LAB 14

Edition 6 August 2019 – Draft for consultation

Guidance on the calibration of weighing machines used in testing and calibration laboratories

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Changes since last edition

Minor contextual changes.
Change to the Air buoyancy formula at 3.8.2 to align with version in OIML R111:2004.

1. Introduction

1.1 Laboratories that have been assessed by UKAS as meeting the requirements of ISO/IEC 17025 *General Requirements for the Competence of Testing and Calibration Laboratories* may be granted UKAS accreditation. Several guidance publications on the application of these requirements, providing extra information, detail and limitations are listed in the Publications and Technical Articles area at www.ukas.com.

1.2 This publication (LAB 14) provides guidance for laboratories using weighing machines in support of their accredited testing or calibration activities, and that may wish either to calibrate their weighing equipment in-house, or to use an external calibration body. ***LAB 14 is not intended to be a set of requirements for those laboratories accredited for calibrating weighing machines for their customers - the guide EURAMET cg-18 is more applicable in these cases.*** In addition, LAB 14 does not cover all the requirements of ISO/IEC 17025, which remains the authoritative document, nor does it cover specific calibration requirements defined within some published standards for particular tests. Following the guidance given in LAB 14 will help laboratories be able to demonstrate, under assessment, that they meet the general requirements of ISO/IEC 17025 applicable to the use of weighing machines. Alternative methods may be used provided they are shown to give an equivalent outcome.

1.3 The term 'calibration' is used extensively in this publication. Broadly speaking, calibration is the *process* of obtaining metrological values for measuring devices or reference materials/standards (a complete definition for calibration and other metrological terms can be found in the International Vocabulary of Metrology - VIM, see bibliography). The results of the calibration are certified on a calibration certificate. Calibration is NOT the adjustment of a measuring system, often mistakenly called "self-calibration", nor is it the verification of calibration of a measuring device or reference material/standard. Adjusting the measuring system usually invalidates existing calibration results for that system, although this is not to be confused with the use of built-in adjustment weights (4.3.2).

2. Calibration of Weights

2.1 As a convenience, weights can be classified in accordance with the Recommendation of the International Organisation of Legal Metrology (OIML), as set out in their current document R111-1 (see Bibliography) which also contains information on the use and construction of weights. It should be noted that OIML R 111-1 has not been written to match any industrial, scientific or testing measurement situations, therefore, the conformity of a weight with an OIML classification does not of itself assure that it is suitable for any particular intended application, and the construction, material, finish, magnetic properties and deviation from nominal value should be considered for appropriateness by the end user. Each class specifies maximum permissible errors from a range of nominal mass values, but the classification that can be given to a weight also depends upon its material, density, corrosion resistance, hardness, wear resistance, brittleness, magnetic properties, construction and surface finish.

It is not necessary for the purposes of accreditation to use weights that are certified as meeting one of the OIML classification specifications, but most major weight manufacturers make their weights to conform. Weights designed to meet other or older national specifications may also be available. Any type of weight may be used as long as its characteristics are appropriate to the stability and accuracy required in the environment and application in which it is to be used.

2.2 Weights that are used for their known mass value should be calibrated regularly*. The appropriate calibration period will depend upon the amount of drift between successive calibration values that is acceptable for the application, compared with the drift that the weights have historically shown under their conditions of storage and use. One easily interpreted way of monitoring this is to plot a graph for each weight, showing its successive calibration values against time. Bars can be drawn for each calibration point that show the values to which the previous calibration could have drifted and still be acceptable. The way each weight is drifting can then be seen at a glance, and weights in a set can be compared to see if there are common effects that could indicate handling or environmental problems. For all weights, the change in measured mass between successive calibrations should be no more than the acceptable drift limits that are used in the uncertainty budget for the use of the weight. If monitoring shows that weight values drift unacceptably between calibrations, then some action is needed. Generally, a desire for control of quality and cost-effectiveness would lead to a review of handling techniques and storage, the suitability of the weight type and environment for the application. However, in the short term and where weights are in constant use or unavoidably in a hostile environment, increasing the frequency of re-calibration may be necessary.

**A check weight is generally used simply to apply a load that was the same as on a previous occasion, in order to see if the value indicated by a weighing machine is the same as on that previous occasion. Consequently, although it needs to be sufficiently stable, its actual value is not needed and therefore it does not need to be calibrated. If the same check weight is regularly used for several weighing machines, the indicated values obtained can be used to deduce stability: if all the weighing machines change together, it can be inferred that the weight has changed value, whereas if only one weighing machine shows changing output, it must be that machine that has changed its characteristics. If all the machines (probably those having 1 million or more digits in their range) move together on the basis of the periodic check, the effect may be due to environmental changes in the density of the air.*
Note that the use of a check weight on a weighing machine does not 'calibrate' the machine.

2.3 Weights should always be kept uncontaminated because any cleaning (except light dusting with a soft brush) will tend to alter the mass of the weight, leading to a need for recalibration. Where cleaning is deemed necessary, abrasives or polishes must not be used. If it is necessary to use pure water or some organic solvent, a period of stabilisation ranging from hours to weeks may be necessary, depending upon the accuracy class and material of the weight. With the exception of cast iron weights, masses must not be handled with bare hands, but with tweezers, lifters or using clean non-abrasive gloves. (Where tweezers and lifters are used, they should be constructed with a suitable surface to avoid metal-to-metal contact).

2.4 Weights used either for weighing operations or for the calibration of weighing machines should have calibrations traceable to the SI system of units and should have an accuracy or measurement uncertainty appropriate for the associated process.

2.5 Calibrations recognised by UKAS as traceable to the SI system of units, through national standards realised at the National Physical Laboratory or other recognised National Metrology Institutes, should be evidenced by appropriate calibration certificates, and can be provided:

(a) by the National Physical Laboratory or the National Metrology Institute of another country that is covered by a mutual recognition agreement with the UK (usually a Member State signatory of the CIPM MRA) or,

(b) by a UKAS accredited calibration laboratory or,

(c) by an accredited calibration laboratory accredited by an overseas body that is party to the international multilateral agreements for accreditation bodies (usually signatories of the ILAC MRA) or,

(d) in-house, using documented procedures that have been assessed as appropriate by UKAS. This might be through the use of reference standard weights owned by the laboratory, or through the use of a suitable calibrated weighing machine. The reference standard weights should be in a current state of calibration in accordance with (a), (b) or (c) above and paragraph 2.2. Where traceability of any weighing is via a weighing machine, consideration should be given to the probability that the characteristics of the machine remain close to those found during the calibration. For some applications, a machine may be considered likely to have changed its characteristics by an unacceptably large amount in only a short period, and the most practical way of achieving demonstrated measurement traceability may then be by comparison weighing against calibrated reference weights. This approach will also tend to reduce measurement errors arising from drift of the instrument, and from environmental effects. A weighing machine used in this way for comparison weighing may not need to be calibrated, although the uncertainty of measurements arising from its resolution, repeatability and non-linearity will still need to be estimated.

2.6 Where weights are used as part of testing equipment, for example in a pressure or force measuring machine, they should be calibrated and used in a manner similar to normal weights. Their values may be expressed in units other than mass, provided that the method of conversion is clearly indicated and understood.

3. Considerations in the Use of the Weighing Machines

3.1 Before a weighing machine enters service, it should be checked at the exact site of use to make sure it functions adequately for the application. These checks will need to be repeated whenever it is re-positioned – even if it is only briefly removed and then replaced in the original location, as the act of moving it is likely to change its characteristics.

After brief, careful removal and repositioning a sensitivity offset is more likely than a change of eccentricity or repeatability and this can be corrected by applying built-in adjustment weights when available, otherwise a sensitivity check will be required.

3.2 All weighing machines will be affected to a greater or lesser extent by draughts, vibration, movement from inadequate support surfaces and temperature changes, whether across the machine or with time. Note that 'vibration' is often interpreted by building/environmental design professionals as being acoustic frequency; but weighing machines are often relatively insensitive to these; conversely, very low frequency movements or deflections under load that are often neglected in table design considerations can have significant effects on the stability of weighing machines. Electronic weighing machines can also be affected by other influences, or cause measurement errors in the way they interact with weights. Influences to consider include electrical and electromagnetic interference and magnetic effects.

3.3 Some influences will show themselves as instability in the weighing indications, but some will be less obvious as they can cause consistent indication errors. **It should not be *assumed* because a machine has been in service for some time that it is making correct measurements.**

3.4 Air Movements and Heat Sources

3.4.1 The environment should be assessed for obvious influences. If there is any discernible draught or possibility of air movement, its significance can be assessed by turning off the source of the draught where possible, or by arranging a crude draught shield such as a cardboard box, and looking to see how the loaded indication changes. If there is a discernible change in the indicated value or its stability, then consideration should be given to suitable precautions during use. If a permanent shield is used, care should be taken that the materials used are not prone to holding static electrical charges, which can affect measurements.

3.4.2 If it is absolutely necessary to site a weighing machine near a window, screening should be considered to avoid heating the machine by direct sunlight, and to reduce the possibility of air movements when the outside and inside temperatures are different. Care should also be taken to avoid locating weighing machines over or close to sources of heat, such as radiators and ovens, as these are likely to cause measurement problems due to direct heating and the presence of convection currents in the air.

3.4.3 If the weighing machine has a weighing chamber with transparent windows/doors, ambient light will cause greenhouse heating of the inside of the chamber. If possible, the door should be left slightly ajar when not in use, to allow the temperature to equilibrate with the environment in which it is being used.

3.5 Support Surfaces and Vibration

3.5.1 Where significant vibration is present, it can often be detected by touching the support surface with the fingers. If vibration can be felt, and if it is possible to switch the source of it off, changes in the loaded indication can be looked for. In general, a better solution is to find a location that is unaffected by vibration or flexing. The adequacy of the supporting surface can be checked by tapping and pressing the surface next to the machine whilst it is indicating a small load value, and seeing if the indication changes in any way. If it does, consideration should be given to using a firmer support. Similarly, a ‘heavy foot-fall’ may be applied to the floor next to the support surface, and seeing if the machine’s indication is disturbed. Care should always be taken to ensure that the weighing machine is levelled, where available using the built-in electronic level control or the bubble level that is often attached to the frame.

3.6 Electrical and Electromagnetic Interference

3.6.1 Areas where electronic weighing machines are in use (including as appropriate adjacent areas outside the room) should be assessed for potential sources of electrical, electromagnetic and magnetic interference. Equipment such as induction furnaces can be very ‘noisy’ in all three. Switching on machinery, ovens and other heating equipment may generate line-borne interference through the power supply, as may spark-inducing equipment. Mobile telephones, ‘walkie-talkie’ radios, radio communication centres, emergency services’ radio transmitters and spark-inducing equipment can all create interference that is capable of changing the indication of some machines while the radio field is present. In all cases where the source of the interference can be put at least temporarily under the laboratory’s control, the source can be turned on or off to establish whether the loaded indication of the machine is in any way affected. If problems are found, then consideration should be given to isolating the machine from the source of the interference, re-locating it, or acquiring a machine that is less susceptible to the interference.

3.7 Magnetic Effects

3.7.1 Many modern weighing machines make use of strong magnets in their principle of operation. As a result, there may be a magnetic field present above and around the load receptor. This makes possible an interaction between what is loaded on the pan and the magnet inside the machine, and can therefore change the value indicated during a weighing. As the effect is likely to increase with the magnetic relative permeability of the material weighed, if ‘magnetic’ materials are ever used on the load receptor during the weighing it is important that the effect of their presence is assessed. Such materials would include stainless steels, irons (including crucibles and weighing boats used for holding materials for weighing), cast irons, tungsten carbide and various cobalt materials and rare earths. A simple experiment will show if there is any effect on the indicated weighing value (see paragraph 3.7.3).

3.7.2 In general, there will not be a significant effect if no magnetic field is detectable on the unloaded load receptor. Moving a simple hand-held compass horizontally and vertically through the volume around and above the load receptor will show by movements of the compass needle if the machine is producing a magnetic field.

Note
Steel reinforcing bars in concrete, electrical cables, motors and other structures may also produce magnetic fields that the compass will detect, and these could also affect the measurement accuracy of the weighing machine. If a field is detected, the magnitude of the effect should be assessed to see if it is significant.

3.7.3 To check whether the weighing machine indications are affected by magnetic influences, the following tests can be applied. Select items that have been or will be weighed, and by moving the compass slowly around, across and up/down them, pick out the item that gives the greatest deflection of the compass needle.

(a) Place the item chosen on the load receptor with a non-magnetic spacer on top of it. (A suitable non-magnetic spacer might be a light and empty cardboard box or similar, providing that it is strong enough to support the selected load and is first acclimatised to the local environment. Avoid plastic items that could hold electrostatic charges.) Note the loaded indication of the weighing machine. Now place the non-magnetic spacer on the load receptor with the test load on top of it. Note the loaded indication. The two indications should, of course, be the same. Because the strength of a magnetic field drops off very quickly as the distance from the source increases, the change in effect when the test-load is further from the pan may lead to significant changes in indicated weight. Repeat the loadings to be sure that any difference found is not due to drift or the repeatability of the machine.

(b) Now place the test load on the load receptor without the non-magnetic spacer, and note the loaded indication. Invert the test load, replace it on the load receptor in reverse orientation, and note the loaded indication again. Repeat the two loadings if necessary to be sure any variation is not due to drift or the repeatability of the machine.

3.7.4 If there is no difference in the indications at either (a) or (b), the machine can be assumed not to have measurement problems associated with magnetism for the application. If there is a difference in the results for (a) but not for (b), the test load was effectively not permanently magnetised, but the machine does give indication errors when used to weigh items of sufficiently high magnetic relative permeability. If there is a difference in the results for both (a) and (b), then the test load was effectively permanently magnetised. The results for (a) will therefore not necessarily be consistently reproducible, but the machine does give indication errors when used to weigh items of sufficiently high magnetic relative permeability.

3.7.5 If consideration of paragraph 3.7.4 above leads to the conclusion that a mass measurement problem exists as a result of magnetic influences, a number of corrective approaches are possible. These include changing the materials loaded on to the load receptor to those with a lower magnetic relative permeability or introducing a non-magnetic spacer to the pan to position the load far enough from the machine not to cause an effect. The necessary separation distance can be found by experiment, but in general doubling the distance of the weight from the transducer might be expected to reduce the effect to one-eighth of the effect observed with no spacer. A suitably large diameter aluminium tube with aluminium end-plates welded top and bottom often proves suitable as a spacer. Where neither of these two solutions is practicable, replacing the equipment may be necessary.

3.8 Buoyancy Effect

3.8.1 Weighing machines are calibrated by accredited laboratories on a conventional mass basis. If the true mass of an object is to be found, or if conventional mass is required but the air density is not 1.2 kg m^{-3}, then an air buoyancy correction must be made. This correction will vary depending on the density of the object weighed and of the air at the time of weighing. In air of density 1.2 kg m^{-3}, no corrections would be required to give conventional mass. However, the correction for true mass would be zero for stainless steel (density approximately 8 000 kg m^{-3}), -7 ppm for brass (density typically 8 400 kg m^{-3}), +1 050 ppm for water (density 1 000 kg m^{-3}) and +1350 ppm for organic solvents (density around 800 kg m^{-3}). For a 1 kg load these corrections would be 0 mg, -7 mg, +1.05 g and +1.35 g, respectively. If the air density is different from 1.2 kg m^{-3}, then other correction values will be needed for both true and conventional mass.

3.8.2 To make buoyancy corrections, the measured values may be multiplied by the factors given in the following formulae:

To obtain conventional mass:

$$\text{Factor} = 1 + \frac{D_a - 1.2}{D_u} - \frac{D_a - 1.2}{D_s}$$

To obtain true mass:

$$\text{Factor} = \left(\frac{\left(1 - \frac{1.2}{8000}\right)}{\left(1 - \frac{1.2}{D_s}\right)} \right) \times \left(\frac{\left(1 - \frac{D_a}{D_s}\right)}{\left(1 - \frac{D_a}{D_u}\right)} \right)$$

where: D_a = density of air during the weighing in kg m^{-3}
D_s = density of the reference weight (usually around 8000 kg m^{-3})
D_u = density of the material being weighed in kg m^{-3}

A reasonable approximation of the air density (uncertainty ± 200 ppm of the calculated air density in the range 900 mbar < p < 1100 mbar, 10 °C < t < 30 °C and h < 80 %) may be obtained from the following formula extracted from OIMLR111-1 2004 E3 †:

$$\rho_a = \frac{0.34848P - [0.009he^{(0.061t)}]}{(273.15 + t)}$$

Where: ρ_a = air density in kg m^{-3}
p = air pressure in mbar
h = relative humidity of the air in %
t = air temperature in °C

†*A better calculation of air density may be obtained by using the formula described in 'Revised formula for the density of moist air' (CIPM-2007), A Picard, R S Davis, M Gläser and K Fujii*

For best results, the weighings to which these corrections should be applied should generally be either by comparison with a calibrated standard weight, or (where the facility is available) by direct weighing after the weighing machine has been adjusted by use of a calibrated weight (see paragraph 4.3.2).

3.8.3 In many practical situations the magnitude of the buoyancy correction is sufficiently small to be neglected and the effect is instead included in the uncertainty evaluation. EURAMET cg-18 (see Bibliography) provides guidance on the treatment of buoyancy as well as the other significant influences on the uncertainty of measurement.

3.9 Calibration - General Considerations

3.9.1 The best and most reliable metrologically traceable results will generally be obtained by comparison weighings, the results being corrected for the calibrated values of the weights. Used this way, the weighing machine need not itself be calibrated, although it should still be characterised for linearity across the difference in indication of the calibrated weight and weighed item, and for repeatability. If this approach is not used, then weighing machines should be calibrated regularly throughout their range. Where a machine is only used over a part of its capacity, calibration may be restricted to this range. In this case, a notice stating the range that has been calibrated should be prominently displayed on the machine. Note that the relative measurement uncertainty of weighing machines is inversely proportional to the load applied, so that at the lower end of the measurement range the machine may not be accurate for its intended application (although this will vary with the application and the design of the weighing machine). In this case, a different weighing machine, usually one with smaller capacity and better resolution, could make more accurate measurements in that range.

3.9.2 Calibrations may be performed in-house in accordance with documented procedures that have been assessed as appropriate by UKAS, using weights that have been traceably calibrated. Details of what would be considered appropriate for in-house calibrations are in Section 4. Alternatively, the calibration of weighing machines may be undertaken by a suitable accredited calibration laboratory, as evidenced by an appropriate calibration certificate.[¶] If a non-accredited external calibrator is used, it will be necessary to ensure that the requirement of ISO/IEC 17025 that the calibrating laboratory can demonstrate competence, measurement capability and traceability is met. The calibration should be performed over an appropriate range to include the minimum and maximum weights to be measured in use. The uncertainty of measurement should also be determined for the calibration to be metrologically traceable.

[¶] ***No weighing machine should ever be sent away for calibration, as the results obtained will not apply to its characteristics after it has been moved.***

3.10 Zero-Tracking

3.10.1 Some electronic weighing machines have a ‘zero-tracking’ facility. When a machine has been either ‘zeroed’ when unloaded, or tared to show zero when a load has been applied, zero-tracking will keep its indication locked to zero, provided that any incremental load change is not greater than a pre-set amount - often half a digit. This means that if a slow load-change may occur at zero indication and needs to be known in order to properly interpret the measurement for which the weighing machine is used, it is important that the zero-tracking facility is disabled either by changing the software setting or by adding a small weight that is present throughout the weighing.

If an undetected slow change of load is not relevant to the measurements for which the weighing machine is being used, and the zero-tracking is usually switched on in use, then it should not be disabled for its routine calibration.

For some applications, a separate measurement with the zero-tracking disabled may be desirable, for example to detect a slow leak in a valve to/from a weigh-tank for gravimetric determination of volume or flow.

3.11 Exercising

3.11.1 Older models of weighing machine should be ‘exercised’ by loading to near maximum capacity or service load several times before being calibrated or used, to achieve appropriate repeatability.

3.12 Hysteresis

3.12.1 When increasing loads are applied to a weighing machine, and then decreased again, there may be a hysteresis effect whereby the indications lag behind the falling load, and show a higher load indication than is actually present. This is mainly an issue with mechanical balances.

3.12.2 This should be taken into account when considering how a calibration should be performed. If the weighing machine will be used with a falling sequence of loadings, a calibration performed with decreasing loads may produce results more indicative of the weighing machine's results in that usage.

3.12.3 A weighing machine is sometimes used in a way that will cause an overshoot of loading-force (as experienced by the machine) before it is used to measure the actual load. Examples would be when the load to be measured is applied to the pan, and exerts a force greater than its own rest weight as it comes to a halt; or when liquid is discharged from above into a weighing tank – as it falls, at contact with the loaded surface it creates a dynamic pressure that is experienced by the weighing machine as a loading-force, such that when the flow is stopped the liquid in the tank appears to have reduced its weight. In both of these cases, the weighing machine may over-indicate the load that is present. It may be appropriate to estimate the apparent over-load, and then calibrate the machine with static loads to this point, removing the final maximum incremental load to determine whether a significant hysteresis effect has been caused.

3.13 Calibration and Check Intervals

3.13.1 The frequency of calibration will depend upon the type of machine, the risk of the weighing application, and the required weighing process tolerance as well as its use (see for example ILAC-G24:2007). Dial-on single-pan mechanical machines can be calibrated meaningfully because they are weight-comparison devices that use internal weights and lever-ratios that are relatively stable in their values over time; whereas electronic machines are essentially force-measurement devices, and the calibration of them produces a 'snapshot' of the instrument's characteristics in its environment at a particular moment. (See paragraph 2.5 d). The machine should generally be calibrated fully (see paragraph 4.3.3) at least once a year, unless sufficient evidence has been obtained to show that the machine has remained well within acceptance limits and that the interval can be extended.

3.13.2 Periodic or before-use checks and built-in adjustments should be made on weighing machines (see section 6) and the results recorded. This applies whether the machine has been calibrated in-house or by an external organisation. Historically the advice has been to perform daily checks however, as is the case for calibration, the frequency of these checks should be determined on the basis of the risk associated with the weighing application.

3.13.3 Other regular checks (intermediate checks) may be required between full calibrations, dependent upon use and intervals between full calibrations. In particular, regular repeatability or eccentric-load indication tests can be helpful in the early detection of faults developing in the weighing machine (see paragraph 5.3). Results of intermediate checks should be recorded, and analysed for trends and their significance to the measurements for which the weighing machine is used.

3.13.4 Whenever possible, a weighing machine that is already in service should always be calibrated immediately prior to any event that will change its characteristics; this is so that its in-service performance is known, and decisions can be taken as to whether it was meeting its specified service limits when last used, and so that estimates can be made of possible performance changes between calibrations.

3.13.5 Full calibrations should be performed after a significant change in the laboratory's environmental conditions, a disturbance or change in position of the weighing machine, or following service or repairs carried out on the weighing machine (whether carried out by the user or by a service agent). Intermediate checks, or full calibrations, should also be performed when there is any reason to believe that any other change has occurred which may affect the accuracy of the weighing machine, or where servicing is planned that can be expected to adjust its characteristics.

3.13.6 If any intermediate check reveals a significant change in the accuracy of a weighing machine a full calibration should be carried out. As a result, it may be necessary to review the validity of measurements made on the machine since the previous calibration. Consideration should also be given to repair and/or adjustment of the machine, and modification of any external factor that may have caused the change in accuracy. As in paragraphs 3.13.4 and 3.13.5, where servicing work is carried out it should be preceded by, and followed by further full calibrations.

4. In-House Calibration of Weighing Machines

4.1 Introduction

4.1.1 This section describes general procedures that would be assessed as appropriate if adopted for calibrations performed in-house. Further details can be found in EURAMET cg-18 which also includes guidance on uncertainty evaluation.

4.1.2 For the purpose of this section weighing machines include balances and electronic and mechanical industrial weighing equipment (see Appendix A).

4.2 Weights Required for In-House Calibrations

4.2.1 The series of weights held should cover the range of the weighing machine. Where a particular weighing machine is used only over a very limited range it is possible to reduce the number of weights held. If the design of a weighing machine requires a specific value of weight to be provided to set the weighing range, then this should also be provided, even if it is outside the limited weighing range as defined above.

4.2.2 The design and accuracy of weights used for in-house calibrations should be appropriate to the weighing machine being calibrated, and where possible should have a 95% confidence level uncertainty of calibration less than half the smallest resolution or recorded scale interval of the weighing machine to be calibrated. Where groups of weights are to be used to make up a single load, this criterion should be applied to the arithmetic sum of the weights' individual calibration uncertainties.

4.2.3 The apparent mass of weights used will be affected by their buoyancy in the air in which they are used, and this will change with the air density. The calibration value of the weights will have been certified for air density 1.2 kg m^{-3}. If the buoyancy effect caused by a different air density at the time of use leads to an error in the applied load that is greater than acceptable levels, e.g. one half of the resolution of the weighing machine being calibrated, a correction can be made (see paragraph 3.8.2).

4.2.4 Weighing machines as described in Table 1 can usually be calibrated using calibrated weights in the pattern of the designated OIML class. The table assumes that the uncertainty of calibration of the weights used will be 1/3 of its specified maximum permissible error. In most cases it will be possible to obtain smaller calibration uncertainties than this, and it may therefore be possible to use a weight of a lower class. However, when selecting suitable weights, attention should still be given to properties of the weights other than accuracy, such as magnetism, corrosion and wear resistance. In most laboratory applications, it would not be appropriate to select a class lower than F2 and, due to handling requirements; it is not common practice to use E1 weights for routine calibration purposes.

Table 1 A possible selection table of weights for calibration of weighing machines

	Resolution							
Capacity	**100 g**	**10 g**	**1 g**	**100 mg**	**10 mg**	**1 mg**	**0.1 mg**	**<0.1 mg**
Up to 50 g		M3	M3	M3	M2	F2	E2	E1
Up to100 g	M3	M3	M3	M3	M1	F1	E1	E1
Up to 500 g	M3	M3	M3	M2	F2	E2		
Up to 1 kg	M3	M3	M3	M1	F1	E1		
Up to 5 kg	M3	M3	M2	F2	E2			
Up to 10 kg	M3	M3	M1	F1	E1			
Up to 50 kg	M3	M2	F2	E2				
Up to 100 kg	M3	M1	F1					
Up to 500 kg	M2	F2	E2					

Note: This table should be interpreted in conjunction with paragraphs 4.2.2 and 4.2.4.

4.2.5 Weights should be stored in such a fashion that they are acclimatised to the weighing conditions. Failure to acclimatise can result in errors due to air convection.

4.3 General Calibration Procedure

4.3.1 The documented procedure for in-house calibration of a weighing machine should involve sufficient measurements to define the performance of that machine.

Note: For multi-interval or multiple range instruments where intervals or ranges are switched automatically these measurements may only be required on one such interval/range.

4.3.2 Where the machine to be calibrated is electronic, and has a self-adjustment or (incorrectly named) 'calibration' facility that allows the output of the machine to be adjusted between zero and an internally or externally applied weight, it is advisable for this facility to be operated prior to the calibration, and also for it to be operated regularly before the weighing machine is used. This enables the calibration to relate to the 'fixed' points of the adjusting weight(s) used at different times – the adjusting weight becomes, in effect, a transfer standard for resetting the weighing machine between calibrations.

4.3.3 The procedure should include tests for the following parameters, except where the construction or use of the machine renders a particular test inappropriate:

(a) *Repeatability*, using a minimum of five repeated measurements. This test should be done at or near the nominal maximum capacity of the machine, or at other values where this is justified in view of a specific application of the instrument e.g. the largest load generally weighed, returning to zero after each reading[#]. If the items being weighed on the machine are likely to be relatively widely distributed about the centre of the receptor, then use of a group of applied weights may obtain a more realistic measure of the in-service repeatability. It is not necessary for the weight used for a repeatability test to be traceably calibrated.

 # EURAMET cg-18 suggests that the test load could be between ½ maximum and maximum capacity.

(b) *Sensitivity*, or the value of a scale division (should be omitted for machines with digital displays). The sensitivity of mechanical weighing machines will generally change with load, and it is therefore necessary to measure the sensitivity at a load similar to that for which the machine is used. For a machine used across its range, it would be appropriate to measure the sensitivity with no load, loaded at half its capacity and loaded at or near its full capacity.

(c) *Error of indication from nominal or conventional mass value*, covering at least five points (which can include zero), evenly spread over the range; extra points may be required to make the even spread convenient, or to cover specific loadings used in the normal application. The use of sequential weights from a set, that causes the loads to bunch at the lower end of the machine's capacity and only have one or two at the higher end, should be avoided. For machines that have internal weights (eg dial-up weights) each individual weight setting should be tested: this is because the machine weighs by comparison against the individual weights dialled up, and each must be compared to the external reference weights.

(d) *Eccentric or off-centre loading*, using at least 1/3 of the maximum capacity, typically placed between 1/2 to 3/4 of the distance from the centre of the load receptor to the edge, in a sequence of centre, front-left, back-left, back-right, front-right, and then the difference for each of the off-centre points should be calculated. It is not necessary for the weight used for the eccentric-load indication test to be traceably calibrated.

(e) *Effect of tare and/or balancing mechanism* (only for graduated balance/tare mechanisms).

4.3.4 The error allowed for a particular machine, for a particular test, should be set by the laboratory after considering the use to which the machine is put.
Manufacturer's specifications for weighing machines will often be inappropriate for the application.

4.3.5 In order to comply with the requirements of ISO/IEC 17025, the laboratory needs to ensure that a suitable uncertainty of measurement is calculated for the weighing machine calibration. Worked examples that are consistent with the ISO *Guide to the Expression of Uncertainty in Measurement* are available in UKAS publication M3003 and in EURAMET cg-18. When using the calibrated weighing machine a further uncertainty of measurement should be calculated for which the uncertainty of the calibration will be one contribution. (See for example chapters 7.4 and 7.5 of EURAMET cg-18)

5. Use of Calibration Results

5.1 A typical set of certified calibration results will consist of a repeatability figure, a set of eccentric load measurement data, a set of error of indication measurements across the range of interest, and a set of data representing the uncertainty of measurement that is usually expressed at a confidence level of (approximately) 95%. This uncertainty figure applies only to the measured values obtained during the calibration and should not be used as an estimate of the maximum indication error that the machine will give in use.

5.2 Repeatability is generally expressed as a standard deviation figure for each measuring range calibrated, based on a sample of 5 or more repeat readings. To estimate the range that will include ~95% of all the indications that the weighing machine might produce for a given load under the same conditions, multiply the repeatability standard deviation by the appropriate value for Student's '*t*' (look up $\nu_{eff} = n$-1, where *n* is the number of loadings, in Table 2 - reprinted from UKAS publication M3003). Note that this figure will include the effects of normal eccentric loading in use, providing that users are trained to load reasonably closely to the centre of the receptor. If the items being weighed on the machine are likely to be relatively widely distributed about the centre of the receptor, then use of a group of applied weights may obtain a more realistic measure of the in-service repeatability.

Table 2	**Student '*t*' values**										
ν_{eff}	1	2	3	4	5	6	7	8	10	12	14	16
k_{95}	13.97	4.53	3.31	2.87	2.65	2.52	2.43	2.37	2.28	2.23	2.20	2.17
ν_{eff}	18	20	25	30	35	40	50	60	80	100	∞	
k_{95}	2.15	2.13	2.11	2.09	2.07	2.06	2.05	2.04	2.03	2.02	2.00	

Note:
Although repeatability is often presented as a separate quantity on a typical calibration certificate it should nevertheless still be incorporated into the evaluation of the uncertainty of measurement.

5.3 Although the 'eccentricity' test gives a numerical value of the indication error when the load is applied off-centre, the result should not be taken as a limit on the range of eccentric load indication errors that the machine could produce. A particular load used in certain defined positions on the load receptor may not be typical of use, and will generally not be extreme. The eccentric load indication error is some function of the load applied, its distance from the centre of the load receptor, and its angular position on the receptor. The calibration does not produce enough information to define this function, and so no predictions of the indication error in use can be derived. If the machine is used properly, with loads positioned near the centre of the receptor, the indication errors in use are likely to be smaller than those found during the calibration. Conversely, a heavier load nearer the edge of the receptor could produce a larger indication error than that found by the calibration.

Note:
The main benefit of the eccentric loading test is to monitor the condition of the weighing machine. Records should be maintained of the results, and each test carried out at the same loading and positions. It will then be possible to detect deterioration in the condition of the machine, and to monitor if it performs below acceptable limits. Repair of the machine can then be arranged before it leads to poor measurement results.

5.4 The measurements of error of indication across the range of the machine can be used to either plot the error curve of the machine and hence make corrections for particular loadings, or to estimate the maximum error of indication that is likely to affect the weighing result if no correction is made to a weighing result.

5.5 If no calibration corrections are applied to indications on the weighing machine in use, then the associated uncertainty evaluation should include an additional contribution corresponding to the uncorrected error of indication. It should be noted that this approach is not consistent with best metrological practice or guidance, which recommends that all such corrections should be applied, although in practice it may be acceptable for some measurements.

6. Periodic or Before-Use Checks on Weighing Machines

6.1 Checks should be carried out between full calibrations on a periodic, risk-determined or before use basis. Where the weighing machine is electronic and has a self-adjusting (sometimes incorrectly called 'calibration') facility that allows the output of the machine to be adjusted between zero and a internally or externally applied weight(s), it is advisable for this facility to be operated prior to the periodic check, and also for it to be operated regularly before the weighing machine is used, to permit compensation for changing environmental factors such as temperature and air density.

6.2 The checks should include checking or adjusting the zero of the weighing machine, followed by the placement of a single weight (usually of a size appropriate to the normal range of use for the weighing machine) on the load receptor. This may be a calibrated weight, but an uncalibrated weight kept for the purpose and which has been weighed immediately following the last full calibration of each machine for which it is used as check weight will also allow the user to know if the machine has maintained its indication when subjected to the same stimulus – this being the purpose of the check. (See paragraph 2.2) The machine's indication should be recorded.

6.3 The commonly used default load for check weights is the maximum capacity of the weighing machine; however, machines that self-adjust will often exhibit more consistent behaviour at this load than around 2/3 – 3/4 of capacity. A check weight value selected to be in this intermediate range may therefore provide a more realistic indication of variation in the machine's performance.

6.4 The procedure for the periodic, or before-use, check should define an action limit or error allowance that is appropriate for the use of the machine.

6.5 If the action limit is exceeded, a full calibration (with or without adjustment) should be carried out before further use of the weighing machine.

7. Glossary of Terms

Capacity The greatest load a weighing machine is designed to weigh. Sometimes marked on it as 'Max'.

Calibration Specific types of measurement performed on measuring instruments to establish the relationship between the indicated values and known values of a measured quantity.

NB: The term 'calibration' as defined internationally does not include adjustment of the instrument.

Conventional mass For a weight taken at 20°C, the conventional mass is the mass of a reference weight of a density of 8000 kg m^{-3} which it balances in air of a density of 1.2 kg m^{-3}.

Range The least and greatest load for which a machine is or can be used, and for which continuous mass values will be displayed with the same resolution.

Repeatability A measure of a weighing machine's ability to display the same result when repeated measurements are made under the same weighing conditions.

Resolution The mass value of the smallest scale or digital interval displayed by the weighing machine. Sometimes marked on it as 'd'.

Span The mass value of the difference between the greatest and least load for which continuous mass values will be displayed with the same resolution.

Sensitivity The number of divisions change in reading per unit mass.

Tare Facility which enables the weighing machine reading to be adjusted to read zero with an object on the load receptor.

Turning point The reading at the extremity of the swing of the pointer, ie, where it changes its direction of motion. Not applicable to digital indicating devices.

Uncertainty The amount by which a true value may differ from a measured value, at a given confidence level.

More formal definitions of these terms can be found elsewhere e.g. in the international vocabulary of metrology (VIM) or in more specialised publications e.g. Dictionary of Weighing Terms (Springer).

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8.6 *Dictionary of Weighing Terms*, Springer (2009), ISBN 978-3-642-02013-1

8.7 ISO/IEC 17025:2017 *General Requirements for the Competence of Testing and Calibration Laboratories*

8.8 ILAC-G24 2007(E) *Guidelines for the determination of calibration intervals of measuring instruments*

Appendix A - Examples of Types of Weighing Machines

A1 SINGLE PAN - ELECTRONIC

A1.1 Most of these machines measure the total net downwards force or weight, rather than compare forces. A common type is the electromagnetic force compensation machine, described in paragraph A1.2. Other machines may use load cells as the transducer.

A1.2 An electromagnetic force compensation machine has a coil, rigidly attached to the pan, placed in the field of a magnet. When a weight is placed on the machine, the load receptor lowers, moving a position sensor and resulting in an increase in the coil current. This causes a magnetic counter force to be generated which returns the pan to its original position, and the resultant compensation current is measured as a voltage change. The weight on the pan is in direct proportion to the measured voltage, and thus the value of the weight may be obtained. Since the main operation of the weighing machine is electrical/electronic rather than opto-mechanical, it is generally referred to as an 'electronic weighing machine'.

A1.3.1 Because the machine displays its output in units of mass directly related to the net down-force it experiences at the load receptor, it is susceptible to mass measurement errors as the density of the air that is displaced by the load varies from the reference value of 1.2 kg m^{-3}. Even with temperature compensation built into the design, there is also likely to be a change in the indicated mass value for any given load as the instrument's temperature changes.

A1.3.2 To overcome these and other problems, manufacturers often include a facility that applies one or more accurately adjusted weights to the load mechanism, enabling the controlling electronics to 'span' the change in electrical output of the transducer between zero and load to indicate the adjusted value of the applied weight. This means that weighings carried out on the machine while conditions are the same as during the 'spanning' are effectively comparisons against the adjustment weight. This arrangement reduces the magnitude of a number of measurement errors. In general, a better weighing result can be expected if the facility is operated before the machine is used, but it should be noted that only zero and the stored values of the applied weights are set, and therefore the intermediate values may vary in response to ageing and environmental factors.

A1.3.3 This adjustment facility is sometimes initiated automatically, and sometimes manually, depending on the machine. It has historically been referred to by manufacturers as the 'Calibration' or 'Cal' function. In most designs the adjustment weight(s) are contained inside the machine housing and are applied by the machine itself, but in some cases the weights have to be applied externally by the operator.

A1.4.1 Because of the magnetic fields used by electromagnetic force compensation machines, and which may be detectable through the load receptor, there may be significant measurement errors when magnetically susceptible materials such as irons and tungsten carbide are applied to the load receptor. Even stainless steels can cause an effect, and these should always be austenitic, not martensitic.

A1.4.2 It is not necessary for the applied load to be permanently magnetised for there to be an effect, although this is likely to make the effect more pronounced and less predictable. Simply to be significantly magnetically susceptible (to be attracted to magnets) will often be sufficient to cause a measurement error.

A1.4.3 For these reasons it is appropriate to consider whether any potentially magnetically susceptible materials are used with the weighing machine, either for weighing or, as in the case of crucibles or weighing boats, for holding material being weighed. If there is any possibility of this happening, the machine should be evaluated to see if it is significantly affected by magnetic influences; if it is, possible preventative measures can then be assessed. See section 3.7 for more information. If no preventative measures are possible, consideration should be given to whether the machine is fit for purpose.

A2 SINGLE PAN - TWO KNIFE EDGE

A2.1 These machines are either termed top-loading or analytical, and are usually critically damped.

A2.2 In a top-loading machine, the pan is supported above the balance beam by a linkage system and there is usually no arresting mechanism.

A2.3 An analytical machine has the pan suspended below the balance beam and the beam is arrested during loading and unloading of weights on the pan.

A2.4 These machines have built in weights so that when a weight is placed on the pan an equivalent weight is removed from the pan assembly, thus ensuring that the weight to be supported by the knife edges in the machine is approximately constant. Machines of this type are referred to as constant load machines. An optical or digital display indicates the value of the weight on the pan.

A3 TWO PAN - THREE KNIFE EDGE

A3.1 These weighing machines have three knife edges that lie in a plane. Two of the knife edges support the pans and are nominally equidistant from the central knife edge. This type of weighing machine is known as an 'equal arm machine' and may be damped or undamped.

A3.2 When two approximately equal weights are placed one on each pan, the beam comes to rest at an angle to the horizontal when the centre of gravity of the system lies directly under the central knife edge. This position is known as the rest-point and is indicated by means of a pointer attached to the beam.

A3.3 Damped weighing machines usually have a light and optical projection system to image a scale or graticule onto a screen and damping is usually arranged to be critical, that is the pointer crosses the rest-point once and then comes to rest. The damping medium may be oil or a magnetic field, but is usually air.

A3.4 Undamped weighing machines, although subject to a small amount of natural damping, are operated in a dynamic mode, that is, readings are taken without waiting for the pointer to come to rest. Readings are taken of the pointer turning points and the centre of the swing or rest-point is obtained from a standard formula, $[(t_1 + t_3)/2 + t_2]/2$, where t_1, t_2 and t_3 are successive values of the turning point. It is usual for at least the first swing after release of the beam to be ignored, as it may be unrepresentative of the decay of subsequent swings.

A4 OTHER INDUSTRIAL MACHINES

A4.1 Other weighing machines generally used for industrial weighing include platform machines, counter machines and weighbridges. Most of these have flat plate load receptors and use mechanical or electronic (load cell or force compensation motor) measurement systems.

A4.2 These fall into three main groups:

(a) Platform machines using load-cell sensors, usually having no lever mechanism for amplification (or reduction) of the applied force.

(b) Platform machines employing mechanical levers for reduction of the applied force using a mechanical indicator such as a steelyard, or pointer and dial - also used for the smaller counter machines; or an electronic display from a force compensation motor.

(c) Some counter machines are essentially two-pan mechanical devices, but do not use a simple beam. These require the use of weights to counterbalance the major part of the force. An analogue scale indicates the difference in the two weights.

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