Physikalisch-
Technische
Bundesanstalt

DKD

Guideline DKD-R 10-8

Static calibration of calibration devices for torque wrenches

Edition 02/2020

https://doi.org/10.7795/550.20200825A

Deutscher Kalibrierdienst (DKD) – German Calibration Service

Since its foundation in 1977, the German Calibration Service has brought together calibration laboratories of industrial enterprises, research institutes, technical authorities, inspection and testing institutes. On 3rd May 2011, the German Calibration Service was reestablished as a *technical body* of PTB and accredited laboratories.
This body is known as *Deutscher Kalibrierdienst* (DKD for short) and is under the direction of PTB. The guidelines and guides developed by DKD represent the state of the art in the respective areas of technical expertise and can be used by the *Deutsche Akkreditierungsstelle GmbH* (the German accreditation body – DAkkS) for the accreditation of calibration laboratories.
The accredited calibration laboratories are now accredited and supervised by DAkkS as legal successor to the DKD. They carry out calibrations of measuring instruments and measuring standards for the measurands and measuring ranges defined during accreditation. The calibration certificates issued by these laboratories prove the traceability to national standards as required by the family of standards DIN EN ISO 9000 and DIN EN ISO/IEC 17025.

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Suggestion for the citation of sources:
Guideline DKD-R 10-8, Static calibration of calibration devices for torque wrenches, Edition 02/2020, Revision 0, Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin. DOI: 10.7795/550.20200825A

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Published by Physikalisch-Technische Bundesanstalt (PTB) for the Deutscher Kalibrierdienst (DKD, German Calibration Service) as result of the cooperation between PTB and the DKD Technical Committee *Torque*.

Foreword

DKD guidelines are application documents that meet the requirements of DIN EN ISO/IEC 17025. The guidelines contain a description of technical, process-related and organizational procedures used by accredited calibration laboratories as a model for defining internal processes and regulations. DKD guidelines may become an essential component of the quality management manuals of calibration laboratories. The implementation of the guidelines promotes equal treatment of the equipment to be calibrated in the various calibration laboratories and improves the continuity and verifiability of the work of the calibration laboratories.

The DKD guidelines should not impede the further development of calibration procedures and processes. Deviations from guidelines as well as new procedures are permitted in agreement with the accreditation body if there are technical reasons to support this action.

Calibrations by accredited laboratories provide the user with the security of reliable measuring results, increase the confidence of customers, enhance competitiveness in the national and international markets, and serve as metrological basis for the monitoring of measuring and test equipment within the framework of quality assurance measures.

The present guideline has been drawn up by the DKD Technical Committee *Torque* and approved by the Board of the DKD.

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1 Scope of application

Below, calibration devices for torque wrenches are also referred to as torque wrench calibration devices.

This Guideline applies to the calibration of torque wrench calibration devices using torque transfer wrenches as transfer standards. It supports the corresponding requirements of DIN EN ISO 6789 [1]. A method for determining the relative measurement uncertainty of these devices is also described.

This guideline excludes the use of fixed-length calibration beams and discs as transfer standards. The reason for this is that the determination of the parameter "span" for different lever arm lengths is not possible with this type of equipment; hence, it would not be possible to carry out an adequate calibration or to adequately determine the measurement uncertainty. Within the context of this Guideline, torque wrench calibration devices are special torque measuring devices which – because of their design – allow torque to be applied via a torque measuring instrument with lever arm. This Guideline takes into account the different conditions of force introduction and their effect on the calibration item as opposed to those of torque measuring instruments according to DIN 51309 [2].

Calibration devices with integrated zero suppression or zero spreading that cannot be switched off during calibration must not be switched off and on again for taring purposes during the entire calibration process after being switched on, unless additional taring during use is required by the manufacturer in the technical documentation. Pursuant to this Guideline, instruments which only allow the detection of peak values are not considered capable of being calibrated.

The torque wrench calibration device comprises the entire device – from torque transducer up to and including the display unit.

This guideline is applicable from 2020-03-01 onwards; in addition, Guideline DKD-R 3-8 (Edition 09/2018) may be applied until 2022-02-28. If the present Guideline should be used together with Guideline DKD-R 3-7 (Edition 09/2018), i.e. a measuring device calibrated according to DKD-R 10-8 (Edition 02/2020) should form the basis for calibrations according to DKD-R 3-7 (Edition 09/2018), then the hysteresis of the calibration device must be included in the measurement uncertainty budget according to DKD-R 10-8.

2 Symbols

With regard to the application of this DKD guideline, the formula symbols given in Table 1 apply.

Table 1: Symbols, units and designation

Symbol	Designation	Unit
M	**Torque**	N·m
M_N	Nominal torque	N·m
M_A	Initial value of the measuring range (lower range value)	N·m
M_E	Measuring range end value	N·m
M_K	Calibration torque	N·m
	DU = Display unit of the output signal (e.g. N·m, mV/V, V, Hz)	
I	**uncorrected display value of the display unit**	DU
I_S	Display value before installation into the calibration device and in vertical position (transducer zero value)	DU
$I_{0,j}$	Display value before loading in mounting position j (zero value)	DU
$I_{f,j}$	Display value after relief (unloading) in mounting position j	DU
$I_j\,(M_K)$	Display value with increasing calibration torque M_K in mounting position j	DU
$I'_j\,(M_K)$	Display value with decreasing calibration torque M_K in mounting position j	DU
X	**Display value of the indicating device corrected by the zero value**	DU
$X_j\,(M_K)$	Display value corrected by the zero value with increasing calibration torque M_K in mounting position j	DU
$X'_j\,(M_K)$	Display value corrected by the zero value with decreasing calibration torque M_K in mounting position j	DU
$X_{L,red}(M_K)$	Display value corrected by the zero value with reduced lever arm length	DU
$X_{L,nom}(M_K)$	Display value corrected by the zero value with nominal lever arm length	DU
$X_V(M_K)$	Display value corrected by the zero value with rotated connection profile	DU
Y	**Calibration result**	DU
$Y(M_K)$	Calibration result for calibration torque M_K	DU
Y_E	Calibration result at measuring range end value M_E	DU
$Y_a(M_K)$	Interpolated calibration result for calibration torque M_K	DU
	Geometric quantities	
l	Lever arm length of the torque transfer wrench	mm
l_{red}	Reduced lever arm length according to Table 3	mm
l_{nom}	Nominal length of lever arm or nominal lever arm length according to Table 3	mm

Table 1: Symbols, units and designations (continued)

Symbol	Designation	Unit
	Quantities for the consideration of the measurement uncertainty	
$b(M_K)$	Reproducibility with calibration torque M_K	DU
$b'(M_K)$	Repeatability with calibration torque M_K	DU
$b_L(M_K)$	Span with different lever arm lengths and calibration torque M_K	DU
$f_a(M_K)$	Regression deviation with calibration torque M_K	DU
$f_q(M_K)$	Indication error with calibration torque M_K	DU
f_0	Zero deviation (difference of the zero points before and after loading)	DU
$h(M_K)$	Hysteresis with calibration torque M_K	DU
r	Resolution of the display unit of the calibration device	N·m
$w_{TN}(M_K)$	Relative standard uncertainty of the torque value M_K of the torque transfer standard	%
$W_{TN}(M_K)$	Relative expanded uncertainty of the torque value M_K of the torque transfer standard	%
$w(M_K)$	Relative standard uncertainty of the calibration result with calibration torque M_K	%
$W(M_K)$	Relative expanded uncertainty of the calibration result with calibration torque M_K with cubic regression function	%
$W'(M_K)$	Relative error span of the calibration result with calibration torque M_K (see also Annex D)	%

3 Requirements for torque wrench calibration devices

3.1 Description and identification of the torque wrench calibration device

Functionally, a torque wrench calibration device consists of a device for holding a torque transducer, the torque transducer itself and an indicating device.

All parts of the torque wrench calibration device (including cables for electrical connection) must be individually and uniquely identified (e.g. naming the manufacturer, type, 4- or 6-wire circuit or the like, and the serial number). The nominal torque must be indicated.

3.2 Torque introduction

On the measuring side, the torque can be applied in axial direction by means of exchangeable adaptation parts which must transmit the transverse forces and bending moments generated by the force introduction via the lever arm with sufficiently low deformation; furthermore, it must be ensured that these adaptation parts do not lead to any radial displacement of the torque vector which would affect the measurement uncertainty. Both horizontal and vertical alignment of the measuring axis is possible.

As a minimum requirement, it must be possible to vary the lever arm length for generating the torque via the transfer standard within the range of lever arm lengths of commercially available torque wrenches according to the measuring range to be calibrated. The force introduction at the lever arm of the transfer standard must be such that additional parasitic forces and moments are avoided.

4 Calibration of the torque wrench calibration device

4.1 General information

The calibration consists of introducing torques, transverse forces and bending moments into the torque wrench calibration device. The combination of these forces and bending moments corresponds to the real application conditions for calibrating torque wrenches. The corresponding indications of the calibration device and the torque transfer standard are recorded.

An electrical display unit may be replaced by a similar one if its deviations do not significantly affect the result due to its technical specification and measurement uncertainty (the additional measurement uncertainty caused by replacing the display unit should not exceed 1/3 of the relative uncertainty of the torque wrench calibration device w_{KE}).

The dead weight of the transfer standard may not generate any inadmissible additional disturbing forces or moments which would impair the measurement uncertainty. If there is a support bearing on the measuring side of the torque transducer of the torque wrench calibration device, the possibility of an improper torque shunt caused by the dead weight of the transfer wrench must be checked. It should be close to the weight of comparable torque wrenches in the measuring range of the torque wrench calibration device to be calibrated.

It must be ensured that the torque introduction parts for the adaptation of transfer standards to the torque wrench calibration device can transmit at least 1.2 times the maximum calibration torque while ensuring a linear deformation behaviour.

Before calibrating the torque wrench calibration device, its calibration capability must be ensured.

4.2 Resolution of the indication device

4.2.1 Scale reading

The graduation lines on the scale must be of equal thickness and the width of the pointer must be approximately equal to the width of a graduation line.

The resolution r of the display unit is defined as the smallest fraction of a scale division still possible to be estimated, and results from the ratio between the width of the pointer and the centre distance between two adjacent scale lines (scale spacing). The recommended ratios are 1/2, 1/5 or 1/10. A spacing of 1.25 mm or greater is required to estimate one tenth of the scale division on the scale.

4.2.2 Numeric display

The resolution r is considered as one digital step of the last moving digit on the digital display plus half the range of the fluctuation. In case of indicating devices with active zero suppression or zero spreading, it must be bypassed by means of appropriate procedures, e.g. a preload during taring in order to determine the display fluctuation.

4.2.3 Units

The resolution r is converted into torque units and specified as such.

4.3 Preparing for calibration

4.3.1 Indicating device

The indicating device must be adjusted according to the manufacturer's or customer's specifications. All variable settings (especially sampling rate and filter settings) must be recorded. The indicating device must be checked for adequate stability of the zero point before starting the calibration.

4.3.2 Temperature and humidity equalisation

Before calibrating the torque wrench calibration device, it is necessary to achieve an equilibrium of temperature and humidity between transducer and environment – with the supply voltage being applied – and to evaluate this equilibrium via the stability of the zero point.

4.3.3 Transducer zero signal

Before starting the calibration and if technically possible, the zero signal of the mechanically unloaded torque wrench calibration device which has not been tared is to be measured and recorded, indicating the position of the measuring axis. The knowledge of the temporal behaviour of the zero signal allows to draw conclusions regarding the temporal stability of the torque wrench calibration device and its history.

4.3.4 Transducer connection

The transducer must be connected in such a way that an increasing clockwise torque results in an increasing positive indication.

4.4 Calibration process

4.4.1 Calibration scope and procedure

To calibrate torque wrench calibration devices, traceably calibrated torque transfer wrenches [3] are used.

The calibration is carried out separately for clockwise and anti-clockwise torque. The calibration of torque wrench calibration devices can be carried out either as a purely static procedure by measuring discrete torque values or as a continuous procedure performed continuously without holding time for discrete torque values

In case of a continuous calibration, it has to be ensured that the procedure of taking the measured values from the torque transfer wrench and from the calibration item does not lead to any relevant measurement deviation. The filter settings of the indicating devices, a possible time difference in the logging of measuring values of the measuring signals of the torque transfer wrench and the calibration item as well as the rate of increase of the torque are some of the influencing factors. The application of continuous calibration procedures requires previous experimental investigations to prove the influence of the process conditions on the measurement uncertainty of the calibration.

4.4.2 Preloading

After installing the torque transfer standard in the torque wrench calibration device and when changing the loading direction, a singular preloading is required by using the final value of the measuring range M_E to be calibrated. The duration of the preload should be kept as short as possible to minimize creep effects. After preloading, it is important to wait until reaching a stabilisation of the zero signal within the minimum resolution at the initial value of the measuring range. An existing residual signal must be recorded.

4.4.3 Position of the measuring axis

During calibration, the position of the measuring axis of the torque wrench calibration device should preferably be in the position in which it is to be used.

4.4.4 Calibration process

The number of measurement series is determined by the desired measurement uncertainty for the torque wrench calibration device according to Table 2. The expanded relative uncertainty or relative error span (see Annex D) to be determined in accordance with Section 5 is to be applied. If the target value for the measurement uncertainty is lower than expected, at least the previously estimated value must be used, or the calibration must be repeated using a smaller target value.

Table 2: Minimum number of required measurement series

Possible change of the mounting position	relative expanded uncertainty ($k = 2$) or relative error span in %	Number of measurement series with nominal lever arm length 0° position		reduced lever arm length 0° position	rotated torque sensor	rotated connection profile
		up	down	up	down	up
Sensor and connection profile rotatable	< 0.5	2	1	1	1	1
	≥ 0.5	2	1	1	-	1
Sensor rotatable, connection profile fixed	< 0.5	2	1	1	1	-
	≥ 0.5	2	1	1	-	-
Sensor fixed, connection profile rotatable	< 0.5	3	1	1	-	1
	≥ 0.5	2	1	1	-	1
Sensor and connection profile fixed	< 0.5	3	1	1	-	-
	≥ 0.5	2	1	1	-	-

The torque wrench calibration device is calibrated in a mounting position with two increasing and one decreasing series and with nominal lever arm length. The two increasing series in the same mounting position determine the repeatability.

To obtain relative measurement uncertainties of less than 0.5 %, measurement of another increasing series is required. If the torque transducer can be used in different mounting positions, this upward series is to be carried out in a position suitable for this transducer. Preferably, the transducer should be rotated by 45° or 180°. If the torque transducer is not used in different mounting positions, an additional increasing series needs to be measured after the torque transfer wrench has been removed from and reinserted in the measuring device. These measurements are used to calculate the reproducibility.

If the torque transfer wrench does not allow calibration in the required mounting position – for example because the connection profile cannot be rotated by 45° – the reproducibility must be estimated based on other information. This information should be obtained from a previous calibration of a corresponding torque transfer wrench with rotating connection profile.

As a rule, the position of the force vector to the deformation body of the torque transducer must be defined and marked accordingly.

To determine the influence of the force introduction point at the lever arm on the calibration result, an additional increasing series must be measured in the 0° mounting position with reduced lever arm length (also see Annex B). The range of variation of the lever arm length is shown in Table 3. These values are based on the typical lever arm lengths of commercial torque wrenches. This measurement series can be measured first, before all other series.

Table 3: Range of variation of the lever arm length

M_N in N·m	l_{red} in mm	l_{nom} in mm
up to 20	100	200
over 20 to 50	200	400
over 50 to 150	300	500
over 150 to 400	400	700
over 400 to 1000	600	1000
over 1000 to 2000	1000	1500
over 2000 to 3000	1300	1800

To determine the influence of the connection profile on the calibration result – for devices in which a connection profile with variable position is used – an additional increasing series in the 0° mounting position must be measured with changed position of this connection profile (see Annex B). This series should be measured prior to the rotation of the torque transducer – if applicable.

If the torque transfer wrench does not allow calibration in the required mounting position – because of a non-rotating connection profile, for example – the influence of the connection profile must be estimated using other information. This information should come from a previous calibration with a corresponding torque transfer wrench with a rotating connection profile.

The minimum number of torque steps (in addition to zero) for each measurement range for a desired expanded relative measurement uncertainty or a desired relative error span should be

< 0.5% 8

or

≥ 0.5% 5

The initial value of the measuring range M_A must be part of the calibration values. The torque steps must be appropriately distributed over the measuring range. Reasonable steps are, for example, steps of 10, 20, 30, 40, 50, 60, 80 and 100 percent or 2, 5, 10, 20, 40, 60, 80 and 100 percent, in each case related to the current end value M_E of the measuring range to be calibrated.

A torque wrench calibration device can be calibrated separately for several torque measuring ranges.

4.4.5 Loading conditions

Ideally, the time between two successive load steps should be kept equal. Changes in the indication due to creep require an exact adherence to the time schedule.

The calibration is to be carried out at a ±1-stable ambient temperature; this temperature must be in the range 18 °C to 28 °C (preferably 22 °C) and is to be recorded.

4.4.6 Zero-point adjustment

The display value at the beginning of each measuring series must be adjusted to zero, except for instruments with active zero suppression or zero spreading (see remarks in Chapter 1).

4.5 Assessment of the torque wrench calibration device

In case of a continuous calibration, the measurement values for the minimum number of torque steps for each series of measurements must be calculated. The calibration result, the spans b, b' and b_{L} as well as the regression deviation f_{a} (or indication error f_{q}) and the hysteresis h have to be determined from these values.

Note: In formulae (1) to (8), the dependence on the calibration torque M_{K} is not explicitly stated.

4.5.1 Calibration result Y

The calibration result Y is calculated according to equation (1) as mean value of the measurement results from the n increasing series ($n \geq 1$) with different mounting positions, without repeating series, with the same mounting position and with nominal lever arm length

$$Y = \frac{1}{n}\sum_{j=1}^{n} X_j = \frac{1}{n}\sum_{j=1}^{n}\left(I_j - I_{0,j}\right). \quad (1)$$

4.5.2 Reproducibility b

The reproducibility in different mounting positions b (this calculation is not necessary when requiring a measurement uncertainty of ≥ 0.5%), is calculated as standard deviation for each torque step according to equation (2)

$$b = \sqrt{\frac{\sum_{j=1}^{n}\left(X_j - Y\right)^2}{n-1}} \quad . \quad (2)$$

4.5.3 Repeatability b'

The repeatability in the same mounting position b' is calculated as magnitude (amount) of the span for each torque step according to equation (3)

$$b' = \left|X_1 - X_2\right| \ . \quad (3)$$

Here, X_1 and X_2 have been determined from the increasing series with identical mounting position and nominal lever arm length.

4.5.4 Influence of the lever length b_{L}

The influence of the lever length b_{L} is calculated for different lever arm lengths as span for each torque step according to equation (4)

$$b_{\mathrm{L}} = X_{\mathrm{L,red}} - X_{\mathrm{L,nom}} \ . \quad (4)$$

4.5.5 Influence of the connection profile b_{V}

The influence of the connection profile b_{V} is calculated for different positions of this profile as span for each torque step according to equation (5)

$$b_{\mathrm{V}} = X_{\mathrm{V}} - X_{0°} . \quad (5)$$

4.5.6 Regression error f_a

The regression deviation f_{a} is determined for each torque step by means of a cubic or linear regression function (3rd or 1st degree function) without constant term, with the indication to be given as a function of torque. The mathematical determination of the regression function is to be carried out in such a way that the sum of the squares of the absolute or relative deviations in the calibrated measuring range yields a minimum. The method used must be specified.

Instead of the regression deviation – for torque wrench calibration devices with a scale indicating the value in the units of the measurand and without the possibility of an electronic adaptation of the indication to the regression function – the indication error is determined according to 4.5.7.

The regression deviation f_a is calculated from

$$f_\mathrm{a} = Y - Y_\mathrm{a}\,. \tag{6}$$

4.5.7 Indication deviation f_q

The indication deviation f_q is only determined for those torque wrench calibration devices whose indication is given directly in the unit of torque and which do not allow the electronic adaptation of the indication to the regression function of the calibration result. It is determined according to equation (7) from the mean value of all increasing series with nominal lever arm length

$$f_\mathrm{q} = Y - M_\mathrm{K}\,. \tag{7}$$

4.5.8 Hysteresis *h*

The hysteresis is determined by measuring first with increasing and then with decreasing torque. It is determined according to equation (8) as mean value of the differences between the indications of the increasing and decreasing series for each torque step with nominal lever arm length

$$h = \frac{1}{m}\sum_{j=1}^{m}\left(I_j' - I_j\right) \tag{8}$$

with the number m for the decreasing rows ($m \geq 1$).

Note: The hysteresis is not used when determining the uncertainty of the calibration result. Nevertheless, it has to be determined and specified in order to judge the quality of the calibration device. Temporal changes in the hysteresis between different calibrations may indicate undetected influences.

5 Determination of the relative expanded uncertainty *W* and the relative error span *W’*

The proposal regarding the calculation of the relative expanded uncertainty W for the results of the calibration of torque wrench calibration devices corresponds to the specifications laid down in GUM [4], document EA-4/02 M: 2013 [5] as well as to the calculation of the relative measurement uncertainty for the calibration results of torque measuring devices according to DIN 51309 [2] or EURAMET cg-14 [6].

The following information serves the purpose of illustrating the calculation of the relative measurement uncertainty of a standard calibration. Depending on the specific application of the torque wrench calibration device to be calibrated, it may be advisable to deviate from this example or to add further uncertainty components. In such cases, the calculation basis must be documented. The example provides information about the uncertainty at the time of calibration. For instance, measurement uncertainty components due to long-term stability or the real adaptation and environmental conditions when using the measuring instrument are not taken into account.

Parameters and spans may only be determined for defined calibration points. In the case of continuous calibrations, the recording of the measurement values for each series takes place at randomly distributed values of the calibration torque. The parameters b, b' and b_L as well as the hysteresis h are determined from interpolated values at predefined reference points. Afterwards, the subsequent measurement uncertainty consideration is carried out as for stepwise calibration.

If linear regression functions are used for torque wrench calibration devices with a scale showing the value in units other than the measurand, the regression deviation must be taken into account as additive amount in the calculation of the relative error span according to (12) due to its systematic character. Further explanations regarding the size of the relative error span can be found in Annex D.

For torque wrench calibration devices with a fixed scale in the unit of the measurand, it does not make sense to determine a regression function. Instead, the indication error is calculated. The display deviation is also of systematic character; however, it cannot be corrected like a known systematic deviation when using the calibrated measuring instrument. It should therefore be included as an additive amount in the calculation of the relative error span according to (13). However, if the scale indicating the value in the units of the measurand is created by adapting the display electronics to the regression function, this case is to be treated in the same way as that of a scale showing the value in units other than the measurand.

5.1 Model

The following product model is recommended to describe the influences on the calibration result of a torque wrench calibration device

$$M = C \cdot M_\mathrm{K} \cdot \prod_{i=1}^{n} \left(1 - \delta M_i\right) \ , \qquad (9)$$

Here, the individual quantities have the following meanings:

- δM_1 Influence of the resolution r of the display unit of the calibration device on the zero signal
- δM_2 Influence of the resolution r of the display unit of the calibration device on the measurement value
- δM_3 Influence of the reproducibility b
- δM_4 Influence of the repeatability b'
- δM_5 Influence of the lever arm length b_L
- δM_6 Influence of the connection profile b_V
- δM_7 Influence of the cubic regression error f_a (for linear regression error, see 5.2, formula (12)).

By using the constant factor C, it is possible to consider cases in which the measurement unit displayed by the torque wrench calibration device differs from that of the torque.

The following is to be kept in mind when using the torque wrench calibration device:

- δM_8 Influence of the non-ideal coupling of the calibration item
- δM_9 Influence of the deviation of the calibration conditions (temperature, relative humidity) from the reference values.

5.2 Uncertainty budget

For uncorrelated input quantities, the relative standard uncertainty $w(M)$ assigned to the torque M is given by

$$w(M)=\sqrt{w_{\mathrm{TN}}^2(M_{\mathrm{K}})+\sum_{i=1}^{n} w^2(\delta M_i)}\,. \tag{10}$$

Here, $w_{\mathrm{TN}}(M_{\mathrm{K}})$ is determined by the influence of the measurement uncertainty of the torque transfer wrench on the calibration torque M_{K}, including a share for the long-term stability and temperature or humidity sensitivity of the transfer wrench if these are not corrected. If a relative error span has been calculated for the transfer wrench, Annex D is to be observed.

The relative standard uncertainty $w(M)$ is calculated from the uncertainty components resulting, for instance, from the calculated characteristic quantities according to 4.5.2 to 4.5.7. The statistical distribution functions according to Table 4 are recommended with respect to the consideration of the random error components. Annex C provides an example for calculating the measurement uncertainty.

For shortened calibration procedures without determining the reproducibility b, the contribution of the reproducibility must be determined by doubling the contribution of the repeatability b'.

The influence of the hysteresis h can be neglected in the consideration of the measurement uncertainty. However, the determination of this characteristic quantity is still part of the calibration procedure and requires critical evaluation with respect to the device's suitability for calibration.

The expanded relative uncertainty W is calculated from the relative standard uncertainty $w(M)$ by multiplication with the appropriate coverage factor k

$$W(M)=k\cdot w(M). \tag{11}$$

The relative error span W' of a calibration is calculated as follows
- for a scale showing the value in units other than the measurand and application of a linear regression function

$$W'(M)=\left|\frac{f_{\mathrm{a}}(M)}{M_{\mathrm{K}}}\right|+k\cdot w(M), \tag{12}$$

- for a scale indicating the value in the units of the measurand

$$W'(M)=\left|\frac{f_{\mathrm{q}}(M)}{M_{\mathrm{K}}}\right|+k\cdot w(M). \tag{13}$$

The uncorrected systematic deviations $f_{\mathrm{a}}(M)/M_{\mathrm{K}}$ and $f_{\mathrm{q}}(M)/M_{\mathrm{K}}$ must be indicated in the calibration certificate, including the correct algebraic sign. [1]

Table 4: Distribution functions for calculating the standard deviations of the experimentally determined characteristic quantities

Characteristic quantity	Distribution function	Relative standard deviation w in %
Resolution r	Type B rectangular distribution	$w_r=\frac{1}{\sqrt{3}}\cdot\frac{r}{2}\cdot\frac{100}{M_{\mathrm{K}}}$

[1] The relative systematic deviations mentioned here are equivalent to the relative measurement deviations of the measuring device b_{ep} according to DIN EN ISO 6789-2:2017-07 [1].

Reproducibility b	Type B normal distribution	$w_b = \frac{b(M_K)}{\sqrt{n}} \cdot \frac{100}{Y(M_K)}$
Repeatability b'	Type B normal distribution	$w_{b'} = \frac{b'(M_K)}{\sqrt{2}} \cdot \frac{100}{Y(M_K)}$
Influence of lever length b_L	Type B rectangular distribution	$w_L = \frac{1}{\sqrt{3}} \cdot \frac{b_L(M_K)}{2} \cdot \frac{100}{Y(M_K)}$
Connection profile b_V	Type B rectangular distribution	$w_V = \frac{1}{\sqrt{3}} \cdot \frac{b_V(M_K)}{2} \cdot \frac{100}{Y(M_K)}$
Regression deviation f_a	Type B triangular distribution	$w_f = \frac{1}{\sqrt{6}} \cdot \frac{f_a(M_K)}{2} \cdot \frac{100}{Y(M_K)}$

6 Calibration certificate and recalibration

6.1 Calibration certificate

If a torque wrench calibration device meets the requirements of this Guideline at the time of calibration, the calibration laboratory will issue a calibration certificate in accordance with DAkkS 71 SD 0 025 [7], containing, inter alia, the following information:

a) ordering party of the calibration (customer),

b) identity of all elements of the torque wrench calibration device and torque introduction parts as well as designation of the torque transfer standard,

c) information regarding clockwise and anti-clockwise torque as well as lever arm lengths,

d) calibration result with indication of the expanded relative uncertainty, the relative error span and the uncorrected relative deviations according to 5,

e) the regression function - if necessary (not with a scale indicating the value in the units of the measurand),

f) ambient conditions (temperature and relative humidity) during calibration,

g) date and, if necessary, place of calibration,

h) information related to the identification of the calibration laboratory,

i) reference to this Guideline,

j) position of the measuring axis during calibration (horizontal and/or vertical),

k) support distance of the force introduction point from a reference point of the calibration device in the direction of the torque axis (figure showing the indicated distance) and

l) reference as to the 0° position of the sensor (a picture showing the connection of the cable, for example).

The calibration certificate should also include:

m) table of measured values and calculated characteristic quantities according to sections 4.5.2 to 4.5.8 and

n) a graphic representation of the characteristic curve.

6.2 Recalibration

In accordance with this Guideline, the torque wrench calibration device must be recalibrated after 26 months at the latest.

The torque wrench calibration device also needs to be recalibrated if it has been subjected to an overload greater than that of the overload test (see 4.1), after a repair has been made or after improper handling which may have an influence on the measurement uncertainty.

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Annex A Application of calibrated torque wrench calibration devices

The calibration is only valid for applications in which the torque wrench calibration device is used in accordance with the calibration conditions. It must be ensured that the device is not subjected to torques greater than the nominal torque, or to disturbing forces and torques due to inadequate installation parts and adaptation conditions during use which may cause greater deviations than those determined during calibration.

If a torque wrench calibration device is used at a temperature deviating from the temperature at which it was calibrated, the additional measurement uncertainty caused by this is to be calculated from the manufacturer's specification on the influence of temperature on the zero point and the characteristic value; it is to be considered accordingly.

Similarly, deviating values of relative humidity may affect the calibration results of a torque wrench calibration device and must therefore be handled accordingly.

Annex B Examples of calibration sequences

The following diagrams show examples of calibration sequences for a torque wrench calibration device.

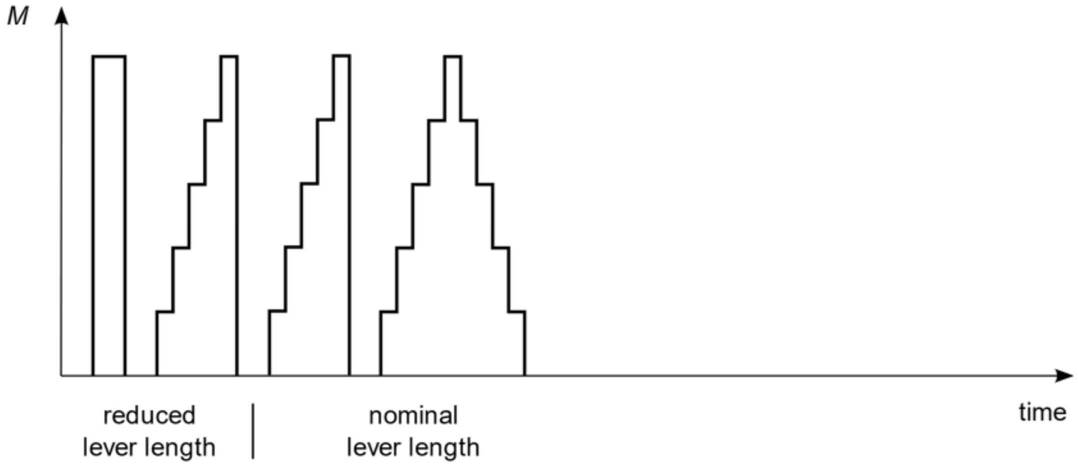

Figure B.1: Example for the calibration procedure of a torque wrench calibration device with fixed torque sensor and fixed connection profile and a desired measurement uncertainty of ≥ 0.5 %

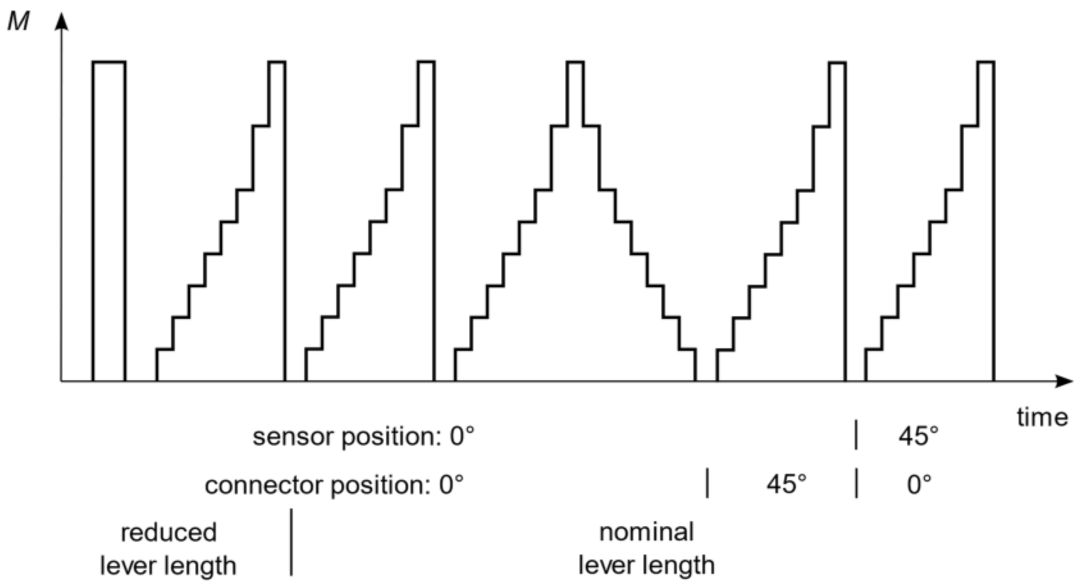

Figure B.2: Example of the calibration procedure of a torque wrench calibration device with a desired measurement uncertainty of < 0.5 %

Annex C Example of a calibration result

Calibration item

Torque wrench calibration device

- Designation: DmS-KE 100 Nm
- Nominal torque: 100 N·m
- Display unit: N·m
- Torque sensor: rotating
- Nominal lever arm length: 500 mm
- Reduced lever arm length: 300 mm
- Digital step: 0.001 N·m
- Fluctuation of readings: 0.001 N·m
- Target uncertainty: 0.2 %

Calibration standard

Torque transfer wrench

- Designation: DmTS 100 Nm
- Nominal torque: 100 N·m
- Display unit: N·m
- Connection profile: fixed

Measurement data

Clockwise torque, display values of the calibration item in N·m

Calibration torque at standard in N·m	Preloading	0° reduced	0° /1 up	0° /2 down	0° /2 down	45° sensor	45° connector
0	0.000	0.000	0.000	0.000	0.001	0.000	-
2	-	2.002	2.002	2.001	2.002	2.001	-
4	-	4.004	4.004	4.002	4.003	4.002	-
10	-	10.010	10.008	10.006	10.010	10.006	-
20	-	20.020	20.012	20.012	20.020	20.012	-
40	-	4.040	40.018	40.024	40.038	40.025	-
60	-	60.060	60.026	60.036	60.050	60.038	-
80	-	80.080	80.038	80.048	80.058	80.050	-
100	100.111	100.100	100.052	100.060	100.060	100.065	-

Anti-clockwise torque, display values of the calibration item in N·m

Calibration torque at standard in N·m	Preloading	0° reduced	0° /1 up	0° /2 down	0° /2 down	45° sensor	45° connector
0	0.000	0.000	0.000	0.000	-0.001	0.000	-
2	-	-2.002	-2.002	-2.001	-2.002	-2.001	-
4	-	-4.004	-4.004	-4.002	-4.003	-4.002	-
10	-	-10.010	-10.008	-10.006	-10.010	-10.006	-
20	-	-20.020	-20.012	-20.012	-20.020	-20.012	-
40	-	-40.040	-40.018	-40.024	-40.038	-40.025	-
60	-	-60.060	-60.026	-60.036	-60.050	-60.038	-
80	-	-80.080	-80.038	-80.048	-80.058	-80.050	-
100	-100.111	-100.100	-100.052	-100.060	-100.060	-100.065	-

Evaluation

Calibration result

Clockwise torque:

Calibration torque in N·m	Calibration result Y in N·m	$W(k=2)$ in %	W' in % 1)	W' in % 2)	W' in % 3)	$W_{TN}(k=2)$ in %
0	0.000	-	-	-	-	-
2	2.002	0.154	0.229	0.173	0.173	0.050
4	4.003	0.145	0.220	0.163	0.163	0.050
10	10.007	0.118	0.188	0.132	0.132	0.050
20	20.012	0.114	0.174	0.118	0.118	0.050
40	40.022	0.119	0.173	0.122	0.122	0.050
60	60.032	0.121	0.174	0.124	0.124	0.050
80	80.044	0.118	0.173	0.120	0.120	0.050
100	100.059	0.116	0.175	0.119	0.119	0.050

Anti-clockwise torque:

Calibration torque in N·m	Calibration result Y in N·m	$W(k=2)$ in %	W' in % 1)	W' in % 2)	W' in % 3)	$W_{TN}(k=2)$ in %
-0	0.000	-	-	-	-	-
-2	-2.002	0.154	0.229	0.173	0.173	0.050
-4	-4.003	0.145	0.220	0.163	0.163	0.050
-10	-10.007	0.118	0.188	0.132	0.132	0.050
-20	-20.012	0.114	0.174	0.118	0.118	0.050
-40	-40.022	0.119	0.173	0.122	0.122	0.050
-60	-60.032	0.121	0.174	0.124	0.124	0.050
-80	-80.044	0.118	0.173	0.120	0.120	0.050
-100	-100.059	0.116	0.175	0.119	0.119	0.050

Explanations:

The stated expanded relative uncertainty refers to the case of an adjustable scale showing the value in units other than the measurand and the application of a cubic regression function. In addition, the relative error spans containing $W(k=2)$ are given

1) for the case of the calibration item being an instrument with a scale indicating the value in the units of the measurand,

2) for the case of applying a linear regression function separately for clockwise and anti-clockwise torque and

3) for the case of applying a common linear regression function for clockwise and anti-clockwise torque.

The last case is not identical with a calibration result for alternating torque. However, the joint regression function makes it possible to adapt the display unit optimally for clockwise and anti-clockwise torque by means of only one calibration factor.

The regression functions used are shown below.

Relative values of the characteristic quantities

Clockwise torque:

Calibration torque in N·m	b'/Y in %	b/Y in %	b_L/Y in %	b_V/Y in %	f_a/Y in %	f_q/Y in % 1)	f_a/Y in % 2)	f_a/Y in % 3)	h/Y in %
0	-	-	-	-	-	-	-	-	-
2	0.050	0.035	0.000	0.173	0.008	0.075	0.019	0.019	0.050
4	0.050	0.035	0.000	0.173	0.009	0.075	0.019	0.019	0.025
10	0.020	0.014	0.020	0.173	0.007	0.070	0.014	0.014	0.040
20	0.000	0.000	0.040	0.173	0.000	0.060	0.004	0.004	0.040
40	0.015	0.012	0.055	0.173	-0.001	0.054	-0.003	-0.003	0.035
60	0.017	0.014	0.057	0.173	0.000	0.053	-0.003	-0.003	0.023
80	0.012	0.011	0.052	0.173	0.000	0.055	-0.001	-0.001	0.012
100	0.008	0.009	0.048	0.173	0.000	0.058	0.002	0.002	-

Anti-clockwise torque:

Calibration torque in N·m	b'/Y in %	b/Y in %	b_L/Y in %	b_V/Y in %	f_a/Y in %	f_q/Y in % 1)	f_a/Y in % 2)	f_a/Y in % 3)	h/Y in %
-0	-	-	-	-	-	-	-	-	-
-2	-0.050	-0.035	0.000	0.173	0.008	0.075	0.019	0.019	0.050
-4	-0.050	-0.035	0.000	0.173	0.009	0.075	0.019	0.019	0.025
-10	-0.020	-0.014	0.020	0.173	0.007	0.070	0.014	0.014	0.040
-20	0.000	0.000	0.040	0.173	0.000	0.060	0.004	0.004	0.040
-40	-0.015	-0.012	0.055	0.173	-0.001	0.054	-0.003	-0.003	0.035
-60	-0.017	-0.014	0.057	0.173	0.000	0.053	-0.003	-0.003	0.023
-80	-0.012	-0.011	0.052	0.173	0.000	0.055	-0.001	-0.001	0.012
-100	-0.008	-0.009	0.048	0.173	0.000	0.058	0.002	0.002	-

Explanations:

Since the torque transfer key has a fixed connection profile, the contribution of the connection profile has been derived from a previous measurement with another transfer wrench without fixed connection. The previous measurement showed a maximum standard deviation w_V of 0.05 % for the characteristic quantity *connection profile*. With this, b_V/Y can be calculated.

Further explanations: see "Calibration result", above.

Regression functions

The regression functions are specified for the cases mentioned above. With X and M having the following meaning:

X - indication of the calibration item

M - corresponding torque.

1. Cubic regression function

   - clockwise torque

   $$X = 1{,}00068 \cdot M - 0{,}46 \cdot 10^{-5} \cdot M^2 + 0{,}37 \cdot 10^{-7} \cdot M^3$$
   $$M = 0{,}99932 \cdot X + 0{,}46 \cdot 10^{-5} \cdot X^2 - 0{,}37 \cdot 10^{-7} \cdot X^3$$

   - anti-clockwise torque

   $$X = 1{,}00068 \cdot M + 0{,}46 \cdot 10^{-5} \cdot M^2 + 0{,}37 \cdot 10^{-7} \cdot M^3$$
   $$M = 0{,}99932 \cdot X - 0{,}46 \cdot 10^{-5} \cdot X^2 - 0{,}37 \cdot 10^{-7} \cdot X^3$$

2. Linear regression function, separately for clockwise and anti-clockwise torque

   - clockwise torque

   $$X = 1{,}00056 \cdot M$$
   $$M = 0{,}99944 \cdot X$$

   - anti-clockwise torque

   $$X = 1{,}00056 \cdot M$$
   $$M = 0{,}99944 \cdot X$$

3. Linear regression function for both clockwise and anti-clockwise torque together

   $$X = 1{,}00056 \cdot M$$
   $$M = 0{,}99944 \cdot X$$

Classification (see Annex E)

Class	Cubic regression function 1		Linear regression function 2		Linear regression function 3	
	from	to	from	to	from	to
	in N·m		in N·m		in N·m	
	Clockwise torque					
0.1 0.2 0.5 1	2	100	2	100	2	100
	Anti-clockwise torque					
0.1 0.2 0.5 1	-2	-100	-2	-100	-2	-100

Annex D Relative error span

According to GUM [4], measurement results must be corrected for all significant known systematic deviations. In some cases, this may require more than a reasonable effort. For instance, this is the case with:

- measuring instruments with a scale indicating the value in the units of the measurand that cannot be adjusted and for which a significant indication error has been detected
- measuring instruments that allow the scale to be adjusted by means of a linear regression function, but for which a function of a higher order would have to be applied because of the detected significant non-linearity.

In such cases, the relative error span is calculated according to (12) or (13). It does not represent a measurement uncertainty but is to be understood as a specification limit meant to enable the comparison of different measuring instruments – including those for which an expanded relative measurement uncertainty according to GUM has been calculated.

If the measuring instruments considered here form part of a traceability chain, the standard uncertainty of their measured values must not be obtained by dividing the relative error spans by the coverage factor k. Instead, systematic deviations and measurement uncertainties must be considered separately. Depending on the requirements of other standards and guidelines to be considered, it may be necessary to calculate quantities in the same way as the relative error span, according to (12) or (13). This requires knowledge of both types of contributions. In the case of this Guideline, this applies both to the standards used for calibration (transfer wrenches) and to the subsequent use of the calibration devices calibrated according to this Guideline.

Annex E Classification of the measuring instrument

Principle of classification

The measuring range for which the torque wrench calibration device is assigned a specific class includes all calibration torques for which the corresponding classification criteria are fulfilled – starting from the end value of the measuring range to the lowest calibration torque.

Classification criteria

The initial value of the measuring range M_A for classification must be ≤ 20 % of M_E.

The following criteria are to be taken into account:

- relative reproducibility $b\,/\,Y$
- relative repeatability $b'\,/\,Y$
- relative influence of the lever length r $b_L\,/\,Y$
- relative influence of the connection profiles $b_V\,/\,Y$ and
- relative regression $f_a\,/\,Y$ or indication error $f_q\,/\,Y$.

Table E.1 shows the permissible values of these different parameters for the respective class of the torque wrench calibration device and the corresponding required relative expanded uncertainty of the calibration torques.

The last column gives the maximum permissible expanded relative uncertainty (or relative error span) of the torque transfer wrench used as transfer standard for calibration.

Table E.1: Classification features of the torque wrench calibration device

Class	$\lvert b/Y\rvert$ in %	$\lvert b'/Y\rvert$ in %	$\lvert b_L/Y\rvert$ in %	$\lvert b_V/Y\rvert$ in %	$\lvert f_a/Y\rvert$ or $\lvert f_q/Y\rvert$ in %	Initial value of the measuring range M_A	W_{TN} $(k = 2)$ in %
0.1	0.10	0.05	0.10	0.10	0.05	≥ 2000 r	0.02
0.2	0.20	0.10	0.20	0.20	0.10	≥ 1000 r	0.04
0.5	0.50	0.25	0.50	0.50	0.25	≥ 400 r	0.10
1	1.00	1.00	1.00	1.00	0.50	≥ 200 r	0.20

Published by:

Physikalisch-Technische Bundesanstalt
Deutscher Kalibrierdienst
Bundesallee 100
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