or the person responsible for the balance to be calibrated to see if they have any special requirements. Normally a calibration at four loads across the weighing range (excluding zero) is sufficient. However the client may wish to have measurements at other loads on the scale.

Ask the client if they normally tare the balance before a weighing (recommended) or not. Follow the client's practice for the balance calibration.

Ask the client if they regularly adjust the scale factor of the balance before use. Most balances have a scale factor 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 factor of the balance to read correctly when weighing objects of density 8000 kg/m^3 in air of density 1.2 kg/m^3. Some balances require an external weight to be loaded by the operator for the scale factor adjustment.

The scale factor adjustment compensates for local gravity (as discussed earlier), for drift in the electronics and, most importantly, for variations in temperature. For electronic balances, the sensitivity of the scale factor to temperature is typically in the range 1 ppm/°C to 5 ppm/°C (ppm is parts per million) and its value is usually given in the specifications of the balance. For example, if the sensitivity to temperature is 4 ppm/°C and the balance temperature changes by 5 °C then the balance reading will change by 20 ppm or 2 mg at 100 g. To put this in context, some accredited balance calibration agents can calibrate balances with a least uncertainty of one-tenth of this and 2 mg is twenty times the resolution for a typical 200 g balance.

2. Prepare for the calibration

Prior to calibrating a balance:

- Check that the balance is in a fit state to be calibrated. Inspect its condition and location. Make a note of anything that might be affecting its performance (such as drafts, lack of cleanliness, or a poor balance table).
- Make sure that the balance has been switched on for an appropriate amount of time (at least an hour and preferably overnight). Advise the client in advance.
- Place the standard weights to be used for the calibration in the balance chamber or near the balance (Figure 2) and leave them for sufficient time to reach thermal equilibrium. <u>This may mean putting the weights near or in the balance chamber the balance the day before the calibration.</u> See Table B.2 in OIML R111-1 [3] for guidance on thermal stabilization times. For example, a 100 g weight that is 5 °C colder than the balance requires 4 hours to warm up if it is to be used for a balance calibration with a least uncertainty of 2 ppm.
- Place the thermometer near the balance for measuring the ambient temperature.
- Record the details of the balance in the worksheet or calibration software including location, model and serial number, scale range (or ranges), resolution (for each range of a dual range balance) and temperature sensitivity coefficient (from the balance manual).

Figure 2. Setup for balance calibration, showing pan position error measurement.

- Obtain a unique identification number for the calibration, such as a certificate or job number, and record it in the worksheets or calibration software.

3. Perform as-found measurements

- If the client regularly adjusts the scale factor, then adjust it now. Do not make any other adjustments at this stage.
- Perform a repeatability measurement at close to full capacity as follows. Record the balance reading for 10 successive loadings of the balance with the same weight, removing the load between each reading. A single standard weight is recommended for the repeatability measurement. Repeatability is a measure of short-term random variations in a balance reading and should be determined using the same procedure as that for normal weighings. That is, if the client normally tares the balance before each weighing, then tare the balance before each loading in the repeatability measurement. Also, record each reading as soon as the balance indicates that the reading is stable (unless you have a good reason to do otherwise).
- Calculate the repeatability as the standard deviation σ_R of the 10 balance readings. This is also the standard uncertainty u_R due to repeatability. That is

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

where r_i is the i^{th} balance reading, $\bar{r}$ is the mean of the n balance readings and $n = 10$. The Excel function STDEV can be used to calculate u_R.

- Calculate the error in the balance reading for this load as the average balance reading $\bar{r}$ minus the known mass of the weight (or group of weights) from their calibration certificate.
- If desired, perform and evaluate a second repeatability measurement at half capacity.
- It may also be useful to perform a pan position error measurement as explained in Section 5.1.

4. Adjust or service if necessary

If any of the as-found measurements do not meet the balance specifications, then inform the client and check if any additional as-found measurements are required. The client may need to assess the consequences for weighing results previously recorded with the balance.

- Perform and record any additional as-found measurements requested by the client.
- If necessary, with the client's permission, arrange for the balance to be serviced and adjusted (or service and adjust the balance if this is a normal part of your business).

At this point, all the preparation for the balance calibration has been completed (following steps 1 to 4 above), any deficiencies identified in the as-found measurements have been corrected and you expect the balance to perform to specification. You are now ready to perform the calibration.

5. Perform the calibration measurements

Check that the balance is level. If the client regularly adjusts the scale factor, then adjust it again now. Note these actions in the worksheet.

5.1 Measure the pan position error of the balance

Pan position error (or corner load error) is determined by placing a weight of approximately one-third of the capacity of the balance at positions centre – rear – left – front – right – centre in sequence. This sequence, which allows monitoring of any drift in the balance zero, is shown in Figure 3 for circular and square pans.

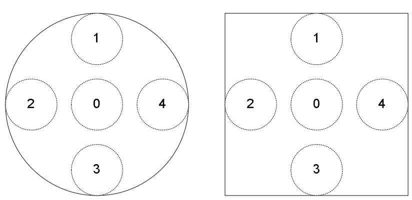

Figure 3. Weighing positions and sequence for pan position error measurement on a circular and a square pan.

Before starting the pan position error measurements, zero the balance with no load. Don't tare the balance before or during the pan position error measurements. Use a single weight whenever possible and position it off-centre with the outer edge of the weight near the edge or the lip of the pan as shown in Figure 2.

To perform a pan position error measurement:

- Perform the sequence of six pan position error measurements and record the results in the worksheet (Figure 4).

Position	Reading /g	Reading - Av. Centre /g
0 (centre)	49.999 9	
1	49.999 9	-0.000 1
2	50.000 2	0.000 2
3	50.000 1	0.000 1
4	50.000 0	0.000 0
0 (centre)	50.000 1	
	Average reading at centre =	50.000 0
	Pan position error =	0.0002 g
	Nominal mass of weight =	50 g
	Off-centre distance =	25 mm

Figure 4. Worksheet for pan position error measurement.

- Subtract the average of the two centre readings from each of the off-centre readings. Ignoring minus signs, take the largest of these differences as the pan position error.
- Record the nominal mass value of the weight used and the off-centre distance (pan centre to weight centre). The pan position error should be no more than about three times the balance resolution.

5.2 Measure the hysteresis of the balance

The purpose of this measurement is to check if the balance reading for a particular weight depends on whether the load was increased or decreased to reach this value; any difference is hysteresis. In practice, electronic balances do not exhibit hysteresis unless there is a problem such as dirt in the weighing cell. This will normally degrade the repeatability as well. To perform a hysteresis measurement:

- With no weights on the pan, zero the balance and record the zero reading r_{Z1}.
- Put a weight (or weights) on the pan to obtain a reading close to half-scale, and record the first half-scale reading r_{H1}.
- Without removing these weights from the pan, add additional weights to bring the reading to near full-scale and remove them immediately (Figure 5). Don't stack the weights!
- Record the second half-scale reading r_{H2}.
- Remove all weights from the pan and record the zero reading r_{Z2}.
- Calculate the hysteresis as $(r_{H2} - r_{H1}) - (r_{Z2} - r_{Z1})/3$.
  If the hysteresis is greater than or equal to the balance resolution, the balance may need servicing.

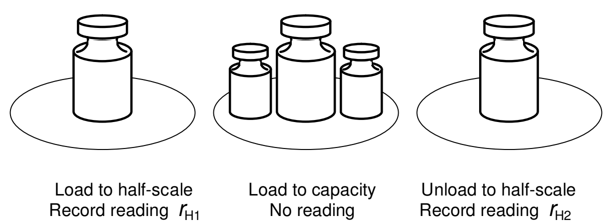

Figure 5. Illustration of a hysteresis measurement.

5.3 Measure the repeatability of the balance

Using the method described in Section 3, perform a repeatability measurement at close to full capacity. Calculate the standard deviation σ_R of the 10 balance readings from (1).

If desired, perform further repeatability measurements at other loads across the scale range. If repeatability measurements are to be recorded at several loads, an option is to combine the repeatability and linearity measurements, using the average balance readings to calculate the linearity errors.

5.4 Measure the linearity of the balance

In this measurement, which is the key part of a balance calibration, standard weights with known mass values are used to determine the error in the balance reading at several different loads. Normally a minimum of five measurements are performed at loads spread equally from zero to approximately full scale. For example, for a 205 g capacity balance, the loads would be 0 g, 50 g, 100 g, 150 g and 200 g. However, the client may request measurements at particular loads and other loads may be added to better characterise regions where linearity errors are largest or where the balance is most commonly used.

Perform linearity measurements as follows:

- If the client regularly adjusts the scale factor, then adjust it again now.
- Record the ambient temperature. The temperature is measured at this time because the linearity measurement is the only part of a balance calibration that is affected by temperature.
- Record the balance reading for each load in turn, following the advice in Section 3 on taring the balance and recording the reading. Centre each load on the pan so that the pan position error is not significant (see Section 6.6).
- Record the ambient temperature again.
- For each load, enter the weight identifiers and the total mass of the weight(s) used into the worksheet, taking the mass values from the calibration report(s) for the weights. Calculate the difference between the balance reading and the mass value. This difference is the linearity error (Figure 6).

Weight Identifiers	Standard Mass /g	Balance Reading /g	Linearity Error = Reading - Mass
50·	50.000 127	50.000 1	-0.000 03
100·	100.000 142	100.000 1	-0.000 04
100· + 50·	150.000 269	150.000 0	-0.000 27
200·	200.000 179	199.999 9	-0.000 28

Figure 6. Worksheet table for linearity measurements.

At this point, all the measurements for the balance calibration have been recorded and values have been calculated for pan position error, hysteresis, repeatability, and linearity. The next step is to evaluate the measurement uncertainties and best accuracy of the balance.

6. Evaluate the measurement uncertainties

The influences to take into account in evaluating the measurement uncertainty are balance resolution, balance repeatability, calibration of the standard weights, instability in the standard weights, pan position error and temperature.

6.1 Balance resolution

The resolution of a balance is the smallest increment in the scale reading. Usually this is 1 in the last displayed digit. The standard uncertainty due to balance resolution a is $u_{RS} = 0.41a$ with infinite degrees of freedom ($\nu = \infty$) and a coverage factor $k = 2.0$ from Table G.2 in [5]. This value is the uncertainty in the difference between a balance reading with a load and a zero reading, each of which has a standard uncertainty due to resolution of $0.29a$ (from F.2.2.1 in [5]). In practice, u_{RS} may be rounded up to

$$u_{RS} = 0.5\,a\,. \tag{2}$$

6.2 Balance repeatability

The standard uncertainty due to repeatability is given by (1) in Section 3 above. For 10 loadings, the degrees of freedom $\nu = 9$ and coverage factor $k = 2.26$.

Calculate the worst case repeatability for the balance in the form of an expanded uncertainty as $2.26\sigma_R$ or the resolution of the balance, whichever is greater (Figure 7). For σ_R, use the largest of the measured repeatability values.

Load:	50 g	100 g	200 g
1	50.000 0	100.000 2	200.000 2
2	50.000 2	100.000 2	200.000 3
3	50.000 2	100.000 2	200.000 1
4	50.000 2	100.000 2	200.000 2
5	50.000 0	100.000 0	200.000 0
6	50.000 1	100.000 1	200.000 1
7	50.000 1	100.000 1	200.000 2
8	50.000 1	100.000 3	200.000 0
9	50.000 2	100.000 2	200.000 0
10	50.000 2	100.000 1	200.000 1
Mean /g =	50.000 13	100.000 16	200.000 12
Standard deviation u_R /g =	0.000 082	0.000 084	0.000 103
Worst case repeatability /g =			0.000 233

Figure 7. Analysis of repeatability measurements.

6.3 Calibration of the standard weights

Calculate u_{Mcal} for each weight (or group of weights) used in the linearity measurements using:

$$u_{Mcal} = U_{Mcal} / k \tag{3}$$

where U_{Mcal} is the expanded uncertainty in the mass value for the standard weight from the calibration certificate, normally with $k = 2.0$.

If the loading is a group of weights, then the standard uncertainties for the weights in the group are simply added together to obtain the standard uncertainty in the mass of the group. A simple sum of the uncertainties is used for the calibration uncertainty because the mass values of the weights are likely to be correlated (i.e. not independent). Interestingly, if all weights in the group have the same relative uncertainty, then the sum also has this relative uncertainty

For example, if the expanded uncertainty in the mass value (from the calibration certificate) is 7 µg for the 50 g weight and 10 µg for the 100 g weight, both with a coverage factor of 2.0, then the standard uncertainty u_{Mcal} for the linearity measurement at 150 g is:

$$u_{Mcal}(150\,\text{g}) = \frac{7\,\mu\text{g}}{2.0} + \frac{10\,\mu\text{g}}{2.0} = 8.5\,\mu\text{g}$$

6.4 Mass instability in the standard weights

Mass instability is important because it is often the major source of measurement uncertainty in a balance calibration. Before looking at the uncertainty due to mass instability, it is worth considering the reasons for mass instability and the ways of reducing it.

Mass instability is mainly caused by contamination and/or wear, so the key to mass stability is proper care and handling of the standard weights. Handle weights with clean gloves (leather, cotton or nitrile/vinyl) or a clean soft cloth. Only pick up weights of Class M_1 [3] or lower with bare hands. Don't let weights get dirty. Remove any dust with a clean, fine haired brush. If necessary, gently wipe them clean with a soft clean dry cloth or chamois. If your weights become unacceptably dirty and you want to clean them, then get them calibrated before and after cleaning to establish the loss in mass. Keep the weight box clean. Avoid exposing standard weights to extremes of temperature (moisture will condense on cold weights brought into a warmer place and can oxidise any lead adjustment plug). Keep weights away from strong magnets. Be wary of weights of unknown specification and home-made weights – they may be too magnetic [6].

There are three options for estimating the uncertainty due to mass instability.

The first option is to get the uncertainty due to mass instability from the calibration certificate. For example, mass calibration certificates from MSL include a value for the expanded uncertainty due to mass instability U_{Minst} with $k = 2$. From U_{Minst}, calculate a standard uncertainty as:

$$u_{\text{Minst}} = U_{\text{Minst}} / k . \tag{4}$$

The second option is to estimate u_{Minst} for each weight from its calibration history as:

$$u_{\text{Minst}} = \sqrt{u_{\text{Hist}}^2 - u_{\text{Mcal}}^2} \tag{5}$$

where u_{Hist} is the standard deviation of the mass values for the standard weight from the last n (3 or 4) calibrations and u_{Mcal} is the calibration uncertainty discussed above. The value for u_{Minst} calculated this way has a small number of degrees of freedom (approximately $n-1$) and a Welch-Satterthwaite calculation is required to determine the overall coverage factor (see Section 6.7).

The third and preferred option is to treat mass instability as a problem to manage rather than simply as an uncertainty value to estimate. The following process is suggested for managing mass instability and the associated measurement uncertainty:

- Decide what mass stability ΔM_{Stab} is required for each weight. That is, you require mass M to be in the range $M \pm \Delta M_{\text{Stab}}$ with a 95 % level of confidence. For example, you may require a 100 g weight with a mass stable to 1 part in 10^6. In this case, $\Delta M_{\text{Stab}} = 0.1\,\text{mg}$.
- Make sure that each of your standard weights is of sufficient quality to meet this requirement. OIML R111-1 [3] is very useful for this. It describes several different classes of weights and gives a table of maximum permissible errors (MPEs) for a range of weight values and classes. These MPEs can be used as starting values for ΔM_{Stab}.
- If possible, establish simple rules for ΔM_{Stab} that apply to all your standard weights. For example, the rule might be "ΔM_{Stab} is the Class E2 MPE" if you are calibrating Class F1 weights. Or the rule could be of the form, "ΔM_{Stab} is 2 ppm or 20 µg, whichever is greater".
- Have each standard weight calibrated with sufficient accuracy and regularity that you can ensure that the change in the mass of each weight between calibrations is less than ΔM_{Stab}. For this, you need the expanded uncertainty in each mass calibration to be $\le \Delta M_{\text{Stab}}/3$.
- Use between-calibration checks (or in-service checks) on the more frequently used weights to confirm their stability, or to identify the need for recalibration. For example, compare a 50 g weight with two 20 g and one 10 g weights (or with a 50 g weight from another weight set).
- Calculate the standard uncertainty due to mass instability u_{Minst} as

$$u_{\text{Minst}} = \Delta M_{Stab}/2 \tag{6}$$

with coverage factor $k = 2$.

For a group of weights, the standard uncertainty due to mass instability is the sum of the standard uncertainties due to mass instability for all the weights in the group. A simple sum is used because changes in mass over time may be correlated. For example, all the weights may get lighter through wear.

6.5 Temperature

The uncertainty due to temperature arises because the scale factor of a balance depends on temperature as discussed in Section 1. The standard uncertainty u_{S} due to this effect is given as:

$$u_{\text{S}} = \delta T\, s\, M \big/ \sqrt{12} = 0.29\, \delta T\, s\, M \tag{7}$$

where δT is the change in temperature since the last scale factor adjustment, s is the sensitivity coefficient from the balance manual and M is the mass value for which u_{S} is estimated. The sensitivity variation is treated as a rectangular distribution [5].

It is usually possible to make this uncertainty insignificant by adjusting the scale factor immediately prior to the linearity measurements (and even during these measurements). Consider for example, a linearity measurement at 200 g on a balance with a sensitivity drift s of 4 ppm/°C and a temperature change δT of 0.2 °C since the last scale factor adjustment. For this measurement, u_{S} is 0.046 mg or 0.2 ppm of the mass, which is negligible for a balance calibration agent accredited to calibrate balances with a least uncertainty of 2 ppm.

6.6 Pan position error

The uncertainty due to pan position error can usually be made insignificant by careful centring of the weights on the pan. Before starting the weighings in a balance calibration, particularly the linearity measurements, estimate how accurately the weights need to be centred in order to keep the pan position error less than about half the resolution. As a guide, the pan position error can be scaled by load and by distance from the centre of the pan.

For example, suppose the pan position error for a 200 g capacity balance is 0.2 mg when measured using a 50 g weight at a distance of 25 mm from the centre of the pan.

For the pan position error to be less than 0.05 mg (half resolution) during a linearity measurement at 100 g, the centre of mass of the 100 g weight must be less than a distance d from the centre of the pan, where

$$d = \left[25\,\text{mm} \times \frac{50\,\text{g}}{0.2\,\text{mg}} \right] \times \frac{0.05\,\text{mg}}{100\,\text{g}} = 3\,\text{mm} . \tag{8}$$

In general this is easily achievable for single weights and the pan position error will be negligible.

But for the linearity measurement at 150 g, following (8), the 100 g and 50 g weights must be positioned on the pan as shown in Figure 8 so that their combined centre of mass is within 2 mm of the centre of the pan. If for a particular situation you feel this is not achievable, consider instead measuring the linearity at 140 g and using two 20 g weights positioned on either side of a 100 g weight (as in the centre image of Figure 5).

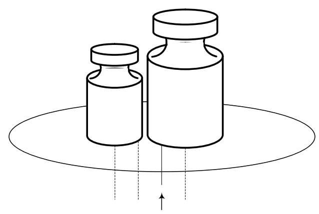

Figure 8. Centring two unequal weights. When used together, a 50 g weight is placed twice as far from the centre of the pan as a 100 g weight.

6.7 Combined uncertainty in linearity measurement

The standard uncertainty in each linearity measurement is determined by combining the component standard uncertainties from resolution, repeatability, calibration of the standard weights, mass instability of the standard weights, temperature and pan position error as follows:

$$u_C = \sqrt{u_{RS}^2 + u_R^2 + u_{Mcal}^2 + u_{Minst}^2 + u_S^2 + u_P^2}\ . \quad (9)$$

Use u_R calculated from the repeatability measurement at full capacity unless the repeatability was measured at the linearity load of interest, in which case use that u_R.

An example of this calculation is given in Figure 9 for a load of 200 g. u_{RS} is from (2) with $a = 0.1\,\text{mg}$, u_R is from Figure 7, u_{Mcal} is from (3) with $U_{Mcal} = 27\,\mu\text{g}$ and $k = 2.0$, u_{Minst} in this case is from the mass calibration certificate with $U_{Minst} = 200\,\mu\text{g}$ (1 part in 10^6) and $k = 2.0$, u_S is from Section 6.5 and the pan position error was made negligible following Section 6.6.

Nominal Load: 200 g

std uncert	value /mg	$(\text{value})^2 / (\text{mg})^2$
u_{RS}	0.05	0.002 50
u_R	0.103	0.010 61
u_{Mcal}	0.0135	0.000 18
u_{Minst}	0.1	0.010 00
u_S	0.046	0.002 12
u_P	0.0	0.000 00
	u_c^2 = sum of $(\text{value})^2$ =	0.02541 mg^2
	$U_c = 2.2 \times u_c$ =	0.351 mg

Figure 9. Calculation of combined uncertainty for the linearity measurement at 200 g.

Strictly, the repeatability uncertainty u_R includes the resolution uncertainty u_{RS} so a better value for u_C is obtained from the more complicated equation

$$u_C = \sqrt{\max\left(u_{RS}^2, u_R^2\right) + u_{Mcal}^2 + u_{Minst}^2 + u_S^2 + u_P^2} \quad (10)$$

where $\max\left(u_{RS}^2, u_R^2\right)$ means the maximum of u_{RS}^2 or u_R^2. Either equation (9) or (10) may be used.

The expanded uncertainty in each linearity measurement is $U_C = k\,u_C$. It is sufficient to use $k = 2.2$ because k is expected to lie in the range 2.0 to 2.26. The component uncertainties u_{RS}, u_{Mcal}, u_{Minst}, u_S and u_P each have a large number of degrees of freedom (corresponding to $k = 2.0$) while u_R has 9 degrees of freedom ($k = 2.26$). Alternatively, a value of k may be calculated via the Welch-Satterthwaite formula [5].

The expanded uncertainty U' to report in the calibration certificate for each load is the greater of this calculated uncertainty U_C and the least uncertainty of measurement U_{CMC} for the laboratory performing the balance calibration. That is

$$U' = \max\left(U_C, U_{CMC}\right) \quad (11)$$

Calibration laboratories accredited to ISO/IEC 17025 will have terms of accreditation specifying a CMC (Calibration and Measurement Capability) or least uncertainty of measurement U_{CMC} that a laboratory is able to quote in a calibration certificate.

6.8 Calculate best accuracy values

Best accuracy, as the name suggests, is the smallest measurement uncertainty that can be achieved for a weighing result from a single loading of the balance. Best accuracy is an expanded uncertainty [5] and assumes that the balance is still performing as it was when calibrated. For each load, it is defined as

$$\text{Best accuracy} = U' + L \quad (12)$$

where L is the absolute value of the linearity error measured for that load, and U' is from (11).

An example calculation of best accuracy is given in Figure 10 for loads of 50 g to 200 g. The best accuracy for any range is simply the largest calculated best accuracy within the range of interest. For example, from the results in Figure 10, the best accuracy for the range 1 g to 100 g is 0.29 mg.

Nominal Load /g	50	100	150	200
U_c /mg	0.220	0.247	0.311	0.351
Least Uncertainty U_{CMC} /mg	0.1	0.2	0.3	0.4
U' = greater of U_{CMC} or U_c	0.220	0.247	0.311	0.400
Magnitude of linearity error L /mg	0.027	0.042	0.269	0.279
Best Accuracy $L + U'$ /mg	0.25	0.29	0.58	0.68

Figure 10. Calculation of best accuracy.

7. Prepare the calibration certificate

A sample calibration certificate is given in Figure 11. A general guide to what to include in a balance calibration certificate is given in 5.10 of [7]. In particular, a balance calibration certificate should include:

7.1 *Balance details.*

Balance type, maximum capacity, model number, serial number, location, scale range(s) and resolution(s).

7.2 *Temperature range during the calibration.*

This can be the temperature range just for the linearity measurements.

7.3 Balance repeatability.

Report both the standard deviation of 10 readings (near full capacity) and the worst case repeatability error from Section 6.2.

7.4 Results of the linearity measurement.

Report corrections to apply to balance readings (negative of linearity error), including expanded uncertainties *U′* and the associated coverage factor(s).

7.5 Balance best accuracy or limit of performance.

Report the best accuracy for each load at which the linearity error was measured. Clearly define the best accuracy and how it depends on scale factor adjustment using words such as those given in the sample balance calibration certificate (Figure 11).

7.6 Pan position error or corner load error.

Report the nominal mass used and the off-centre distance.

7.7 Hysteresis.

Report the measured hysteresis value either under the general comments section or elsewhere. For example, Measured hysteresis: 0.0001 g. This is optional if the hysteresis is zero.

7.8 General comments on balance condition & location.

Such as given in Figure 11.

References and Bibliography

[1] C M Sutton and J E Robinson, 2012, *Assuring the Quality of Weighing Results*, MSL Technical Guide 12, version 2, http://msl.irl.cri.nz/training-and-resources/technical-guides .

[2] E C Morris and K M T Fen, 2002, *The Calibration of Weights and Balances*, Monograph 4: NML Technology Transfer Series, 2nd ed., (Sydney: CSIRO).

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

[4] Appendix C of the CIPM MRA, available on the BIPM key comparison database, http://kcdb.bipm.fr .

[5] 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.

[6] C M Sutton, 2004, *Magnetic Effects in Weighing*, MSL Technical Guide 6, http://msl.irl.cri.nz/training-and-resources/technical-guides .

[7] NZS ISO/IEC 17025:2005 *General requirements for the competence of testing and calibration laboratories* 2nd ed. (Wellington: Standards New Zealand).

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 August 2010
Temperature at time of calibration: 20.4 °C to 20.6 °C

REPEATABILITY

Standard deviation (SD) of 10 repeat readings: 0.00010 g
Worst case repeatability error in any single reading: 0.00023 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 at different loads.

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

Each best accuracy value is the measured linearity correction (ignoring the sign) plus the associated expanded uncertainty. It is calculated assuming that the scale factor is adjusted prior to use. If this is not the case, then an uncertainty component for temperature variations should be added to each best accuracy value using the temperature sensitivity coefficient from the balance manual.

The balance has been calibrated using weights of known mass and density, following MSL Technical Guide 25 v4. The results are on the basis of weighings in air of density 1.2 kg/m^3 against weights of density 8000 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.

GENERAL COMMENTS ON BALANCE CONDITION AND LOCATION

In good condition. Located on a sturdy bench away from drafts.

Certificate No: BW/2010/0001	Dated: 20 August 2010
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 11. Sample balance calibration certificate.

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/.

Prepared by C M Sutton, J E Robinson, M T Clarkson and G F Reid.
Version 4, August 2012.

MSL is New Zealand's national metrology institute, operating within Industrial Research Limited under the authority of the New Zealand Measurement Standards Act 1992.