Calibration

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Calibration

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Definition

Operation that, under specified conditions, in a first step, establishes a relation between the **quantity values** with **measurement uncertainties** provided by **measurement standards** and corresponding **indications** with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a **measurement result** from an indication.

Note 1: A calibration may be expressed by a statement, calibration function, **calibration diagram**, **calibration curve**, or calibration table. In some cases, it may consist of an additive or multiplicative **correction** of the indication with associated measurement uncertainty.

Note 2: Calibration should not be confused with **adjustment of a measuring system**, often mistakenly called "self-calibration," nor with **verification** of calibration.

Note 3: Often, the first step alone in the above definition is perceived as being calibration (JCGM 200: *2012*, Definition 2.39).

Theory and Application

Basic Concepts

According to the definition given in the *International Vocabulary of Metrology* (JCGM 200: *2012*, Definition 2.39), calibration establishes a relation between the quantity value provided by a measurement standard and the corresponding indication provided by a measuring instrument or system. Calibration also requires determination of the uncertainties associated with the measurements performed. A calibration can be executed either on a measuring instrument (or system) or on a measurement standard.

The **calibration of a measuring instrument** allows determining the deviation of the indication of the measuring instrument from a known value of the measurand provided by the measurement standard, with associated measurement uncertainty. In other words, the deviation of the indication of an instrument from the conventional "true value" of the measurand is established and documented. For example, this is the case of calibrating micrometers or other dimensional measuring instruments using gauge blocks.

The **calibration of a measurement standard** can be performed by comparing its quantity value and associated measurement uncertainty to a reference indication (with associated measurement uncertainty) obtained by a calibrated measuring system. For instance, a measuring system calibrated by a primary reference standard can be used to calibrate a secondary measurement standard. Also a comparison between two measurement standards can be viewed as a calibration if the comparison is used to check (and, if necessary, to correct) the quantity value and measurement uncertainty attributed to one of the two measurement standards. This is, for example, the case of the calibration of gauge blocks through comparison with other previously calibrated gauge blocks.

In certain fields, such as measurement of quantities in biological samples and medical applications, a measurement standard used for calibration can be called "calibrator" (see JCGM 200: 2012, Definition 5.12).

As explicitly stated in the *International Vocabulary of Metrology*, calibration should not be confused with verification nor with adjustment. Verification in fact is the "provision of objective evidence that a given item fulfils specified requirements" (JCGM 200: 2012, Definition 2.44). For example, this is the case of checking if a measuring system achieves the performance properties stated by the manufacturer. Adjustment, on the other hand, is "the set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured" (JCGM 200: 2012, Definition 3.11). Calibration is a prerequisite for adjustment, and after the measuring system has been adjusted, a recalibration must usually be performed.

Calibration is typically performed in metrological laboratories under controlled environmental conditions. The relation established by a calibration maintains its validity under the specified operating conditions in which the calibration is performed.

In general, for daily operation of a measuring system in a company, a global calibration is usually not needed. A task-related calibration can be performed, which is a calibration of only those metrological characteristics that influence the measurement uncertainty for the intended use (see ISO 14978:2006).

Why Are Calibrations Necessary?

There are technical and legal reasons why calibration is performed. Four main reasons for having an instrument calibrated are, e.g., outlined in the EURAMET handbook "Metrology – in short" (2008):

1. To establish and demonstrate metrological traceability

2. To ensure readings from the instrument are consistent with other measurements

3. To determine the accuracy of the instrument readings

4. To establish the reliability of the instrument, i.e., that it can be trusted

To guarantee interchangeability of parts, it is fundamental to establish traceability of measurements to national standards by means of calibration. In particular, suppliers and customers producing and assembling parts with other components must ensure valid measurement results and need to measure parts with the "same measure." For organizations with quality management systems, calibration is also a requirement of ISO 9001, which states that "when necessary to ensure valid results, measuring equipment shall be calibrated, or verified, or both, at specified intervals, or prior to use, against measurements standards traceable to international or national measurements standards" (ISO 9001: 2008).

Documentation of Calibration Results

The results obtained by a calibration are documented in a calibration certificate or calibration report. The associated measurement uncertainty must be stated.

Information gained with calibration may be expressed by a statement, a function, an additive or multiplicative correction of the indication, a **calibration diagram**, or a **calibration curve**. For the latter ones, the *International Vocabulary of Metrology* gives the following definitions.

Calibration diagram: graphical expression of the relation between **indication** and corresponding **measurement result**.

Note 1: A calibration diagram is the strip of the plane defined by the axis of the indication and the axis of measurement result that represents the relation between an indication and a set of **measured quantity values**. A one-to-many relation is given, and the width of the strip for a given indication provides the **instrumental measurement uncertainty**.

Note 2: Alternative expressions of the relation include a **calibration curve** and associated **measurement uncertainty**, a calibration table, or a set of functions.

Note 3: This concept pertains to a **calibration** when the instrumental measurement uncertainty is large in comparison with the measurement uncertainties associated with the **quantity values** of **measurement standards** (JCGM 200: *2012*, Definition 4.30).

Calibration curve: expression of the relation between **indication** and corresponding **measured quantity value**.

Note: A calibration curve expresses a one-to-one relation that does not supply a **measurement result** as it bears no information about the **measurement uncertainty** (JCGM 200: *2012*, Definition 4.31).

While a calibration curve needs a separate statement for measurement uncertainty, a calibration diagram delivers a complete statement of the information obtained with calibration, including the measured value and the associated measurement uncertainty.

Calibration Hierarchy

To ensure metrological traceability, a calibration made at a local level, such as an industrial internal calibration (also called in-house calibration), must be linked to a national standard by an unbroken chain of calibrations, with each step explicitly supported by appropriate documentation (ILAC P10:01/ *2013*). The measurement uncertainty necessarily increases along the sequence of calibrations, starting from the national level down to the local level. Therefore, the prerequisite of metrological traceability is the establishment of a calibration hierarchy as shown in Fig. 1.

The calibration hierarchy is defined in the *International Vocabulary of Metrology* as follows.

Calibration hierarchy: sequence of **calibrations** from a reference to the final **measuring system**, where the outcome of each calibration depends on the outcome of the previous calibration.

Note 1: **Measurement uncertainty** necessarily increases along the sequence of calibrations.

Note 2: The elements of a calibration hierarchy are one or more **measurement standards** and measuring systems operated according to **measurement procedures**.

Note 3: For this definition, the “reference” can be a definition of a **measurement unit** through its practical realization or a measurement procedure or a measurement standard.

Note 4: A comparison between two measurement standards may be viewed as a calibration if the comparison is used to check and, if necessary, correct the **quantity value** and measurement uncertainty attributed to one of the measurement standards (JCGM 200: 2012, Definition 2.40).

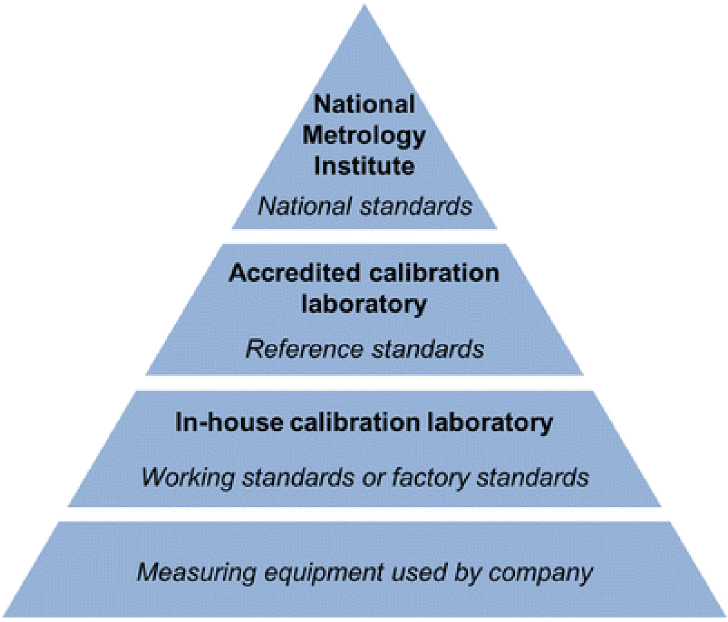

Fig. 1
Illustration of a calibration hierarchy

Organizations Performing Calibration

Different organizations perform calibrations (Fig. 1): national metrology institutes, accredited calibration laboratories, and in-house calibration laboratories (ILAC P10:01/ 2013). In each step of the calibration chain, measurement standards are used to calibrate measuring equipment of the next step. For example, an accredited laboratory can calibrate a company's working standard against a reference standard. Accredited laboratories must fulfill the requirements of (ISO 17025: 2005). Above the national organizations, at the international level, decisions concerning the International System of Units (SI) and the realization of the primary standards are taken by the Conférence Générale des Poids et Mesures (CGPM). The development and maintenance of primary standards is coordinated by the Bureau International des Poids et Mesures (BIPM), which also organizes intercomparisons on the highest level. The International Laboratory Accreditation Cooperation (ILAC) promotes laboratory accreditation and the recognition of competent calibration and test facilities around the world.

Calibration Interval

Calibrations must be repeated at appropriate intervals (ILAC G24: 2007). A measurement instrument, for example, should be periodically recalibrated because changes in its characteristics can occur during its use and after some time. Recalibration on appropriate intervals ensures detection of these possible changes. The length of these intervals will depend on a number of variables, such as:

Uncertainty required
Frequency of use
Way of use

Environmental conditions at use
Stability of the equipment

Cross-References

Accuracy
Measurement Uncertainty
Traceability

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