Instrument Systems
KONICA MINOLTA Group

Calibration makes the difference

Keep the error budget as low as possible

In light measurement technology, there are hardly any limits to the variety of measurements and measurands. The realization of the measurement setup also plays an important role for the correct interpretation of measurement results, as it has a significant impact on the error budget. When are measurement results precise, accurate or even absolute?

In a measurement, the value of a physical quantity is quantified by comparison with a suitable measuring instrument. For example, a photodetector provides a signal that is proportional to the emitted power of a light source. The quality of this signal results from its measurement uncertainty. Does the repetition of the measurement provide the same signal and thus precise measurement results? Are the measurements of calibrated photodetectors accurate and thus comparable? Are the measurement results traceable to national standards and therefore absolute?

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PAPER

\\ EACH MEASUREMENT HAS ITS OWN MEASUREMENT UNCERTAINTY

An important finding in the science of measurement (metrology) is that every measurement has a measurement uncertainty that cannot be avoided. The measured value is therefore only an estimate of the value searched for and the measurement uncertainty is the measure of the reliability of the measurement. A complete result in metrology always includes not only the numerical measured value with unit but also the determined measurement uncertainty. This depends on the measurement method used. The measurement uncertainty of the measuring instrument is only one of several contributions to the measurement uncertainty budget of the performed measurement. Other factors, such as the stability of the measurement object and the execution of the measurement (e.g., exact setting of distances), also contribute to this (Figure 1). The person responsible for the measurement must determine the budget for all factors.

Measuring instruments are often used for quality assurance. A consistent quality of the manufactured products should also apply to different production lines at different locations. To ensure the comparability of measurement results, the so-called 'Meter Convention' was concluded in 1875. It created an internationally uniform metric system for units of measurement, called the SI system (Système international d'unités). Since

Fig. 1: Measurement setup for the calibration of a spectrometer with integrating sphere to irradiance with a reference lamp.

revision 2019, the SI system has comprised seven SI base units based on seven constants, including the speed of light c. This ensures that the selected definitions of the SI units are independent of a concrete realization. Photometric measures are all related to the light intensity (candela, cd). Their definition takes place via the photometric radiation equivalent Kcd, which ensures the link with the historical definition of the candela.

\\ CONTINUOUS CALIBRATION CHAIN

In practice, the SI units are passed on, thus ensuring metrological traceability, by means of calibrations (Figure 2). Traceability is based on a chain of measurements that can be clearly traced back to

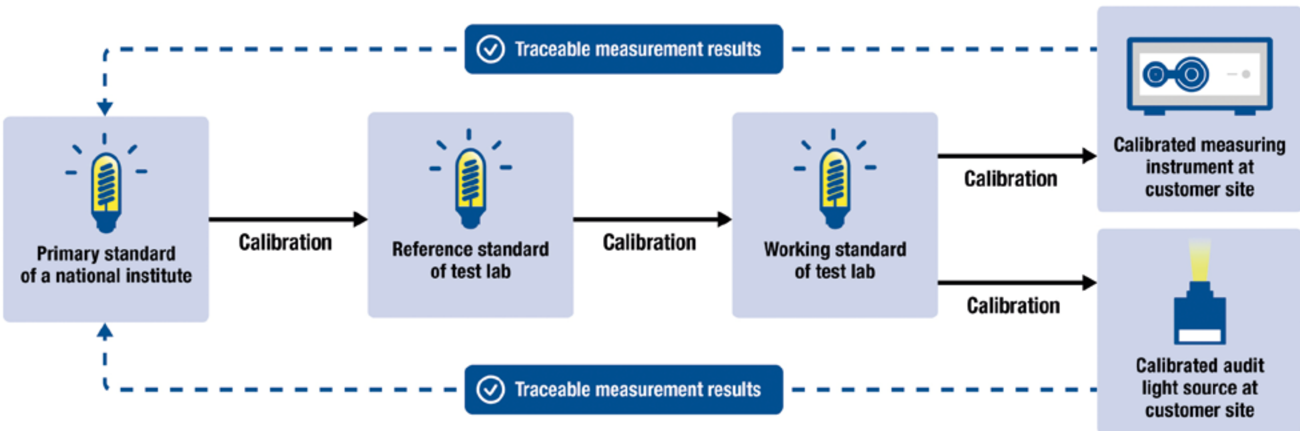

Fig. 2: Continuous calibration chain from the national Institute to the customer.

a primary representation of the SI units. In light measurement technology, reference light sources have been used since its beginnings both for the transmission of the units and for the calibration of measuring systems as so-called calibration standards. In many applications, their spectral distribution corresponds approximately to that of a Planck emitter with a temperature of 2,856 K, the 'standard light type A'.

There are two basic methods for calibrating measuring instruments and light sources in light measurement technology:

- In direct calibration, a detector is calibrated with a reference light source (standard) or, conversely, a light source with a reference detector (standard).
- In indirect calibration, a detector is calibrated with another detector (standard) by means of comparative measurements on the same light source (transfer standard) according to the substitution method or, conversely, a light source with another light source (standard) by measuring with the same detector (transfer standard).

For the comparability of the measurement results, it is important to ensure an uninterrupted calibration chain from the measuring instrument used to a primary standard (realization of the SI base unit). Measuring instrument manufacturers and test laboratories therefore often use so-called reference standards (reference standards), which have been calibrated by a metrology institute (e.g., PTB or NIST) to ensure the best possible metrological traceability. Since the number and service life of reference standards is limited, so-called use or work standards (working standards) are regularly generated for daily laboratory operation according to the procedures described above. These are used daily in the test laboratory to calibrate and test the measurement objects (e.g., spectroradiometers and light sources).

\\ REGULAR CONTROL REQUIRED

Leading manufacturers of light measurement technology often operate an accredited test laboratory for the quality assurance of their devices. Here, the measuring instruments produced undergo a detailed quality check and the results are documented in test certificates. In Germany, test laboratories are accredited to DIN EN ISO / IEC 17025:2018 by the DAkkS (German Accreditation Body) to ensure the comparability of measurement results. DAkkS is a full member of ILAC (International Laboratory Accreditation Cooperation), which also ensures the international validity and recognition of accreditation. The standard underlying the accreditation defines the requirements

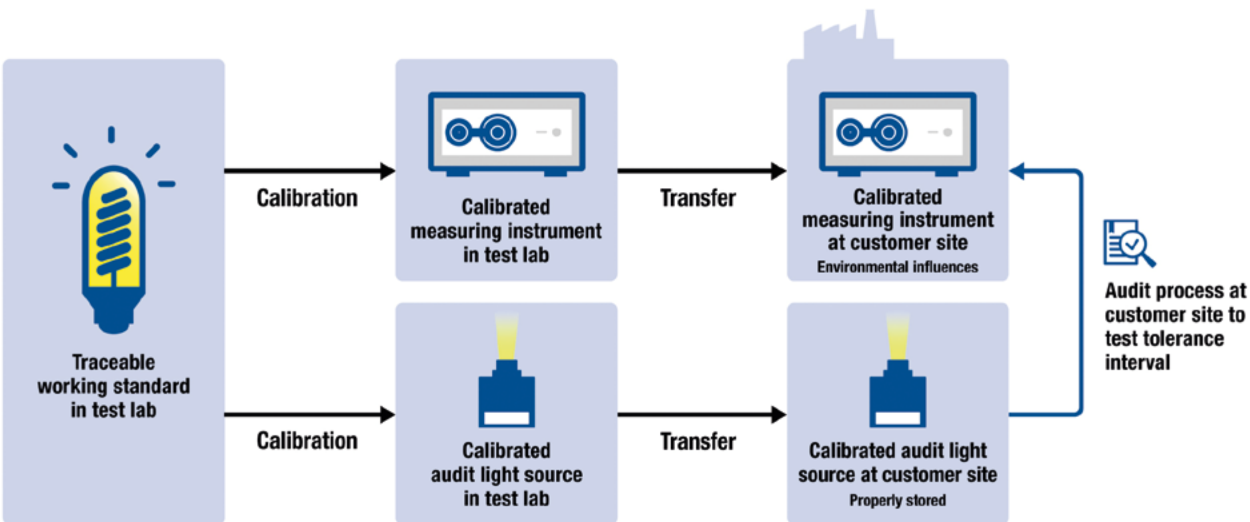

Fig. 3: Regular audits with, e.g., audit light sources ensure that the measurements keep within with the specified tolerance.

placed on the test laboratory. Special emphasis is placed on technical details, such as the selection of test methods, validation, metrological traceability and the assessment of measurement uncertainty.

Due to environmental influences, measuring instruments are subject to changes that can have an impact on the results. Each device should therefore be subjected to a regular inspection, by which compliance with the specified tolerance interval is checked. For example, this kind of audit is carried out with a set of calibrated light sources at the customer's site (Figure 3). The right time for recalibration at the manufacturer can be exactly determined, based on previously-defined test criteria. High-quality, stable measuring instruments achieve reliable results over very long periods of time, which can be ensured by regular audits.

\\ PRECISE, ACCURATE AND ABSOLUTE MEASUREMENT RESULTS

In order to obtain an absolute measurement result that is comparable regardless of the actual execution, the signal of a measuring instrument must be specified as a multiple of a clearly defined SI unit. At the same time, the measurement uncertainty is required for the specific measurement, both of which require traceable calibration. The starting point of a calibration is always a comparison object (benchmark), which is completely known with regard to the quantity to be measured, including the measurement uncertainty, and is traceable through an uninterrupted calibration chain to a realization of the SI units, for example by PTB. In the case of the photodetector, this can be a light source via which the signal is set in relation to the radiated power of the normal. A high-quality measuring instrument provides repeatable, precise measurement results (Figure 4). Its calibration ensures accurate measurement results with low measurement uncertainty. Using national standards, the measurement results are traceable and therefore absolute.

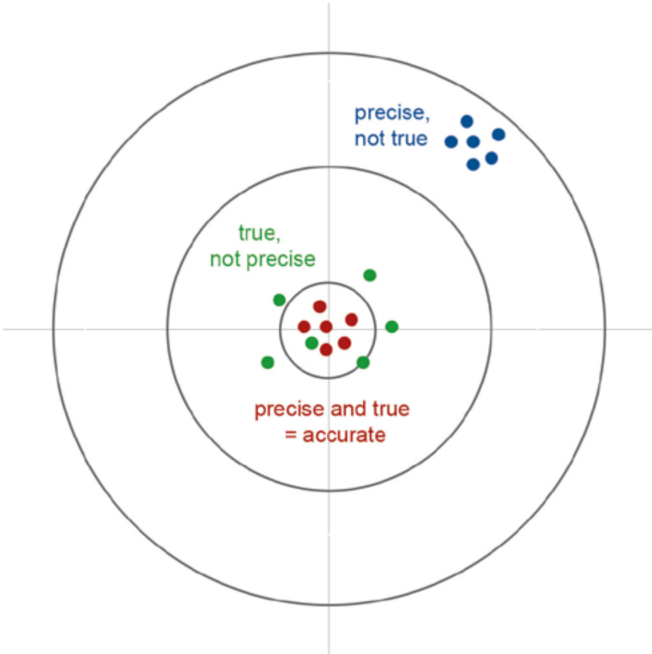

Fig. 4: Difference between precise, correct and accurate measurement results.

Calibration versus Testing

In a calibration, the measurement result of a device is compared with a traceable standard for the relevant measurand and the associated measurement uncertainty is determined.

In a test, the correctness of the measurement result of a calibrated device is ensured by comparison with a traceable standard for the relevant measurand. The correctness applies to the measurement method used within the measurement uncertainty determined for the measuring arrangement.

Instrument Systems GmbH | Kastenbauerstr. 2 | 81677 Munich, Germany | ph: +49 (0)89 45 49 43-58
fax: +49 (0)89 45 49 43-11 | info@instrumentsystems.com | www.instrumentsystems.com