Beamex

Calibration White Paper

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Weighing scale calibration - How to calibrate weighing instruments

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A BETTER WAY TO CALIBRATE

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Weighing scales, weighing instruments, weighing balances… different resources are using different terminology. I will be mainly using the term "weighing instrument" in this article.

Weighing instruments/scales/balances, are widely used in industry for various measurements. Some weighing instruments are small laboratory instruments measuring a few grams and are very accurate. While some industrial weighing instruments are very large ones that measure, for example, mass of trucks. We all see weighing instruments in our everyday life around us, for instance, when we visit a grocery store and weigh vegetables.

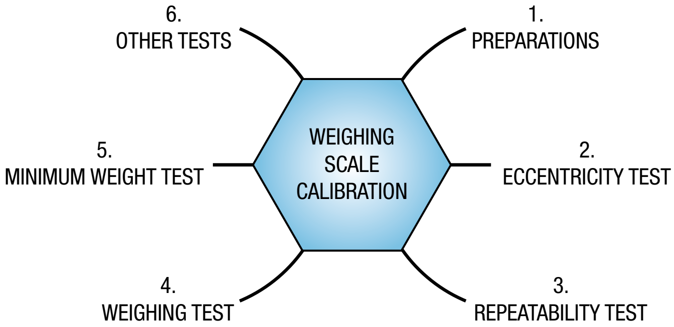
As with any measurement instruments, weighing instruments should also be calibrated regularly to assure that they are measuring correctly and accurately. A proper metrologically traceable calibration is the only way to know how accurately weighing instruments are measuring.

Many weighing instruments are used for legal measurements or measurements used as basis for monetary transfer and these are part of a legal or statutory verification program based on legislation. Often the calibration of weighing instruments is based on a quality system (such as ISO9000), health care, traffic (air, marine) safety or forensic investigation. There are dedicated regulations for weighing instruments and their calibration (EURAMET Calibration Guide, NIST Handbook 44, OIML); more on those later in the article.

In this article, the main focus is to look at the practical considerations and the different tests you should perform when calibrating your weighing instruments.

Calibrating weighing instruments

Let's start by looking at some of the preparations you should make before the calibration and then look at the different tests you should be doing.



1. Preparations before calibration

Before you can start the calibration of the weighing instrument, you should clarify a few things and get prepared. You should find out the technical characteristics of the weighing instrument (max weight, d value), the accuracy requirement (max error allowed and uncertainty) and what to do if the calibration fails (adjustment).

Typically, the whole measurement range is calibrated and the calibration is performed in the location where the instrument is being used. Make sure you have enough weights for the calibration procedure available.

The weighing instrument should be switched on at least 30 minutes before the calibration. The temperature of the weights should be stabilized to the same temperature where the calibration is to be done.

The weighing instrument should be at a horizontal level, especially for small and accurate weighing instruments. Perform a few pre-tests by placing weights close to the maximum of the range on the instrument and to ensure it works normally.

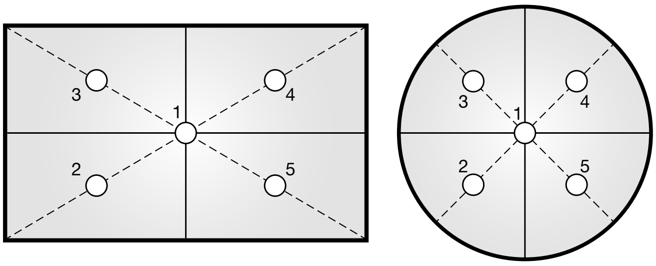
In case the weighing instrument fails in calibration and it is adjusted, you should make an "as found" calibration before adjustment and an "as left" calibration after adjustment.

Next, let's take a look at the different tests that should be done during the calibration.

2. Eccentricity test

In normal use of a weighing instrument the load is not always placed perfectly on the center of the load receptor. Sometimes the results of a weighing instrument can vary slightly depending if the load is placed in different locations on the load receptor. In order to test how much effect the location of the load has, the eccentricity test is performed.

In the eccentricity test, the reference load is placed in a few different specified locations on the load receptor. First, the load is placed in the center of the load receptor (the load's center of gravity) and the result is observed. Next, the load is placed in four different sectors of the load receptor, as illustrated in the picture.



The above picture is for rectangular and round load receptors, but naturally in practice there are many different shapes of load receptors and the location of the load will vary. Standards OIML R76 and EN 45501 will give guidance for different load receptor shapes.

The calibration procedure should specify where to place the load during the test and calibration results (in certificate format) should also document the locations.

The test load used in an eccentricity test should be at least one third (1/3) of the max load of the weighing instrument. The test should preferably be done using just one test load, if possible. That way it is easier to be sure that the load's center of gravity is in the specified location. For a weighing instrument with multiple ranges, the eccentricity test should be done with the highest range.

As the aim of the eccentricity test is to find out the difference caused by the location of the load, it is not necessary to have an accurate calibrated load. It is naturally important to use the same load through the test.

If the eccentricity test is used also to determine the errors of the indication, then a calibrated load should be used.

Procedure for the eccentricity test

The indication is zeroed before the test. The test load is placed to location 1 and indication is recorded. The test load is then moved to location 2 to 5 and indication is recorded in each location. Finally, the test load is placed again to location 1 to check that the indication has not drifted from the earlier indication in location 1.

The zero may be checked between each location to see that it has not changed. If necessary, the instrument can be zeroed in between each test.

Alternatively, you may also tare the instrument when the load is in location number 1, as this makes it easier to see any difference between locations.

3. Repeatability test

As any instrument, also weighing instruments may suffer from repeatability issues. This means that when the same load is measured several times, the result is not always exactly the same. To find out the repeatability of the instrument, a repeatability test is done.

The repeatability test is performed by replacing the same load on the same place on load receptor (to avoid any eccentricity error) multiple times. Test should be done in identical and constant conditions and with identical handling.

The load used should be close to the maximum load of the instrument. Often a repeatability test is done with one load only, but it can be done also with several different load values separately.

The load does not necessarily need to be a calibrated load, as the aim is to find out the repeatability. If possible, the load used should be a single load (not several small loads).

A repeatability test is normally done by repeating the measurement at least 5 times in row. For instruments with a high range (over 100 kg / 220 lbs), it should be done at least 3 times.

In the repeatability test, the instrument is first zeroed, then the load is placed on load receptor and indication is recorded once it is stabilized. Then the load is removed and zero indication is checked and zeroed if necessary. Then the load is placed again, and so on.

For a multi-range instrument, a load close but below the first range max is often sufficient.

4. Weighing test

The purpose of the weighing test is to test the accuracy (calibrate) of the weighing instrument throughout its whole range in several steps, with increasing and decreasing weight.

The most common practice is the following: start with zeroing the instrument without any load. Set the loads of the first test point, wait for stabilization, and record the indication. Continue increasing the loads through all the increasing test points. Once the maximum load is recorded, start decreasing the loads through the decreasing test points.

In some cases, the weighing instrument may be calibrated with increasing loads only or decreasing loads only.

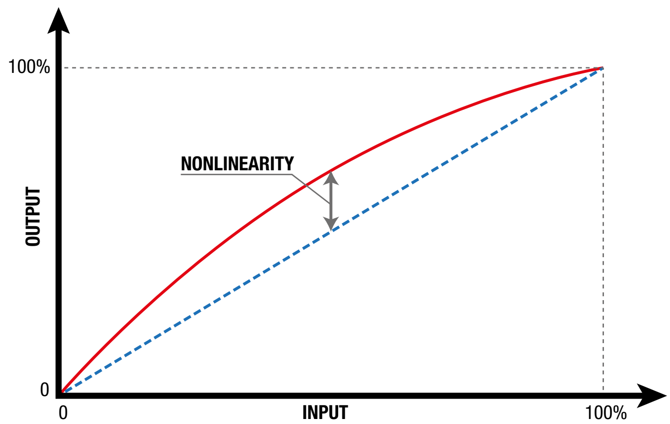
Typically, 5 to 10 different loads (test points) are used. The highest load should be close to the maximum of the instrument. The smallest test load can be 10% of the maximum load, or the smallest weight normally used. Generally, the test points are selected so that they are equally distributed throughout the range. More test points can be used for the typical range of usage of the instrument.

With multi-range instruments, each range is to be calibrated separately.

Linearity

In a weighing test, using multiple points through the measurement range of the instrument helps to reveal any issues with linearity. Linearity issues means that the instrument does not measure equally accurate throughout the range. Even the zero and full span are correct, there may be errors in the middle of the range, which is referred as linearity errors, or unlinearity (or nonlinearity).

Below picture is a general illustration of unlinearity. Even instrument's zero and full range are adjusted correctly, there is error in the midrange due to unlinearity of the instrument:



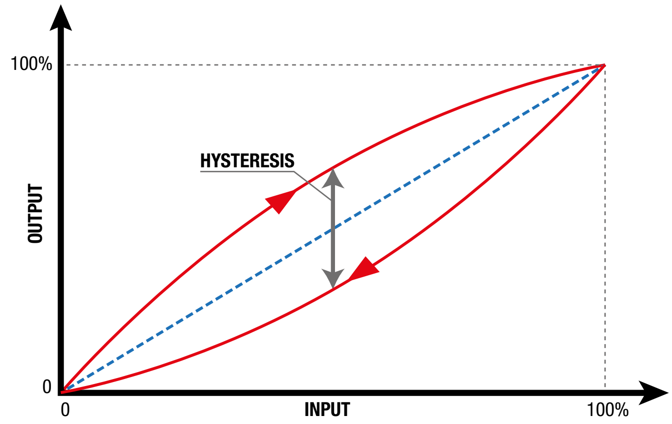
Hysteresis

Hysteresis is the difference in the indication when a test point is approached with increasing or decreasing weight. To find out any hysteresis issues in the instrument, you need to calibrate with increasing and decreasing points.

In a weighing test, when increasing or decreasing the load, it is important not to overshoot or undershoot. This means that when you increase the load, you must approach each test point with increasing weight. You should not add too much weight and then remove it, because then you lose the hysteresis information.

Likewise, with decreasing points, make sure that you approach each point with decreasing weight. Obviously, in order to be able do this, the usage of the test loads should be well planned in advance.

Picture below is a general illustration of hysteresis. When instrument is calibrated, the results are different with increasing and decreasing calibration points:



5. Minimum weight test

Minimum weight test is a test that is not always required to be done. This test is anyhow required within some industries, like the pharmaceutical industry.

The purpose of the minimum weight test is to find the smallest load that can be measured while still achieving reliable measurement results and fulfilling the accuracy requirements. When the measured value gets smaller, typically the relative error of the reading becomes higher. The weighing instrument should not be used to measure any loads smaller than the minimum load.

For the minimum weight test, the two main standards have different approach. Let's take a quick look of those:

The US Pharmacopeia (Chapter 41) – After the recent changes in the standard it does not refer to a minimum weigh test anymore, this has been replaced by the requirement to determinate the instrument's minimum operating range by finding the point where the instrument's repeatability (2 times standard deviation) is 0.10% of reading.

In practice, in some cases the standard deviation can be very small, but the minimum weight to be measured should anyhow not be smaller than 820 times the actual scale interval (d).

EURAMET Calibration Guide 18 (Appendix G) – Has the principle that you calculate the measurement uncertainty for each calibration point and the smallest usable load is the point where the uncertainty is still small enough for the requirements for the instrument.

In addition to the above standard requirements, the requirements in the pharmaceutical industry requires a separate minimum weighing test, where a small test load is measured multiple times to find out the accuracy of the instrument with a small load.

6. Other tests

There are also some other tests specified in the standards, although these are typically not done during a normal calibration, but can be done as a type of approval test or in the initial verification. Example of these tests are:

- Tare test
- Discrimination test
- Variation of indication over time
- Test of magnetic interaction

Weights

For the calibration, it is recommended to use classified reference weights. For example, OIML (Organisation

Internationale de Métrologie Légale) recommendation R111 have recommendations for the classification of the weights (E1, E2, F1, F2, M1, M1-2, M2, M2-3 ja M3).

Handling of weights

Obviously, the weights should be handled so that it does not change the metrological characteristics of the weights. The weights should not be placed on surfaces that will cause scratches or on dirty surfaces. When cleaning weights, special attention should be paid for proper cleaning.

Smaller weights should be handled with gloves, not with bare hands, to avoid any finger grease from getting onto the weights and to avoid warming the weights to a higher temperature than the environment.

When not used, the weights should be stored in their own storage boxes. Weights should be stored so that only authorized personnel have access to them. Very large weights should be covered and stored in stabile environmental conditions. Humidity condensing on weights should be avoided.

Nominal mass / Conventional mass

The terms nominal mass and conventional mass are used when talking about weights.

- **Nominal mass** is the nominal mass of the given weight, and when the weight is accurate enough, when used in legal verification, it is enough to use the nominal mass as the true value.
- **Conventional mass** is the actual calibrated accurate mass of the weight that has been corrected with any required local corrections. To make traceable calibrations, you should always use the conventional mass.

Calibration of weights

Weight should be traceably calibrated regularly using an accredited calibration laboratory or a national calibration laboratory. Typically, the calibration period for weights is 1 to 5 years.

It is also possible that you calibrate the weight yourself, if you have a suitable weighing instrument and reference weights to do that.

For more information on traceability, please see the blog post Metrological Traceability in Calibration – Are you traceable?

Local gravity

Local gravity is slightly different in different locations around the globe. This is due to many things such as the altitude (lower gravity in higher altitudes), latitude (lower gravity closer to equator), local geology and some other factors.

Although gravity does not affect the mass of the weight, it does affect the force of the mass on the weighing instrument (Force = gravity x mass). And since a weighing instrument is measuring the force, the gravity has an effect on the instrument's reading.

If you move your weighing instrument into a new location, you may need to adjust it, depending how accurate the instrument is and how much is it moved.

Often, reference weights are calibrated in a different location than where the weights are being used, which can be in a different city and in some cases that are far away from each other. Therefore, the gravity difference needs to be considered, when you use the reference weight to calibrate/adjust your weighing instruments.

Air buoyancy

When weights are being used, air buoyancy will cause a small force that will make the force of the mass smaller. So, we can think that air buoyancy kind of lifts the weights up very slightly.

The effect of air buoyancy depends on the environmental conditions and on the differences of the density of the weights compared to air density. As the effect of air buoyancy is relatively small, and does not change that much from day to day, it is not always considered.

Effect of convection

If the temperature of the weight differs from the environmental temperature, there will be an air convection around the weight. The bigger the temperature difference is, the bigger the convection is. This convection will have a small effect on the indication of the weighing instrument.

For example, if the weight is colder than environment, the air convection around the weight will go down facing the weighing instrument and cause small additional weight to the weighing instrument. The effect of convection is more relevant with high accuracy instruments, although it is still relatively small.

Substitution load

Substitution loads are something that can be used if there are not enough weights for the calibration. For example, if you have one weight of 100 kg and two weights of 200 kg (total 500 kg) and you need to calibrate a 1,000 kg weighing instrument. What do you do? You calibrate the first points up to 500 kg using the weights you have and then you read the exact indication of the weighing instrument when the 500 kg load is on, then you remove the weights and put some kind of substitution load on the weighing instrument until the indication is exactly the same as it was with the 500 kg weights. Then you know that your substitution load has the same weight as your accurate reference weights. You can then continue adding your weights while keeping the substitution load on till you reach the 1,000 kg.

Calibration certificate

As with any calibration, an essential part of calibration is to document the results in the calibration certificate.

The certificate naturally includes the measurement results of the calibration, i.e. the mass of the weights placed on instrument and the indication of the instrument. This includes all the different measurements/tests that were done during the calibration, as mentioned earlier.

The certificate should also include the total uncertainty of the calibration, this number without related uncertainty does not tell very much about the measurement. The certificate should also include a clear description of the instrument being calibrated and the weights being used as reference. The calibration procedure that was followed should also be included. Environmental conditions during the calibration should also be included in the certificate.

To shortly summarize, certificate should include:

- measurement results
- a unique certificate number
- customer name, address and identification
- name, signature and company of the person who did the calibration
- detailed information on the instrument that was calibrated
- identification of the reference weights being used
- identification of the calibration procedure being used
- calibration date
- environmental conditions
- measurement uncertainty and its coverage factor
- mention of the case when only a partial calibration was done
- a graphical representation of the calibration results if possible (useful visual component)

If the calibration is an accredited calibration, then the regulation will stipulate the contents of the certificate.

Uncertainty

As in any calibration, also in weighing instrument calibration, the uncertainty of the calibration should be known. This purpose of this summary is not to go into details on how to do uncertainty calculations, but to discuss in more general level.

Knowing the error of the scale indication at each calibration is not sufficient. You must also know the uncertainty (how certain you can be) about the error found at each point of calibration. There are several sources of uncertainty of the error in weighing instrument calibration, such as:

- The masses of the weights are only known with a particular uncertainty.
- Air convection causes extra force on the load receptor.
- Air buoyancy around the weights varies according to barometric pressure, air temperature and humidity.
- A substitute load is used in calibrating the scale.
- Digital scale indications are rounded to the resolution in use.
- Analogous scales have limited readability.
- There are random variations in the indications as can be seen in the Repeatability Test.
- The weights are not in the exact middle of the load receptor.

When using the weighing instruments in normal use, there are many things that differ from the calibration, and this will also cause some additional uncertainty to the usage of the instrument. These differences include for example:

- Routine weighing measurements involve random loads, while calibration is made at certain calibration points.
- Routine weighing measurements are not repeated whereas indications received through calibrations may be averages of repeated weighing measurements.
- Finer resolution is often used in calibration.
- Loading/unloading cycles in calibration and routine weighing may be different.
- A load may be situated eccentrically in routine weighing.
- A tare balancing device may be used in routine weighing.
- The temperature, barometric pressure and relative humidity of the air may vary.
- The adjustment of the weighing instrument may have changed.

Standard and expanded uncertainties of weighing results are calculated using technical data of the weighing instrument, its calibration results, knowledge of its typical behavior and knowledge of the conditions of the location where the instrument is used. Calculating the uncertainty of the weighing results assists you in deciding whether or not the accuracy of the weighing instrument is sufficient and how often it should be calibrated.

Recommended references for the uncertainty calculation include EURAMET Calibration Guide 18 and the EA-4/02.

Instrument classes, Tolerance classes, Max permissible error

Standard EN45501:2015 classifies weighing instruments into following four different categories (the symbol marked on the instrument is in parenthesis):

- Special accuracy (I)
- High accuracy (II)
- Medium accuracy (III)
- Ordinary accuracy (IIII)

The verification scale interval, number of verification scale intervals and the minimum capacity per EN45501:2015:

Accuracy class	*Verification scale interval e*	*Number of verification scale intervals n=Max/e*		*Minimum capacity, Min*
		min	*max*	*(lower limit)*
Special (I)	*0.001 g ≤ e*[a]	*50 000*[b]	*-*	*100 e*
High (II)	*0.001 g ≤ e ≤ 0.05 g* *0.1 g ≤ e*	*100* *5 000*	*100 000* *100 000*	*20 e* *50 e*
Medium (III)	*0.001 g ≤ e ≤ 2 g* *5 g ≤ e*	*100* *500*	*10 000* *10 000*	*20 e* *20 e*
Ordinary (IIII)	*5 g ≤ e*	*100*	*1 000*	*10 e*

Maximum permissible error per EN45501:2015:

Maximum permissible errors	*For loads, m, expressed in verification scale intervals, e*	
	Class I	*Class II*
±0.5 e	*0 ≤ m ≤ 50 000*	*0 ≤ m ≤ 5 000*
±1.0 e	*50 000 < m ≤ 200 000*	*5 000 < m ≤ 20 000*
±1.5 e	*200 000 < m*	*20 000 < m ≤ 100 000*

Maximum permissible errors	For loads, m, expressed in verification scale intervals, e	
	Class III	Class IIII
±0.5 e	0 ≤ m ≤ 500	0 ≤ m ≤ 50
±1.0 e	500 < m ≤ 2 000	50 < m ≤ 200
±1.5 e	2 000 < m ≤ 10 000	200 < m ≤ 1 000

Tolerance classes according to NIST Handbook 44 (2017 edition):

Maintenance Tolerances (All values in this table are in scale divisions)				
Tolerances in Scale Divisions				
	1	2	3	5
Class	Test load			
I	0 - 50 000	50 001 - 200 000	200 001 +	
II	0 - 5 000	5 001 - 20 000	20 001 +	
III	0 - 500	501 - 2 000	2 001 - 4 000	4001 +
IIII	0 - 50	51 - 200	201 - 400	401 +
III L	0 - 500	501 - 1000	*)	*)

*) Add 1 d for each additional 500 d or fraction thereof.

Related Beamex products

Among a lot of other functionality, the Beamex CMX Calibration Management Software has a dedicated functionality for the calibration of weighing instruments. It has been around for more than 10 years already. CMX supports various tests such as: Eccentricity Test, Repeatability Test, Weighing Tests and Minimum Weighing Test. Both OIML and NISH Handbook (including latest USP 41 updates) accuracy classes are supported. The functionality can be used either with a computer or a mobile device.

For more information on Beamex CMX and its weighing instrument calibration module, please visit CMX product page and read the brochure, or contact Beamex.

RELATED REFERENCES

The most relevant references for this subject include, but not limited to, following:

- EURAMET Calibration Guide No. 18, Version 4.0 (11/2015)
- EN 45501:2015 - Metrological aspects of non-automatic weighing instruments
- NIST Handbook 44 (2017 Edition) - Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices
- EA-4/02 (2013) - Evaluation of the Uncertainty of Measurement in Calibration
- JCGM 100:2008 - Evaluation of measurement data — Guide to the expression of uncertainty in measurement
- JCGM 200:2008 - International vocabulary of metrology — Basic and general concepts and associated terms
- OIML R76-1 - Non-automatic weighing instruments Part 1: Metrological and technical requirements - Tests
- OIML R 111 - OIML R111: Weights of classes E1, E2, F1, F2, M1, M1-2, M2, M2-3 and M3
- DIRECTIVE 2009/23/EC (2009) - Non-automatic weighing instruments