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A GERMAN CALIBRATION GUIDELINE FOR TORQUE WRENCH CALIBRATION DEVICES REVISED

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Abstract – Torque wrenches are commonly used measuring instruments in many applications. They are calibrated on torque wrench calibration devices. In Germany, at least in the accredited laboratories, the latter are calibrated using precision torque transfer wrenches and applying the corresponding DKD calibration guideline. This guideline was recently revised. The main new ideas and modifications will be presented in this paper.

Keywords: torque wrench calibration device, calibration guideline, DKD-R 3-8, DAkkS-DKD-R 3-8, DKD-R 10-8

1. INTRODUCTION

In the past, prior to 2010, the Deutscher Kalibrierdienst (DKD, German Calibration Service) was responsible for the accreditation of calibration laboratories as well as for the drafting and issuing of calibration guidelines – along with other standardization bodies – in Germany. In the field of torque, the technical committee (TC) “Torque” (committee no. 10) of the DKD elaborated the three calibration guidelines shown in Table 1.

Table 1. DKD torque calibration guidelines in 2009.

Name	Title
DKD-R 3-5	Calibration of torque measuring devices for static alternating torque
DKD-R 3-7	Static calibration of indicating torque wrenches
DKD-R 3-8	Static calibration of torque tool calibration devices [1]

In the year 2010, the DKD became a part of the Deutsche Akkreditierungsstelle (DAkkS), the German Accreditation Body. At that time, all guidelines were transferred to the DAkkS and their names changed to DAkkS-DKD-R. Soon it turned out that the accreditation body DAkkS could not be responsible for technical documents such as calibration guidelines. In addition, the status of the still existing technical committees of the former DKD was not clear. Therefore, the decision was made by PTB to reestablish the “new” DKD on 3rd May, 2011 as a PTB panel for co-operation between the German national metrology institute and the accredited laboratories. The new DKD is the home of the “old” technical committees and one of their main tasks is the maintenance of the DKD calibration guidelines.

Due to contractual reasons, the DAkkS-DKD-R documents, which are at present the basis for many accreditations, still exist in this form, but beginning with the year 2015, all guidelines will be replaced by new guidelines with the former title DKD-R. Guidelines that require a revision will be discussed in the TCs and issued as new versions. One important amendment is that the first number in the name of the guideline (3) will now be the number of the TC which deals with this guideline. For torque this number is 10; therefore, in future all guidelines from the “torque” TC will have the name DKD-R 10-XX with a second number XX. In order not to change too much and to confuse the users it was decided to keep the second number of the old name. This means, the old DKD-R 3-8, which later became DAkkS-DKD-R 3-8, will have the new name DKD-R 10-8. This guideline deals with the calibration of torque wrench calibration devices and it was revised in the TC 10 Torque committee of the DKD. In the following, the main new ideas, improvements and amendments will be explained in detail.

2. TORQUE TRANSDUCERS VS. TORQUE WRENCHES

Torque transducers are calibrated using torque without any additional components, i.e. with “pure” torque. This can be done on a torque calibration machine with a supported lever and deadweights or against a reference torque transducer in a reference calibration machine. In the first case, the torque is generated by a force couple (the weight and the reaction force of the support, which should be an air bearing if smallest uncertainties are aimed at). In the second case, the torque is generated as pure torque by an electric drive and a gearbox.

The main difference between torque transducers and torque wrenches is the cross force that acts at the end of the wrench arm. This force is either used to generate the torque (just like when the worker applies this force to tighten a screw) or it is the reaction force against a support when the torque is generated in the measuring axis, for example, using a drive. For the measurement, both methods are comparable.

Now we have to consider the question as to how the torque with superimposed cross force (and possibly an additional bending moment due to the fact that the cross force also acts at a certain distance in the direction of the measuring axis) can be traced back to torque standards that were established for pure torque. This problem can be solved when the cross force (and additional bending moments) is compensated by a bearing between the torque wrench and the reference torque transducer. The bearing must have sufficiently low friction, and air bearings are used for this purpose at PTB. This method is applied to the calibration of torque transfer wrenches (Figure 1), which are later used for the calibration of torque wrench calibration devices (Figure 2).

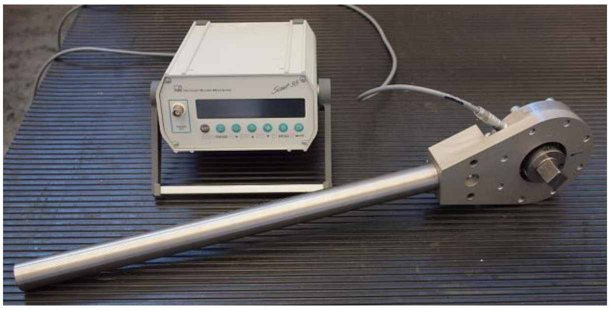

Fig. 1. Torque transfer wrench with electronic display (example).

3. CALIBRATION OF TORQUE WRENCH CALIBRATION DEVICES

The main purpose of the majority of torque wrench calibration devices is the calibration of setting or indicating torque wrenches according to ISO 6789. Such torque wrenches are commonly used in many applications for safety-related bolted connections, for example in the production and maintenance of cars. Unfortunately, ISO 6789 in its present version (2003) does not distinguish between pure torque tools (screwdrivers) and tools working at torque superimposed with cross force and bending moment (torque wrenches). Together, the two are called “torque tools”. Therefore, there are no special requirements for the calibration equipment for the different kinds of these tools. The scope of application of the new DKD-R 10-8 is clearly limited to torque wrench calibration devices. For this reason, the title was changed to “Static calibration of torque **wrench** calibration devices”.

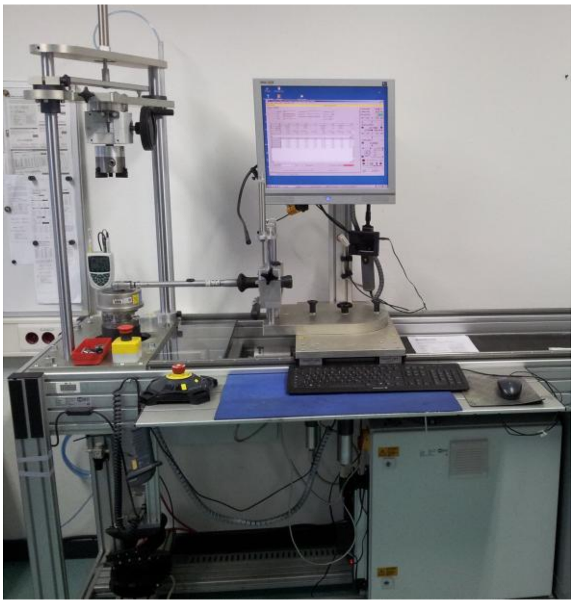

Fig. 2. Torque wrench calibration device (by courtesy of CEH).

3.1. Types of torque wrench calibration devices

There are many different types of torque wrench calibration devices available on the market. Some are manually operated in the sense that the torque is generated by a force applied to a torque wrench by hand. These devices lack the necessary reproducibility and, therefore, they cannot be accredited. The minimum requirement for an accreditation is that the torque is generated by a motor drive or by a hand-operated spindle drive both using a suitable gearbox. That means that the force is not directly applied by hand. Two working principles are possible here: a) the drive turns the torque transducer and the torque wrench connected to the transducer is supported at a certain distance along the lever arm such that it generates the reaction force; b) the torque transducer is fixed and the support of the lever arm moves usually along a straight line due to the acting drive such that it generates the force. Both principles are comparable, there are no great technical advantages of one against the other. In both cases, care has to be taken to allow the wrench its self-adjustment due to the interaction between the connecting profiles (often square drives) and due to its elastic deformation.

Torque wrench calibration devices with mechanical measurement of the torque (often equipped with dial gauges) are usually not suitable for the calibration of torque wrenches according to ISO 6789 due to their inadequate uncertainty. A large contribution is due to the resolution which is quite limited. Nevertheless, such devices can be calibrated using the guideline discussed here.

Another difference in torque wrench calibration devices is the cross force and bending moment reaction. Very precise devices use bearings (in the best case air bearings) to compensate these additional mechanical components. This results in a better reproducibility of the indications of the torque transducer used as reference. By design, these devices are not affected by the value or the direction of the cross force or the bending moment acting in a torque wrench set-up.

3.2. New ideas and modifications of the guideline

In addition to the changed title of the guideline, the attempt was made to take the different types of torque wrench calibration devices into account and to allow an economical calibration of the device, depending on the requirements for the target uncertainty.

One major issue is the **hysteresis**. In the former guideline this parameter was used to determine the uncertainty of the device. In contrast to this procedure, there is no application known where torque wrenches are used in a decremental measurement series, when the torque is reduced from a higher value down to zero. Screws are tightened with increasing torque. To loosen a screw, an increasing torque in the opposite direction must be applied. When the tightening was achieved with clockwise torque, then for loosening anti-clockwise torque must be applied.

Once the necessary torque value has been reached, then there is usually no need for a measurement of the decreasing torque. Therefore it was decided not to include the hysteresis contribution in the uncertainty evaluation anymore. This parameter must be measured, recorded and evaluated like a quality parameter of the device. An application of this is devices with bearings where a low hysteresis value indicates the proper functioning of this bearing. Nevertheless, this parameter is not necessary for the calibration of torque wrenches according to ISO 6789.

Depending on the **target uncertainty**, the **number of measurement series** can be reduced by one. A limit value of 0.5 % expanded relative uncertainty ($k = 2$) was defined. The entire set of series must be measured when the target is lower than 0.5 %. If 0.5 % or more is requested, then the reduced program can be applied. The maximum number of measurement series is six, five incremental and one decremental series: two incremental series in the standard position of the device's torque transducer (0°) for repeatability, one series with decremental torque for hysteresis as mentioned above, one series with reduced lever arm length for measuring the effect of lever length, one series with a changed mounting position of the device's torque reference transducer (rotated by an angle α) and a last series with a changed position of the connector (which can be changed in the device as well as on the transfer wrench usually by an angle of 45° or 90° for square drives).

Depending on the design of the torque wrench calibration device and the transfer wrench that is used for the calibration, it may not be possible to change the **position of the device's reference transducer or the connector** in the device or on the wrench. In the last case of fixed connector positions, the maximum number of series can be reduced to five when the information about the influence of the connector is obtained by other means, for example from a former calibration with a suitable wrench where the position of the connector could be changed. In the first case with a fixed position of the torque reference transducer, the measurement series with changed transducer position is replaced by a series with unchanged transducer position after the transfer wrench has been dismounted and mounted again.

If the **target uncertainty** is 0.5 % or higher, then the measurement of the changed position of the reference transducer - if it cannot be changed, the additional series with unchanged transducer position - can be omitted.

Table 2. Minimum number of measuring series (incr. = incremental, decr. = decremental series).

Target uncertainty in %	0° Nominal lever arm length	0° Nominal lever arm length	0° Reduced lever arm length	Rotated sensor	Rotated connec-tor
Sensor and connector turnable					
< 0.5	2 incr.	1 decr.	1 incr.	1 incr.	1 incr.
≥ 0.5	2 incr.	1 decr.	1 incr.	-	1 incr.
Sensor turnable and connector fixed					
< 0.5	2 incr.	1 decr.	1 incr.	1 incr.	-
≥ 0.5	2 incr.	1 decr.	1 incr.	-	-
Sensor fixed and connector turnable					
< 0.5	3 incr.	1 decr.	1 incr.	-	1 incr.
≥ 0.5	2 incr.	1 decr.	1 incr.	-	1 incr.
Sensor and connector fixed					
< 0.5	3 incr.	1 decr.	1 incr.	-	-
≥ 0.5	2 incr.	1 decr.	1 incr.	-	-

For the **lever arm length**, the increased measuring range of transfer torque wrenches is now considered. For torque wrenches with a range from 2000 N·m to 3000 N·m, the nominal length is shown to be 1800 mm and the reduced length is 1300 mm. It is advised that the first measuring series in the calibration should be the series with reduced lever arm length because the larger mechanical interactions (cross force, bending moment) are associated with the reduced lever length. The terminology has been slightly changed, the former "medium lever arm length" is now named "nominal lever arm length" and "minimum lever arm length" was replaced with "reduced lever arm length".

Figures 3 and 4 show examples of the measurement sequence depending on the target uncertainty and the possible rotational positions of the torque sensor and the connector between sensor and torque transfer wrench.

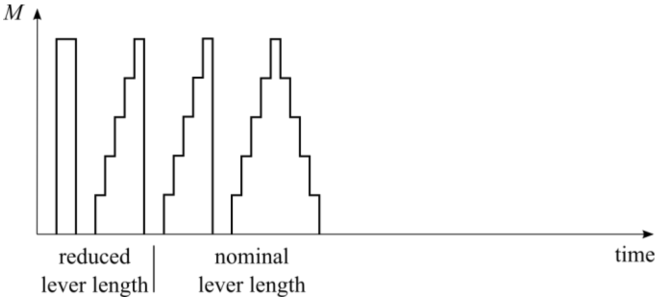

Fig. 3. Calibration sequence of a torque wrench calibration device with fixed torque sensor and fixed connector and a target uncertainty of ≥ 0.5%.

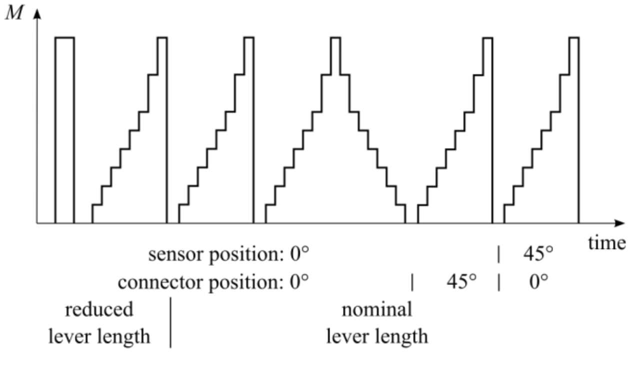

Fig. 4. Calibration sequence of a torque wrench calibration device with a target uncertainty of < 0.5%.

In the past, there have been some difficulties with torque wrench calibration devices when they were calibrated with torque transfer wrenches of special design. Due to the greater height of these wrenches, the cross force associated with the torque acts at a greater distance from the reference transducer in axial direction, thus generating a larger **bending moment**. If the device does not have a bearing, then the bending moment acting on the reference transducer increases with the height of the wrench. But standard torque wrenches that do not have this height are then calibrated under different conditions, because the bending moment will be much lower. The guideline now requires an information about the axial distance of the cross force.

Another problem is connected with the **zero suppression** that is offered by some devices. This feature means that values that are close to zero are displayed as “0” but in fact they can deviate from real zero significantly. It is required that these devices – in case the zero suppression cannot be deactivated for the time of the calibration – shall not be switched off and on for self-taring during the calibration.

An advantage of the new revision of the guideline is that all main **formulas and calculations** remain unchanged. In the former version, there was a classification described in the main text and an uncertainty calculation in the annex. Nowadays, uncertainty plays a more important role and it is therefore now part of the main text, whereas classification has been shifted to an annex. The guideline now contains another annex with a fully calculated example of a calibration result, including uncertainties, which can be used as a reference for evaluation procedures applied by laboratories.

4. CALIBRATION RESULTS

3.1. Calibration result

The calibration result Y is calculated for each torque step as mean value of the incremental series in different mounting positions and at nominal lever arm length without taking into account repeated series as in (1)

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

Here, n is at least 1 in the case of the fixed connector and sensor, and 3 when both connector and sensor are turnable.

There is a number of parameters that have to be determined (3.2 through 3.8). All of them are related to corresponding influencing quantities. Except for the reversibility (3.8), these parameters are then statistically evaluated and combined to obtain a resulting measurement uncertainty or uncertainty interval (see 5).

3.2. Reproducibility

The reproducibility b is calculated for each torque step as the standard deviation of the values of the incremental series as in (2)

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

when the target uncertainty is less than 0.5 %. For uncertainties ≥ 0.5 % this parameter can be omitted and the contribution of the repeatability (3.3) has to be taken instead.

Here, n is at least 2 but this is not limited by the guideline and additional series can be measured.

3.3. Repeatability

The repeatability b’ is calculated for each torque step as the absolute amount of the difference (span) between the values of the initial and the repeated measurements at nominal lever arm length as in (3)

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

3.4. Influence of the lever arm length

The influence of the lever arm length b_L is calculated for each torque step as the difference (span) between the values of the incremental series with reduced lever length and the values of the series with nominal lever length as in (4)

$$b_L = X_{L,red} - X_{L,nom}. \qquad (4)$$

3.5. Influence of the connector

The influence of the connector b_V is calculated for each torque step as the difference (span) between the values of the incremental series with rotated connector and the values of the series with the initial position of the connector as in (5)

$$b_V = X_V - X_{0°}. \qquad (5)$$

3.6. Influence of the regression

The influence of the regression f_a is calculated for each torque step as the difference (span) between the values of the incremental series and the values obtained from the regression function of third (cubic) or first (linear) order as in (6)

$$f_a = Y - Y_a. \qquad (6)$$

The regression function and the method of its determination must be stated. If the indication of the calibration device is fixed (“named scale”), then the influence of the indication deviation (3.7) must be determined instead.

3.7. Influence of the indication deviation

The influence of the indication deviation f_q has to be determined only for devices where the indication in torque units cannot be adjusted (“named scale”) by electronic or other means. It is calculated for each torque step as the difference (the span) between the indicated values of the incremental series and the values of the calibration torque measured with the transfer wrench as in (7)

$$f_q = Y - M_K. \qquad (7)$$

3.8. Reversibility

The reversibility h is calculated for each torque step as mean value of the differences (spans) between incremental and decremental series in the same mounting positions and at nominal lever arm length as in (8)

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

The reversibility is not taken into account for the uncertainty calculation, therefore there is usually no need to measure it in different mounting positions. With $m = 1$ (8) can be reduced to a simple difference between two values similar to the formulas (4) to (7). The parameter h can be used for quality assurance and long-term stability.

5. MEASUREMENT UNCERTAINTIES

The resolution of the torque wrench calibration device and the parameters determined according to 3.2 to 3.6 are statisticaly evaluated using the distributions given in Table 3. In the case of a cubic regression, the residual deviation from the regression function is considered to be a stochastic influence. In this case, the resulting standard uncertainty of measurement can be calculated applying the GUM procedure leading to (9)

$$w(M) = \sqrt{w^2(M_{\mathrm{TN}}) + \sum_{i=1}^{n} w^2(\delta M_i)} \tag{9}$$

with the uncertainty $w(M_{\mathrm{TN}})$ of the torque transfer wrench and the contributions $w(\delta M_i)$ of the relevant parameters (see Table 3). In (9), the resolution must be taken twice if the value is calculated from two indications: one at the applied torque and one at zero torque. The expanded relative uncertainty is then calculated with the coverage factor k as in (10)

$$W(M) = k \cdot w(M)\,. \tag{10}$$

Table 3. Parameters and their statistical evaluation.

Parameter	Distribution type	Standard deviation in %
r	rectangular	$w_r = \frac{1}{\sqrt{3}} \cdot \frac{r}{2} \cdot \frac{100}{M_{\mathrm{K}}}$
b	normal	$w_b = \frac{b(M_{\mathrm{K}})}{\sqrt{n}} \cdot \frac{100}{Y(M_{\mathrm{K}})}$
b'	normal	$w_{b'} = \frac{b'(M_{\mathrm{K}})}{\sqrt{2}} \cdot \frac{100}{Y(M_{\mathrm{K}})}$
b_{L}	rectangular	$w_{\mathrm{L}} = \frac{1}{\sqrt{3}} \cdot \frac{b_{\mathrm{L}}(M_{\mathrm{K}})}{2} \cdot \frac{100}{Y(M_{\mathrm{K}})}$
b_{V}	rectangular	$w_{\mathrm{V}} = \frac{1}{\sqrt{3}} \cdot \frac{b_{\mathrm{V}}(M_{\mathrm{K}})}{2} \cdot \frac{100}{Y(M_{\mathrm{K}})}$
f_{a}	triangular	$w_f = \frac{1}{\sqrt{6}} \cdot \frac{f_{\mathrm{a}}(M_{\mathrm{K}})}{2} \cdot \frac{100}{Y(M_{\mathrm{K}})}$

In the case of linear regression (linear curve fit), the deviations are considered to be systematic and they should not be treated like stochastic uncertainty contributions. The same applies to devices with named scales.

Consequently, the expanded relative uncertainty is determined in a different way and the new quantity is called “uncertainty interval”. With the coverage factor k, the relative uncertainty interval is calculated as in (11)

$$W'(M) = \left| \frac{f_{\mathrm{a,q}}(M)}{M_{\mathrm{K}}} \right| + k \cdot w(M)\,. \tag{11}$$

6. CONCLUSIONS

The new draft of the guideline for the calibration of torque wrench calibration devices brings more clarity to its field of application by restricting it to torque wrenches only. For other torque tools, like screwdrivers, the effect of different lever arm lengths or cross forces and bending moments does not play a role in their calibration.

The draft offers a reduced calibration effort compared with the old 2003 issue, which may be required for a simpler design of the device and/or its higher target uncertainty.

Although the draft has not yet been finally approved (June 2015), it is expected that it will still be issued in 2015.

ACKNOWLEDGMENTS

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REFERENCES

[1] DKD-R 3-8 - *Static calibration of torque tool calibration devices*, Issue 2003-10, DKD, Web: http://www.dkd.eu/dokumente/Richtlinien/dkd_r_3_7.pdf [accessed 2014-01-25].