Technical Guide

Laboratory Balances – Calibration Requirements

Second Edition July 2020

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Laboratory Balances – Calibration Requirements

AS TG 2

Second Edition July 2020

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1 Foreword

The first document published on this subject was Telarc Technical Note Number 1 in 1978. At that time the document provided information on the basic operating principles of single-pan mechanical balances. It also discussed the calibration requirements for such balances and gave details of a few simple user checks on their performance.

Following publication of the Technical Note a number of laboratories sought guidance as to how they could perform a full calibration of their own balances. No suitable text was available at that time covering this topic so, in May 1981, a revised 2nd Edition of the Technical Note was issued providing a full, step by step, calibration procedure.

By mid-1982 it was apparent that electronic balances were rapidly displacing the older style of mechanical balance. Accordingly, a further revision of the Technical Note was required to cover more fully the calibration requirements of these new instruments. The 3rd Edition of the Technical Note issued in September 1982 introduced these revisions and also introduced the concept of single-page, short-form calibration reports for balances which provide calibration information in a form that is readily understood by balance users.

In 1986 the 3rd edition of the Technical Note was replaced by Technical Guide No 2: Laboratory Balances. This Technical Guide, which constitutes a major revision, was prompted by the publication in mid-1985 of a formal text on the subject of balance calibration. This is "*Calibration of Balances*" by Dr David Prowse of the CSIRO Division of Applied Physics (National Measurement Laboratory, Australia).

Dr Prowse's publication covers all aspects of the calibration of laboratory balances and provides guidance on a number of associated topics such as buoyancy effects, uncertainties of measurement, mass calibrations, the balance and its environment and the care and handling of weights. The publication of Dr Prowse's text removed the need for these matters to be discussed in any detail in an IANZ publication.

As Dr Prowse made a valuable contribution to the earlier editions of the IANZ Technical Note and as he has used many of the same references as were used for the IANZ documents it follows that the calibration procedures described are essentially similar to those previously published by IANZ. Laboratories should have no problems, therefore, in adopting Dr Prowse's calibration procedures.

The IANZ Technical Guide thus ceased to be a "how to do it" document. Instead it concentrated on good laboratory practice with regard to balance calibration and provided general advice on various aspects of calibration procedure not otherwise covered in the CSIRO publication.

The 2002 revision of this document (AS TG 2) was a re-issue of the 1986 Technical Guide incorporating editorial changes aimed at making the publication more readable, as well as some small changes to reflect current balance calibration practice e.g. repeatability being considered to be half the readability of the balance if all ten weighings have identical values. A section on performance checking and servicing was included in Appendix 2.

2 Does the balance need calibration?

It is a general criterion for good laboratory practice that all measurements made in a testing laboratory must be traceable (where this concept is appropriate) to the New Zealand national standards of measurement or their equivalent.

As with all such criteria relating to good laboratory practice, the application of this requirement to any particular testing situation must be evaluated to ensure that a laboratory is not required to attain a standard of operation higher than is needed to achieve the reliability of results required in its particular circumstances. Accordingly, when considering a laboratory's calibration programme, the nature of the measurements that are being made, the readability and uncertainty of measurement of the instruments used, the reliability of the measuring system and the skill of the person making the measurements must all be taken into account.

If an instrument is to be used to the very limits of its performance capabilities then it will obviously be necessary for that instrument to be appropriately calibrated and for any corrections arising from that calibration to be applied to the measurements made. If, however, an instrument of high precision is used to make relatively coarse measurements then simple checks on the instrument for gross functional errors will suffice.

For example if an object is to be weighed with an uncertainty of ± 1mg using a balance that is only readable to 1mg then a full calibration of the balance will be required and corrections for linearity errors and errors in any in-built weights will have to be made. Several repeat readings will also have to be averaged in order to reduce repeatability errors to an appropriate level.

In practice few working laboratories would be prepared to undertake such a procedure. It follows, therefore, that a laboratory should not attempt to make measurements with an uncertainty of ± x using an instrument that is only readable to ± x. (See Section 5)

At the other end of the scale a balance readable to 1mg may be used to weigh an object with a required uncertainty of measurement of only ± 1g. In these circumstances a full calibration of the instrument is hardly necessary but a gross functional check would still be required to ensure that there are no gross errors present.

Such considerations must be taken into account when developing a calibration programme but safeguards must be in place to ensure that an uncalibrated balance is not then used for measurements approaching its limits of performance. For example a laboratory may have two balances readable to 1mg say. One balance may be fully calibrated whilst the second, perhaps an older model, is only subjected to gross checks as it is only used for weighing to ± 1g. Should the calibrated instrument break down there is an obvious risk that, as an interim measure, the uncalibrated balance will be used for more precise weighings. Good laboratory practice requires that control systems be put in place to ensure that this does not happen.

3 Types of errors found in balances

The overall error in a balance reading is a combination of individual errors arising from various aspects of the balance's operational characteristics and the manner in which it is used. These component errors include:

(i) Repeatability of the balance mechanism (due to "stiction")

(ii) Non-linearities in the balance's response

(iii) Errors in in-built weights or external calibration weights

(iv) Errors due to off-centre loading of the balance

(v) Errors induced by the environment: temperature, humidity, vibration, dust, fumes, air movement, magnetic interference, electromagnetic interference etc.

(vi) Operator errors

Items (i) to (iv) can be evaluated and quantified by a full calibration of a balance. Items (v) and (vi) do not relate to the instrument itself and so they cannot easily be quantified. Nevertheless, if a balance is calibrated in its normal operating environment then environmental effects will manifest themselves in the balance's performance during calibration.

The main component errors with which we are concerned, therefore, are as follows:

3.1 Repeatability Errors

If the same object is weighed a number of times by the same operator using the same balance within a reasonably short period of time the readings obtained will be randomly dispersed around an average value. This dispersion (which will usually be normally distributed) arises from a variety of factors such as minor random changes in the environment, in operator procedure and "stiction" in the instrument's mechanism. The inability of a balance to precisely repeat a reading results in an error referred to as the repeatability error.

Repeatability error is measured by making a number of repeat readings and calculating the resulting standard deviation "S". The value of "S" then gives an indication of the magnitude of the repeatability error.

If just a single weighing of an object is made (and this is by far the most usual practice in most laboratories) then the worst-case magnitude of the repeatability error in that weighing is ± 3S.

If such a large potential error in a single weighing is unacceptable then a number (n) of repeat weighings can be made and the average taken. In these circumstances the worst-case magnitude of the repeatability error becomes $3S/n^{1/2}$.

For example a balance readable to 1 mg may exhibit a standard deviation of 1 mg. Worst-case errors then become as follows:

No. of weighings averaged	Worst-case potential repeatability error
1	3.0 mg
2	2.1 mg
3	1.7 mg
4	1.5 mg
etc	etc
9	1.0 mg

With such a balance, therefore, at least 9 readings would have to be averaged in order to reduce the worst-case potential repeatability error to the value of the instrument's readability. Not many Laboratories would be willing to go to such lengths. They may prefer to purchase a balance with a lower readability (0.1mg) instead.

Some electronic balances, when subjected to a repeatability test, may repeat the same reading every time leading to the calculation of a standard deviation of zero. It is wrong, however, to presume that the balance exhibits no repeatability error. Allowance must be made for the fact that the balance will be internally rounding its readings and there are hidden potential errors in each reading of up to half the last digit.

A more realistic approach with electronic balances is to regard the standard deviation as being the actual measured value or one half of the readability (last digit) of the balance, whichever is the greater.

3.2 Linearity Errors

No measuring instrument exhibits a perfectly linear response. Non-linearities arise from a number of factors. In an opto-mechanical balance wear on knife edges is a major cause. In electronic balances non-linearities in the response on electronic components, magnets and mechanical linkages will affect the overall linearity of the instrument.

If a balance user wishes to use an instrument to the limits of its readability then corrections for linearity errors must be applied. A full calibration report must be obtained and this must include a table of balance readings and associated corrections. (See Sections 5.10.8 and 6.11.7 CSIRO publication).

Other balance users may be satisfied with a single worst-case linearity error figure. They will then know that at no point on the scale does the linearity error exceed that figure.

3.3 In-Built Weights and Calibration Weights

Most opto-mechanical balances incorporate an array of in-built substitution weights to extend the instrument's weighing capacity beyond the optical scale range. Errors in the true value of these weights will manifest themselves as errors in balance readings. A full calibration procedure will provide the balance user with a list of corrections to the values of in-built weights or, more usefully, corrections to individual dial settings. These corrections must be applied if the balance is to be used to the limits of its readability.

An alternative approach is to undertake just gross checks on the values of in-built weight errors and to quote the worst-case combined error in all weights.

Most electronic balances make use of either an internal or external "calibration" weight. Any errors in the value of this weight will result in a subsequent error in balance readings. A full calibration will include the measurements of any errors in the value of the calibration weight.

3.4 Off-centre Loading Errors

Many balances, particularly top-pan types, are sensitive to off-centre loading of the object to be weighed. Objects should, therefore, be placed in the centre of the pan. Balance users who are required to weigh asymmetrical objects that cannot be placed centrally on the balance pan must determine off-centre loading errors and take them into account when evaluating a balance's overall performance.

3.5 Combining Component Errors

As mentioned above, balance users who wish to use their instruments to the limit of their readability (i.e. to make weighings with an uncertainty of ± the readability of the balance) must undertake a full calibration and determine the repeatability, linearity, in-built weight and off center loading errors. Corrections for all these individual errors must then be applied.

Other balance users may be satisfied with a single figure representing the worst-case combined error that will ever be experienced in any single weighing. The CSIRO publication referred to in Section 1 defines this figure as the "Limit of Performance", (clause 10.4 Page 71). This is a more useful figure for most practical applications. Balance users will know that if they place a sample on the pan, and take a single reading then the worst-case error in the reading obtained will not exceed the "Limit of Performance".

4 Typical Balance Performance Figures

It is unwise to assume a balance is accurate to the last decimal place in its display, especially for high precision balances.

Catalogues and specification sheets advertising balances often provide information about the various component errors discussed in Section 3 but they do not make it clear that these component errors must be combined to evaluate the overall performance of the instrument.

Typical balance specification information taken from manufacturer's catalogues is shown in the following table (Table 1). For each balance the "Limit of Performance" figure has also been calculated to indicate the worst-case error that might be encountered in any single weighing operation.

Table 1: Typical Balance Specification

Balance Type	Capacity (g)	Readability (Discrimination) (mg)	Standard Deviation (mg)	Linearity Error (mg)	Limit of Performance (mg)
Electronic	31	0.01	0.02	0.03	**0.05**
Electronic	162	0.1	0.1	0.2	**0.4**
Electronic	1,200	0.1	30	200	**260**
Electronic	3,100	100	50	100	**200**
Electronic	15,000	1,000	500	1,000	**2,000**

It can be seen from these manufacturer's specifications above that even new balances will exhibit a "Limit Performance" of 2 or 3 times the readability (discrimination) of the instrument and this can even be as high as 12 times the readability.

If laboratories wish to make single weighings (and apply no corrections) with an uncertainty of ± x grams they should use a balance with a readability (discrimination) of ± 0.1x grams.

The figures quoted above apply to new balances. The ratio of "limit of performance" to readability will be even higher in a balance that has not been serviced for some time. The following table relates balance readability (discrimination) to "Limit of Performance" with appropriate comments.

For a balance with a readability of "x" grams

Limit of Performance	Comment
x to 2x	Good performance
2x to 3x	Average performance
3x to 5x	Acceptable performance but service required soon
5x to 7x	Poor performance service required
7x to 10x	Very poor performance

These figures would apply to most balances although, as shown above, some semi-micro balances, even when new, can demonstrate "Limits of performance" in the order of 7 to 10 times their readabilities.

5 Calibration Regimes

Depending upon the use that is to be made of a balance a number of calibration regimes for the instrument can be specified. This Section defines these regimes whilst Section 6 specifies the circumstances under which each regime should be adopted.

Regime A – Full Calibration

(i) Repeatability errors are measured.

(ii) Linearity errors are tabulated.

(iii) In-built weight errors are tabulated.

(iv) Off-centre loading errors are measured.

When in use corrections are applied for (ii) (iii) and (iv) to each balance reading. Multiple readings are averaged to reduce repeatability errors to an acceptable level.

Regime B – Partial Calibration

(i) Repeatability errors are measured and a worst-case figure determined.

(ii) A worst-case linearity error figure is determined.

(iii) A worst-case gross error in in-built weights is determined.

(iv) Off-centre loading errors are measured if relevant.

(v) A single "Limit of Performance" figure is calculated.

The Limit of Performance figure is regarded as being the maximum combined error that might be encountered in any single weighing operation.

Regime C – User Checks

(i) Zero-point check each use.

(ii) Self calibration of electronic balances using internal or external calibration weight.

(iii) Full-scale (optical scale) check on mechanical balances (procedure in Clause 5.2 of CSIRO publication).

(iv) Check on repeatability of balance (six monthly).

Regime D – Gross Functional Checks

(i) Simple check on overall functioning of the instrument to ensure that there are no gross errors.

(ii) Zero-point check.

Calibration Regimes A to D

It would normally be expected that calibrations undertaken in accordance with either Regime A or Regime B would be undertaken by an IANZ accredited calibration agency (see IANZ web site for currently accredited balance calibration agencies), or by balance users themselves should they have the appropriate training skills, facilities and resources to do the work.

Check on balance performance complying with regimes C or D can normally be carried out by balance users themselves or by an external service agency. Accreditation would not be required for such checks.

6 Selection of Calibration Regime

As discussed in Section 2 the choice of a calibration regime for any particular balance will depend upon the readability of the instrument and the uncertainty of measurement that is required to be made. The following chart (Table 2) indicates the regime that would be appropriate under various circumstances:

Table 2: Calibration Regimes

	Readability of Balance (mg)				
Uncertainty of Measurement required ± mg (g)	0.01 (0.00001 g)	0.1 (0.0001 g)	1.0 (0.001 g)	10 (0.01 g)	100 (0.1 g)
0.01 (0.00001 g)	A				
0.1 (0.0001 g)	B	A			
1.0 (0.001 g)	C	B	A		
10 (0.01 g)	D	C	B	A	
100 (0.1 g)	D	D	C	B	A

7 Recalibration Periods

As a general guideline, balances should be recalibrated at yearly intervals until stability of operation is established. Once a stable pattern of calibration data is evident then recalibration periods can be extended to two years or even three years if the instrument is located in a favourable environment.

It is not possible to specify a fixed recalibration period for each type of balance. The period between calibrations will be influenced by such factors as the usage the instrument receives, operator skill and the environment in which the balance is located. Three years is considered a maximum period without a full calibration.

The maintenance of proper calibration records along with records of regular in-house performance checks will assist in determining the frequency of servicing and calibration necessary to provide the assurance of satisfactory balance operation. Minimum in-house performance checks are given in Appendix 2.

8 Weights Used in Balance Calibration

It is usual for Australasian standards laboratories to calibrate reference weights used for balance calibrations with an uncertainty of measurement of 1 part in 10^6 or 0.01 mg whichever is the greater. This would apply in general, to integral stainless steel weights. Weights made of nickel-bronze alloys or plated brass would usually be calibrated with a higher uncertainty, perhaps 5 parts in 10^6. Unplated brass weights or other weights in poor condition may only be calibrated with an uncertainty of 1 part in 10^5 or even 5 parts in 10^5.

The uncertainty in the value of such reference weights dictates the uncertainty with which measurements can be made during a balance calibration exercise and, accordingly, defines the types (capacity/readability) of balance that can be calibrated using the weights.

Just as one would not attempt to calibrate a micrometer using a ruler as the reference, one would not attempt to use weights with an uncertainty of 1 part in 10^6 to calibrate a balance readable to 1 part in 10^7 or 1 part in 10^8. It is not often realized, however, that many modern electronic semi-micro balances cannot be effectively calibrated with the reference weights that are routinely available.

For example a typical electronic balance with a capacity of 30g and a readability of 0.01mg has a resolution of 1 part in 3 million at full scale. Such an instrument cannot reasonably be calibrated using reference weights the true value of which are known with an uncertainty of only 1 part in one million.

In general it must be expected that laboratories equipped with stainless steel reference weights calibrated with an uncertainty of 1 part in 10^6 will be restricted to the calibration of balances with a resolution of 4 parts in 10^6 or lower. If the uncertainty in the weight calibration is higher than 1 part in 10^6 then the resolution of balances that can be calibrated decreases accordingly.

Further information on uncertainties of measurement in balance calibration are given in Section 10 of the CSIRO publication.

9 Balance Calibration Reports

If a balance is to be used to the limit of its readability then Calibration Regime A will be necessary and a full calibration report as described in sections 5.10.8 or 6.11.7 of the CSIRO publication must be obtained. The report must be available at all times adjacent to the balance so that the appropriate corrections can be made to readings.

If Calibration Regime B is adopted then a simplified report as shown in section A3.3 of the CSIRO publication or in the Appendix to this Technical note will suffice. The "Limit of Performance" derived from such a report should be marked on the balance, perhaps using a self-adhesive label.

No formal calibration report is necessary when Calibration Regimes C or D are adopted although records of the user checks undertaken must be maintained.

10 Dual Range Balances

If a balance has a dual range (referred to as a "Delta" range by one manufacturer) then both ranges must be independently calibrated and either two reports issued or a single report prepared with two sets of figures.

11 Terminology

The following terms are used in this document. Reference should also be made to Section 2 (Definitions) of the CSIRO publication:

Capacity of a balance: the maximum mass that can be weighed by the balance.

Readability: the smallest scale division or digital interval of the balance. For some mechanical balances the scale marks may be sufficiently far apart for an estimation to be made of the actual balance reading when the pointer lies between two scale marks. The estimated readability may, therefore, be lower than the marked readability. This does not occur with digital read outs.

Discrimination: the smallest change in mass that can be detected by the balance. For practical purposes discrimination is synonymous with readability.

Resolution: the readability expressed as a proportion of the capacity. For example a balance with a capacity of 3000g and a readability of 0.1g has a resolution of 1 part in 30 000.

Repeatability: the closeness of agreement between results of successive measurements of the same quantity carried out by the same method using the same instrument by the same observer at short intervals of time.

Repeatability Error: the difference between the result of a single weighing and the result that would have been obtained had a large number of weighings been made and the average calculated.

Linearity: the ability of the balance to change its reading in direct proportion (1 to 1) to changes in applied mass.

Linearity Error: the error in balance reading that arises because the instrument does not exhibit a linear response.

In-Built Weights: weights built permanently into the balance mechanism to extend the instrument's capacity using the principal of substitution weighing.

Calibration Weights: reference weights used by a calibration agency to calibrate a balance.

Internal Calibration Weight: a reference weight built into the mechanism of an electronic balance which is used by the balance when it is in self-calibration mode.

External Calibration Weight: a reference weight supplied with an electronic balance which is applied by the balance user prior to switching the instrument into self-calibration mode.

Uncertainty: the range of values within which the true value of a measured quantity is expected to lie. If the mass of an object is measured as being 257g with an uncertainty of ± 1g then its true mass is estimated to lie within the range 256g to 258g.

Limit of Performance: a worst-case combination of all possible sources of error in a single weighing operation. In practice there is less than one chance in 100 (<1%) that combined errors will exceed the Limit of Performance.

12 References

Prowse D.B. *"The Calibration of Balances",* Commonwealth Scientific and Industrial Research Organisation, Australia – 1985 (ISBN 0 643 03829 9)

Appendix 1: Example Balance Calibration Certificate

Ballance & Waite Ltd
Gracefield Rd, PO Box 31-310, Lower Hutt
Tel: (04) 5690 536

BALANCE CALIBRATION CERTIFICATE

Client:

Address:

Balance Type:	Electronic Analytical	Model No:	XX200
Maximum Capacity:	200g	Serial No:	1111

Balance Calibrated At:	Mass Laboratory at above address
Date of Calibration:	Temperature at time of calibration: 20.3 to 21.0ºC

Scale Ranges:	0 to 200 g
Scale Increment/Resolution:	0.0001 g
Readability Taken As:	0.0001 g

REPEATABILITY

Standard Deviation of 10 repeat readings: 0.00013 g

Worst case repeatability error in any single reading (2 x SD): 0.00027 g

(if less than ½ resolution, SD = ½ of resolution)

BEST ACCURACY OF BALANCE

(Taking into account scale increment, readability, linearity, in-built weights if applicable, air buoyancy effects and other temperature effects if applicable, and the uncertainty in the calibration of our reference weights).

Scale Range	Calibration Range	Best Accuracy of Balance
0 to 200g	0 to 50 g	0.00020 g
	50 to 100 g	0.00035 g
	100 to 200 g	0.00062 g

The balance has been calibrated 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

Maximum Error in reading due to off-centre loading of pan: 0.0001 g

(to be added to errors listed above if appropriate).

GENERAL COMMENTS ON BALANCE CONDITION AND LOCATION: In good condition

Certificate No: Dated: Signatory

Checked:

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Appendix 2: Performance Checks and Servicing

Performance Checks

To help detect deterioration in the operation of the balance, regular checking of balance performance is necessary between calibrations. The minimum regime recommended is:

- A monthly single point check using a "calibrated" check weight near full scale. (The weight may be "calibrated" immediately after a full balance calibration)
- Six-monthly repeatability check near full scale and near the most commonly used load point. (Calibrated weights are not necessary for this).

Refer to the following sections in the CSIRO publication:

- 5.9 (Single pan two knife edge ["mechanical"] balances)
- 6.10 (Electromagnetic-Force-Compensation ["electronic"] Balances)

Servicing

Regular servicing including cleaning is necessary to maintain balance performance. Except for the cleaning of external parts and pan, it is recommended that this be performed by the calibration agency annually. (More often if the balance is being used in less than ideal conditions).

Some servicing operations would be considered to invalidate the current calibration certificate. These would include any adjustments, e.g. for pan position error or linearity, alteration/replacement of internal masses or measuring cell components, reprogramming of scale constants (but not use of the CAL function).