Management Systems and the Calibration of Torque Sensors

1 Introduction

The quantity of certifications of management systems shows that many companies place the quality of their products on top level. In order to measure with the correct quantity, the test resource management is a very important component of all QM systems. If it is used correctly, the measurement and test resources need to be calibrated in regular intervals. The demands are well described in the relevant norms, but as soon as a calibration on a measuring instrument must be carried out, the problem occurs which method of calibration is the correct one. Through the many procedures on the market, offered in form of proprietary calibrations according manufacturer's guideline, following a standard XYZ, or even as calibrations according to EN ISO 9001, the user of a measuring instrument can lose the overview quickly. Further, there are the "expensive" DAkkS-calibrations which are offered from accredited calibration laboratories whose sense is recognized by many customers only in case of product liability.
This article is supposed to explain the most usual QM systems and available calibration standards by the example of torque sensors. Only if we have understood which correct test equipment management is needed according to the state of technique and science, we can decide how torque sensors are to be inserted into the test resource supervision, correctly and which calibration laboratory comes into consideration for this service.

2 QM-System and Calibration

In many writings we can read that the standard series EN ISO 9000 has been enforced internationally and therefore the most frequent certifications of the management system occur according this standard. Thereafter, ISO TS 16949, which is understood as a supplement to the standard series EN ISO 9000, imperatively applies for all automobile suppliers. We first want to take a look at both of these QM standards with respect to the test resource management, further we will see what attention has to be paid to calibrations. Then we will take a look at the standards and guidelines for the correct calibration of torque measuring instruments according to the state of techniques.

2.1 Test Equipment Management according EN ISO 9001

The test equipment and test resources can be found in the main chapter 7 "Product realization" and do not take up a lot of space in this standard. In subchapter 7.6 we can learn how to arrange a test equipment management according to this standard. According to this, we must calibrate our measuring equipment regularly. If the measuring equipment is outside of the tolerance, it must be adjusted and the calibration status must be marked on the measuring equipment. More precise information e.g. the meaning of calibration, is not described in this standard. The attentive reader will only find a reference to EN ISO 10012 at the end of the cited chapter with the title "Measurement management systems – Requirements for measurement Processes and measurement equipment".
We also do not find essential hints in the "Guideline for Improvement of Performance" EN ISO 9004.

2.2 Test Equipment Management according ISO TS 16949

As already described above, the EN ISO 9001 is the basis for this standard, so the comment about EN ISO 10012 keeps its validity. In addition, further requirements occur for the test equipment management, as for example recording of

- Traceability to national standard.
- Fulfillment of the metrological requirements after the calibration.

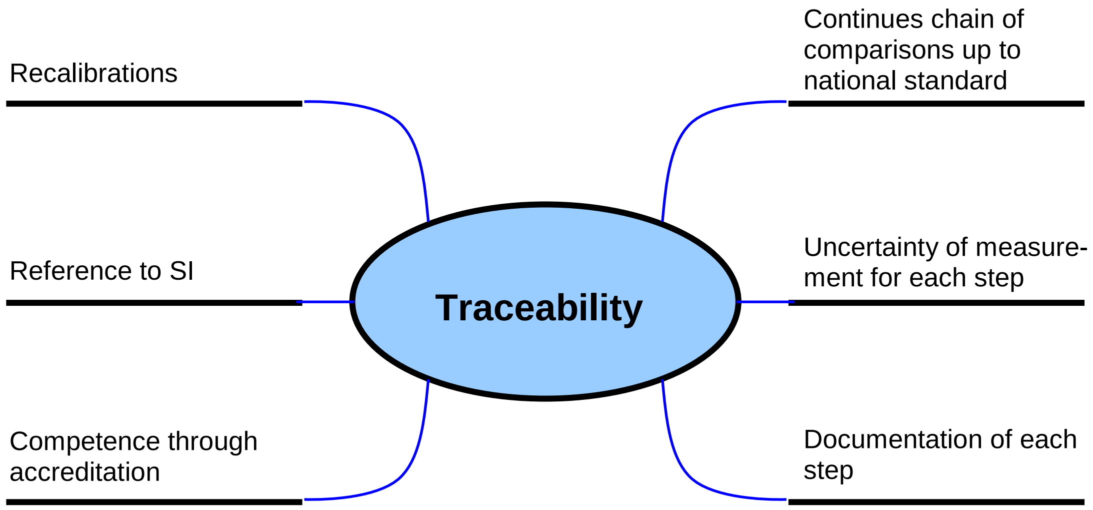
The calibration through external laboratories must fulfill additional requirements such as:

- The lab must show a defined field of activities (in our case torque).
- It must be accredited according to EN ISO/IEC 17025.

3 EN ISO 10012 Measurement systems – Requirements for measurement Processes and measurement

This standard was released in revised form in 2003. Here the correct calibration is described and the necessary elements respectively. From this "dry" text of the standard we can take the information that the **Uncertainty of Measurement** and the verification of the **Metrological Traceability** of the SI (international systems of units) are absolutely to be performed by a calibration. The parts which contribute to the uncertainty of measurement must also be known – at torque these are for example the repeatability and/or the reproducibility, the reversal error, the zero error etc. Further it is described that each measuring process must occur according to documented procedures. This means that there

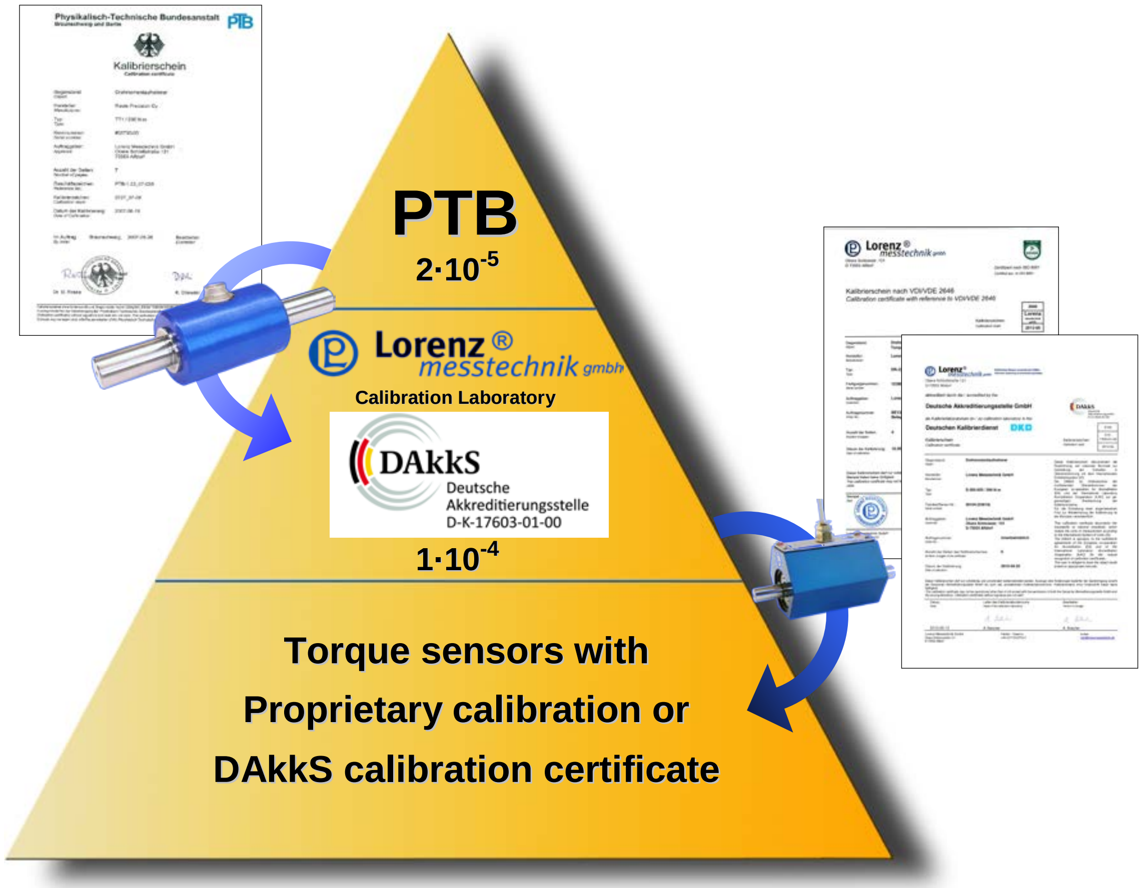
must be a description e.g. a directive for each measuring process. A calibration is also a measuring process and must therefore be carried out according to documented and acknowledged procedures.
The requirement that the uncertainty of measurement must be estimated for each monitored measuring process is the most difficult task. It is recommended to line up an uncertainty of measurement budget according to the worldwide acknowledged rules of GUM (Guide to the expression of uncertainty in measurement).
All relevant actuating variables of the measuring equipment such as the uncertainty of measurement from the calibration, temperature influence, drift and disturbance variables etc. enter this budget. This uncertainty of measurement budget can be created with a common spreadsheet routine.
The national standards for torque in Germany are at the Physikalisch Technischen Bundesanstalt (PTB) in Braunschweig. By these standards, the torque ranges of 1 mN.m (0,001 N.m) up to 200 000 N.m are completely covered.
In guideline DKD-4 (identical to EA-4/07) of the Deutscher Kalibrierdienst, the traceability elements are described more precisely and consist of the parts which are represented in Mindmap (picture 1).



Picture 1: Elements of the traceability

The **competence** of an accredited calibration laboratory is usually acknowledged by the DAkkS outside of the accredited range, provided it is the **same measurement variable,** for example torque (professional competence).

The calibration laboratory of Lorenz Messtechnik GmbH with the registration number D-K-17603-01-00 has its own high-precise standards of which the uncertainty of measurement through calibration was determined by the PTB (Picture 2). These standards are regularly recalibrated by the PTB and act for the check-up and the traceability of the own calibration facility whose uncertainty of measurement was determined to $1{\cdot}10^{-4}$ by this standard. The requirements for traceability of the facility and the standard are guaranteed by the calibration certificates.

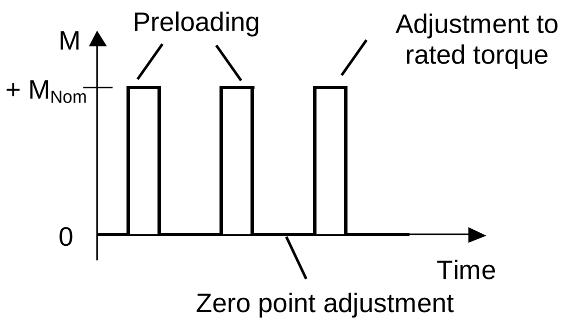


Picture 2: Continous measuring chain of comparisons from the PTB up to the delivered sensor

4 Adjusting and Testing

4.1 Adjusting

Definition: Activity which puts a measuring instrument into a serviceable operating state.
The procedure for torque sensors is represented in picture 3. First, the “memory” of the torque sensor is deleted through several preloadings. Then the actual adjustment process starts with the zero point adjustment and thereafter the adjustment of the rated torque.
After successful adjustment the actual test process can be started.



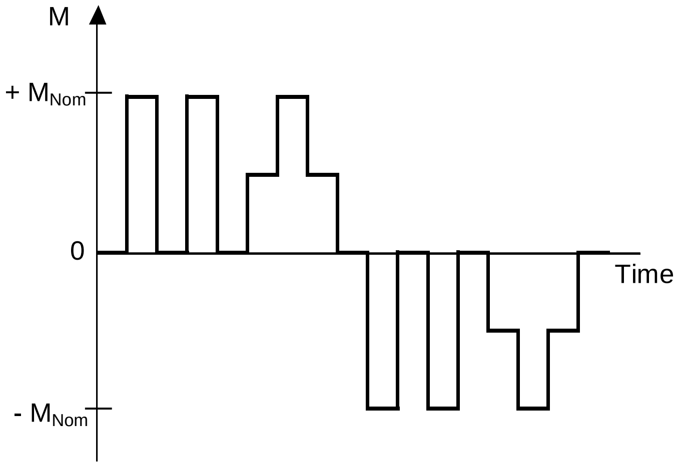
Picture 3: Adjustment of torque sensors

4.2 Testing

Definition of Lorenz Messtechnik GmbH in accordance to DAkkS:
Determination and documentation of several product features.

According to picture 4 following sizes are determined for a torque sensor and are shown in a protocol which is enclosed to the delivery of a new sensor:
The measured values of zero point, 50 % and 100 % of M_{Nom} are acquired and documented.

From these values, the zero signal, linearity, hysteresis and the nominal value of the sensor are calculated and documented in a protocol.



Picture 4: Test process for a torque sensor

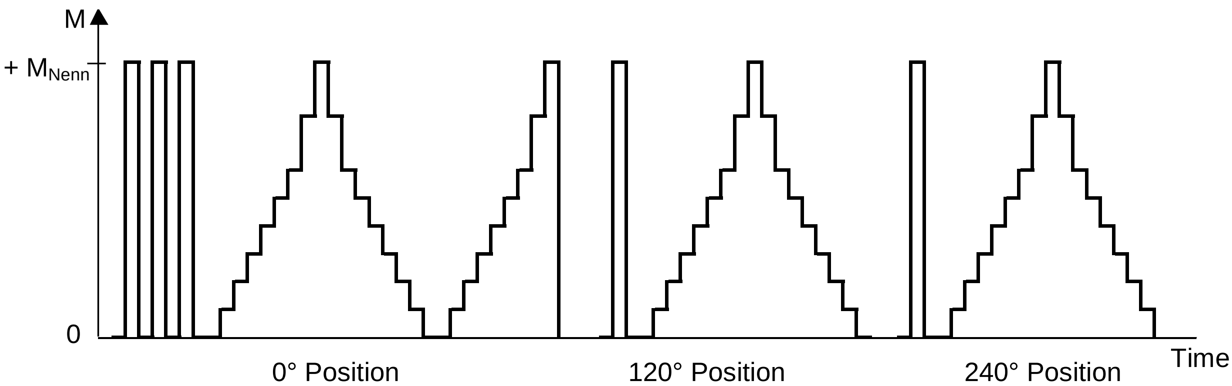
The procedure for the adjustment as well as the testing of the torque sensor is not described or explained in any standard. Therefore the sensor manufacturers can differentiate quite strongly.

5 Calibration of Torque Sensors

The calibration of torque sensors occurs according to acknowledged guidelines and/or standards which are considered as validated procedures. We want to restrict to clockwise torque calibrations.

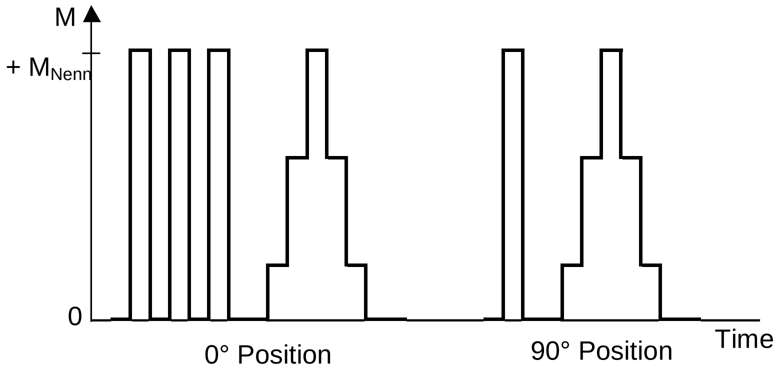
5.1 Calibrating according DIN 51309

The calibration acc. to DIN 51309 is explained closer with an example of a clockwise torque calibration with 8 steps. The load steps are usually 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 80 %, 100 % of the nominal torque $M_{Nom.}$



Picture 5: Course of a calibration according to DIN 51309 with 8 steps

After 3 preloadings (Picture 5) with nominal torque, an increasing series of 9 measuring points and then 8 measuring points for the decreasing series is created.
A further increasing series follows which attends to the determination of the repeatability.
After that, the sensor gets rotated by 120° around its axis in the calibration device. Again, preloading to rated torque follows and subsequently an increasing series and a decreasing series. Another rotation in the calibration device to 240° with subsequent measurement series as represented in the diagram ends the acquisition of the measuring points of a clockwise torque calibration.
Picture 6 represents the course of a single calibration for classes 1 – 5.



Picture 6: Calibration with 3 measuring steps

We can see on the diagram that considerably less measuring points need to be acquired. In addition, the second increasing series in the 0° mounting position can be dispensed because the repeatability is set even with the larger reproducibility. Further, the sensor must be only rotated once in the calibration device. At this calibration, the sensor is compulsorily classified into classes 1 to 5, even though the shown uncertainties of measurement can be small. This is the reason why this calibration type is not used at better measuring devices because the classes suggest the “accuracy” of the sensor which is not necessarily true.
Therefore let us change to another guideline which does not require this classification.

5.2 Calibrations for Torque Sensors according to VDI/VDE 2646

At this type of calibration no classification of the torque measuring device occurs as in case of DIN 51309. The uncertainty of measurement is calculated and shown for each measured value.

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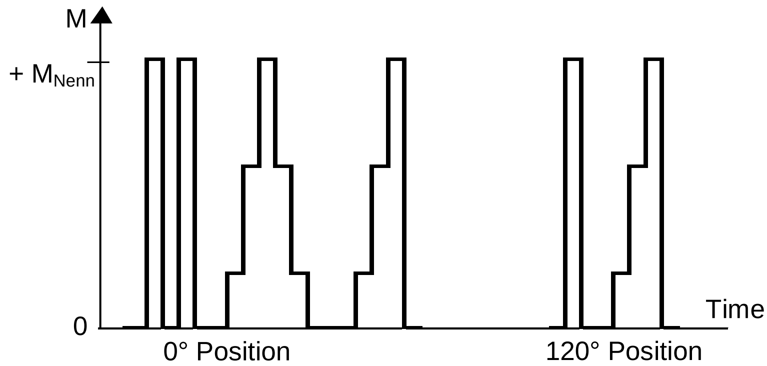
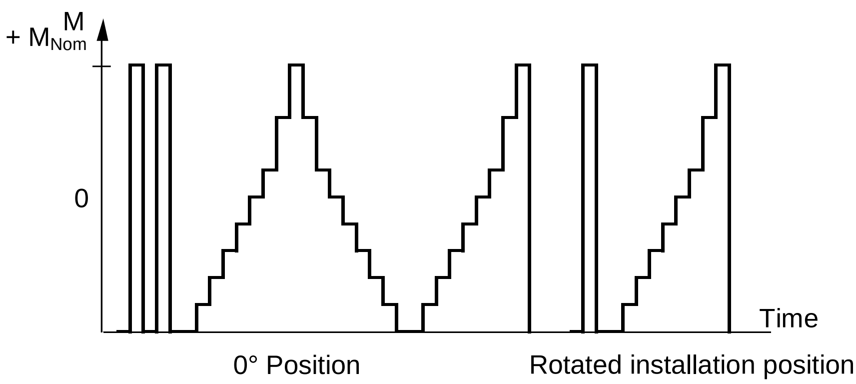


Picture 7: Calibration with 3 measuring steps according to VDI/VDE 2646

The calibration begins as represented in Picture 7 with at least 2 preloading with rated torque and an increasing and decreasing series subsequently. This is followed by another increasing series for the repeatability. Then, the sensor is rotated around its measuring axis, preloaded and followed by another increasing series. Of course, this calibration can be carried out in several steps, e.g. 8 steps, as shown in DIN 51309; see Picture 8 for this.

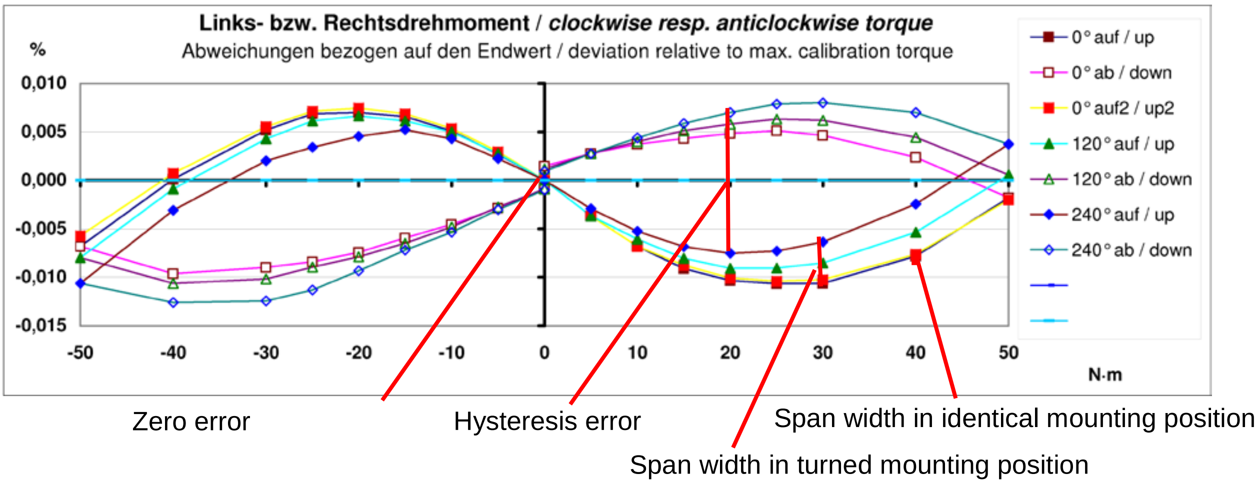


Picture 8: Course of a calibration with 8 measuring steps

In case if the reproducibility is known from a former calibration or if the calibration laboratory can determine it by type tests through documented statistical procedures, the second installation position can be omitted. Calibrations with just one installation position without values for the reproducibility are not validated calibrations and thus do not correspond to the state of technology.

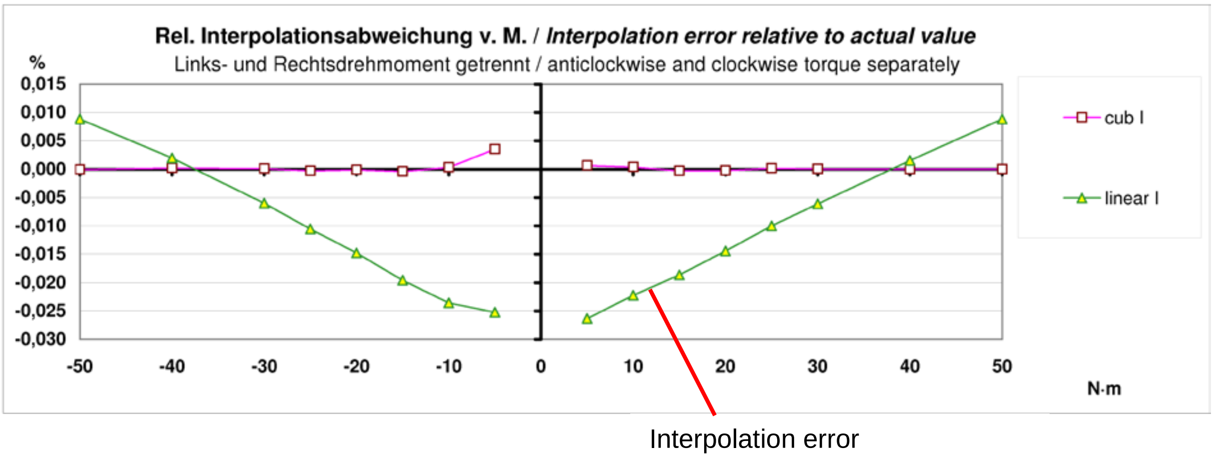
5.3 Separation of the Uncertainty of Measurement Influences into reasonable Parts

The result of a calibration according to DIN 51309 and VDI/VDE 2646 gives measured values of increasing and decreasing series. These deviations can be displayed in % f.s. from a linear smoothing function as shown in Picture 9.



Picture 9: Typical deviation in dependency of torque at a DIN 51309 calibration

The repeatability is determined as span of the measured values from the first 0° installation position. The measured values in rotated installation position contribute to the reproducibility through their span. The reversibility error (hysteresis) is determined from the increasing and decreasing series. The remaining zero error at the end of the load series is calculated as well.
In order to not only indicate the uncertainty of measurement for the fixed measuring points, the interpolation error must be determined as shown in Picture 10.



Picture 10: Interpolation error for linear and cubic equation polynomial at a calibration

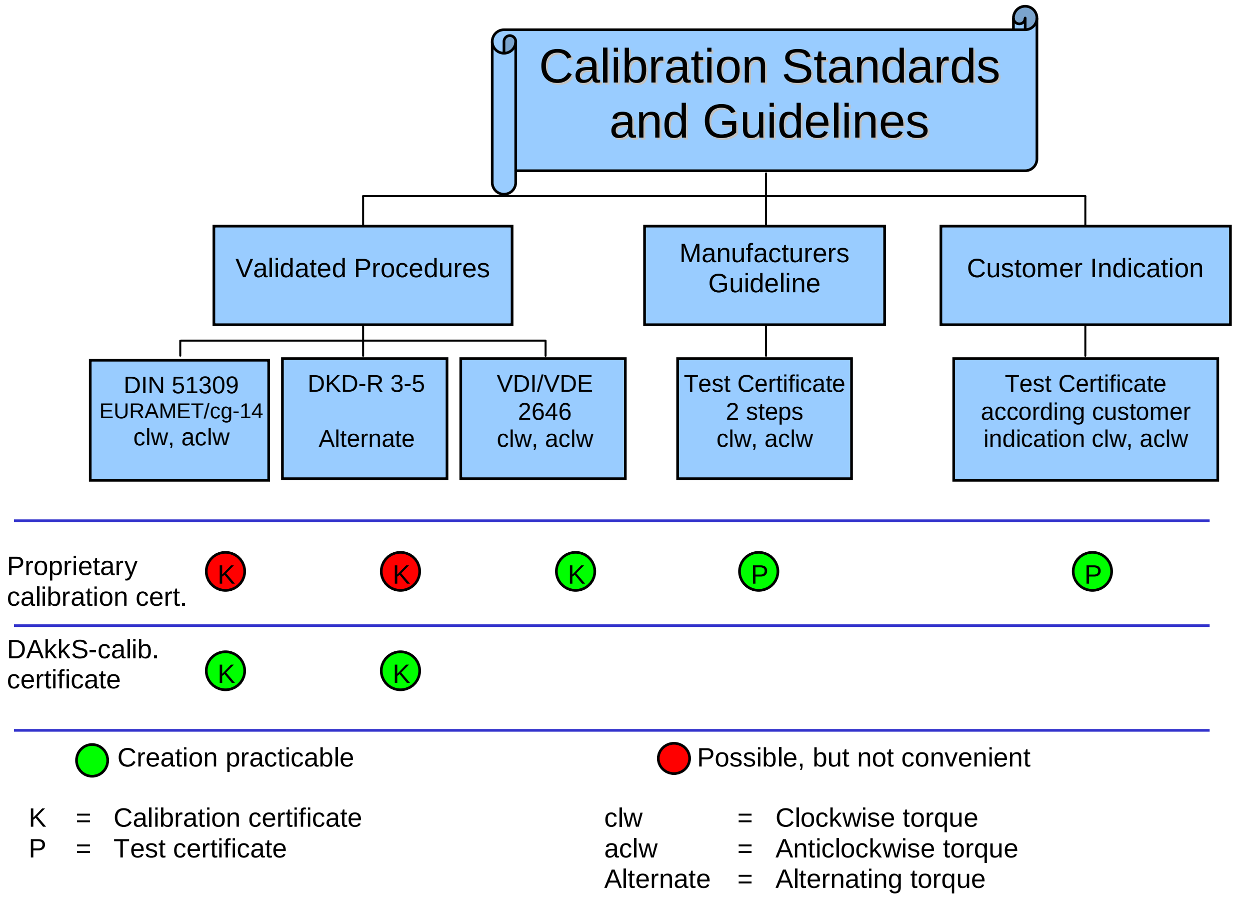
Further, the used display with its resolution and the uncertainty of measurement of calibration device must be considered. The uncertainty of measurement may not be confused with the accuracy. According to DIN 55350, the accuracy is a qualitative term for the extent of the approximation of the measurement result to a true value.

5.4 Classification according to DIN 51309

After frequently reading about the torque sensor classification, here a short consideration of this size. The classes are supposed to make the torque measuring equipment from different manufacturers comparable in an easy way. The parameters for the classification are determined from the uncertainty of measurement contributions of a calibration. The classification is carried out according to the principle that limit values are available for each class and each parameter. If this parameter is exceeded, the classification of the measuring device is rated to a higher class. The higher the class, the higher the parameters contributing to the uncertainty of measurement. This does not apply for the compulsory classification at 3 calibration steps, however.

5.5 Standards and Guidelines for Torque Sensors

Calibration standards and guidelines can be divided into validated procedures, manufacturer guidelines and calibrations according customer requirements. By acknowledged committees (professional groups) the validated procedures are defined to standards and/or guidelines (e.g. DAkkS). In order to offer convenient calibrations, manufacturers have inhouse calibration procedures. These procedures are usually not validated and do not determine the uncertainty of measurement according to the state of technology. In order to determine the uncertainty of measurement, the repeatability, reproducibility, reversibility error, zero point and interpolation error of the sensor must be defined, as shown. Otherwise the calibration procedure can not be considered as validated.
The following graph (Picture 11) shows the most important calibration standards and guidelines valid for torque. The procedures marked with K can be considered as calibrations according to the state of technology. The procedures marked with P test the metrological indications of the sensor such as hysteresis, linearity, nominal value, zero point etc. and are documented in form of a test certificate.
The calibrations marked with K further divide into DAkkS calibrations and proprietary calibrations.



Picture 11: Calibration standards and guidelines for torque sensors.

5.6 DAkkS-Calibrations versus Proprietary Calibrations

As shown, with the available acknowledged standards and guidelines of legitimate calibration laboratories for torque, correctly proprietary calibrations according to EN ISO 9000 which complies with EN ISO 10012, can be carried out. Because today it is not required to carry out calibrations in accordance with ……

If the calibration laboratory is accredited for torque in addition, this laboratory for QM-systems which are certified according to ISO TS 16949, will carry out correct DAkkS or proprietary calibrations which indicate the uncertainty of measurement for each calibration step. DAkkS calibration laboratories have high metrological competence and very well trained personnel for the accredited ranges and are on the actual state of the art. In the hierarchy, these laboratories are placed directly underneath the PTB.

The user of torque measurement technology should also assure that the uncertainty of measurement as well as the component parts which lead to the uncertainty of measurement are indicated in the test certificate. According to VDI/VDE 2646, calibrations without indication of the uncertainty of measurement are invalid. Further the calibration procedure which was used should be indicated. If the calibration procedure is specified “in accordance with….” Or “calibration according manufacturer guideline”, it must be checked if this calibrations corresponds with the state of the art.

At high conclusiveness regarding the product liability, which is always the case when using a reference sensor, a DAkkS calibration is absolutely indicated. These calibration certificates are internationally acknowledged, thus, they have high conclusiveness in case of liability.

6 Literature

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