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GUIDE TO THE CALIBRATION OF HYDRAULIC TORQUE WRENCHES

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Abstract:

This paper describes the new proposal of the calibration of hydraulic torque wrenches. The calibration includes the different metrological effects of the hydraulic torque wrenches like repeatability, reproducibility, and the piston position. A sensitivity analysis is introduced to the different uncertainty contributions of the of hydraulic torque wrenches like the piston position, mounting position and the mechanical adaptation. The measurements show that the piston position has the significant influence on the measurement uncertainty of the calibration result. The uncertainty evaluation of the calibration facility is introduced including the effect of the lateral forces that comes from the application of relatively high torque values with short lever arm lengths. The estimation of the measurement results and the corresponding uncertainty are performed like the calibration standard ISO DIN 51309 without the estimation of the hysteresis. The calibration method and the corresponding validation are accepted from the German DAkkS accreditation body.

Keywords: hydraulic torque wrench; torque; calibration

1. INTRODUCTION

Hydraulic torque wrenches are used to tight or loose thread joints that require higher torque values. The application of the hydraulic torque wrenches is increasing in many industrial applications. The traceability of the applied torque values to the national SI units is required. The absence of an internationally recognised calibrated standard of hydraulic torque wrenches is a big challenge for the application of them. Nevertheless, there is well established metrological infrastructure of the traceability of torque measurement to pure torsional moment loading conditions up to 1.1 MN·m [1]. The metrological infrastructure may be divided into two main arms: the calibration standards and methods [2] and the calibration facilities from the national level to the industry level throughout a non-broken chain of traceability. This is fulfilled through the accredited laboratories. The calibration of reference torque wrenches is also well established in terms of metrological traceability to the SI units [3]. The loading condition is here a combination of torsional moment, bending moment and lateral forces. The calibration method of the calibration devices for the torque wrenches is introduced in the guideline DKD-R 10-8:2020.

In this work a guideline to the calibration of the hydraulic torque wrenches is introduced to provide the traceability to this field of application in the industry. The proposed procedure includes the estimation of the calibration result and the corresponding measurement uncertainty according to the ISO DIN 51309 standard. The parameter *b* estimates the effect piston position as a dominant uncertainty contribution. The estimation of the hysteresis is neglected to fulfil the intended purpose to use of hydraulic torque wrenches. The effect of the bending moment is considered. The bending moment results from the application of the supporting force off-plane to the applied torque. The lateral force has a critical systematic effect on the measurement result [4], [5], this effect is also considered. The lateral force effect is not considered in the traceability of the reference torque transducer according to DIN 51309 (pure torque application).

2. METHODOLOGY

The development of a calibration procedure of the hydraulic torque wrenches should meet the requirements of their future application as accurately as possible. Suitable calibration result and measurement uncertainty should be calculated according to existing standards or guideline. In this work the development of the guideline to the calibration of hydraulic torque wrenches is validated according to section 7.2.2 in the ISO/IEC 17025 standard of General requirements for the competence of testing and calibration laboratories [6]. The methodology to validate the proposed guideline includes:

- introduction of the hydraulic wrenches and their field of application,
- the calibration setup,
- uncertainty analysis including the assessment of the systematic and non-systematic factors influencing the measurement result,

- calibration procedure based on one of the available recognised standards.

3. HYDRAULIC TORQUE WRENCH

Hydraulic torque wrenches are Slider-Crank mechanisms as shown in Figure 1 [7]. They are designed to apply torsional moments M. This achieved through the conversion of the reciprocating motion of the piston-cylinder-arrangement to a rotary ratchet square/hexagon adapter through a connecting rod. The conversion from the applied force F to the torsion moment M depends on the piston position and accordingly the angle of the crank. Theoretically, the support of the piston-cylinder-arrangement does not play a main role to the functionality of the hydraulic torque wrench. A typical hydraulic torque wrench consists of wrench body, socket, or head mainly a square/hexagon adapter, hoses, and source of hydraulic pressure e.g. pump.

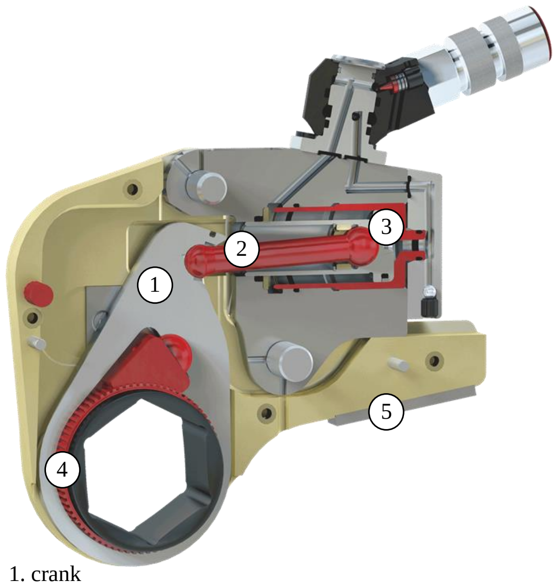
The hydraulic torque wrench is normally operated in one torsional mode, CW, to tightly screw joints. To apply torsion in the CCW direction, the mechanical adapter is rotated to the other side. Then the loading of the piston-cylinder arrangement is the same for both modes.

Three different characteristics of the hydraulic torque wrenches might have an influence on the measurement result. These characteristics are the piston position, the mechanical adapter, and variation of the supporting point (lever arm length). The mechanism of the hydraulic torque wrench is a single degree-of-freedom system. That means the influence of piston position covers the angle of the crank and position of the connecting rod.

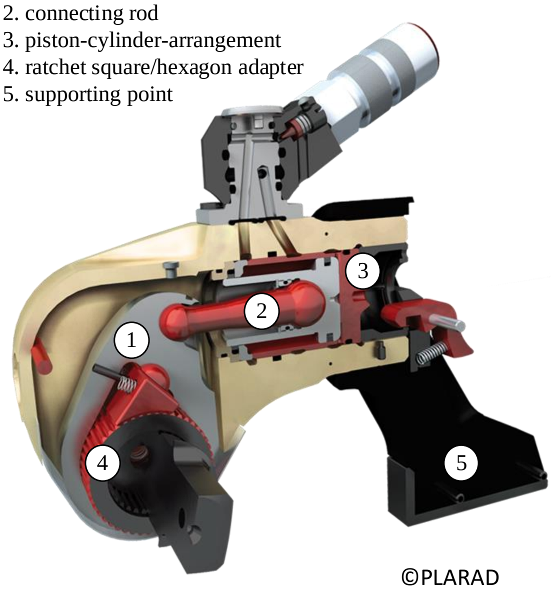
4. CALIBRATION SETUP

The 8 kN·m hydraulic torque wrench calibration facility of DrehmomentService Dr. Peschel (DmS) is shown in Figure 2. The hydraulic torque wrench is mounted to a TB2 20 kN·m torque transducer using the proper mechanical adaptations. The capacity of the machine is limited to 8 kN·m due the effect of the lateral forces. The pressure on the piston is measured using HBM P3ICP pressure transducer.

The application of hydraulic torque wrenches involves three loads: the applied torsional moment on the adapter joint M_z, the lateral force F_y, and the bending moment M_x. The torsional moment is the measurand need to be calibrated. The lateral force is subjected to the supporting point and is calculated as the ratio between the applied torsional moment and the lever arm length. The lever arm length is the distance between the supporting point and the axis of the torsional moment. The bending moment equals to the vectorial multiplication of the lateral force and the distance between the lateral force plane and the fixation point of the torque transducer. The lateral force and the bending moment are considered as parasitic components and must be considered in the design of calibration facility.



1. crank
2. connecting rod
3. piston-cylinder-arrangement
4. ratchet square/hexagon adapter
5. supporting point



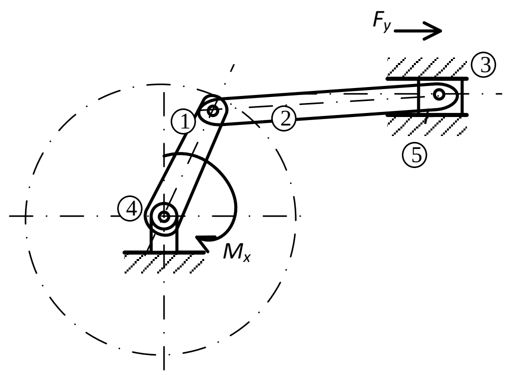


Figure 1: 3D Model of two different types of hydraulic torque wrenches and the corresponding free body diagram of the hydraulic wrench, it can be considered as a typical slider-crank mechanism

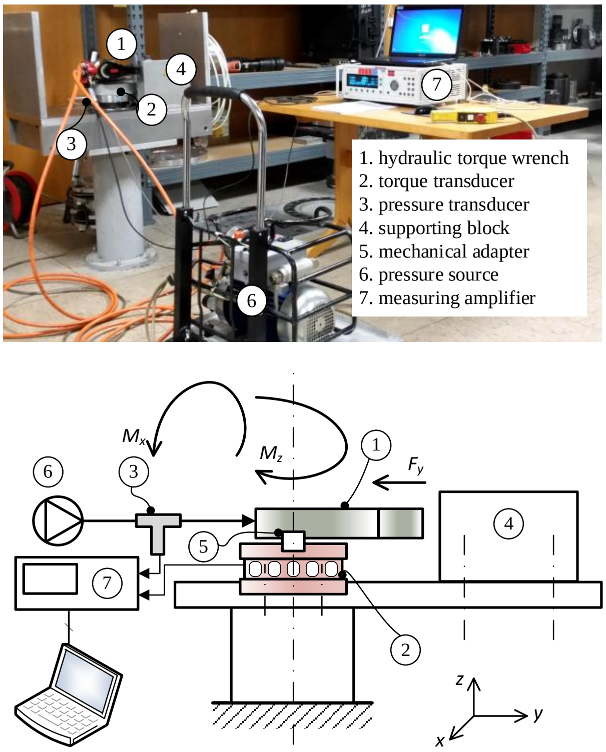


Figure 2: Schematic diagram of the 8 kN·m hydraulic torque wrench calibration facility of DmS and the corresponding photograph

5. UNCERTAINTY ANALYSIS

A detailed uncertainty analysis according to GUM standard [8] is introduced in this work to evaluate the uncertainty of the different contribution of torque wrench characteristics and calibration setup.

Figure 3 represents the Ishikawa diagram of the systematic and non-systematic influences of the measurement result and corresponding uncertainty. The red marked influences are considered in either the calibration procedure or in the uncertainty of the calibration machine. The green marked influences are systematic influences and have been corrected through certain precautions, e.g. the pressure transducer is mounted close to the hydraulic torque wrench to prevent the effect of the pump vibration. the yellow marked influences are neglected in the estimation of the measurement uncertainty.

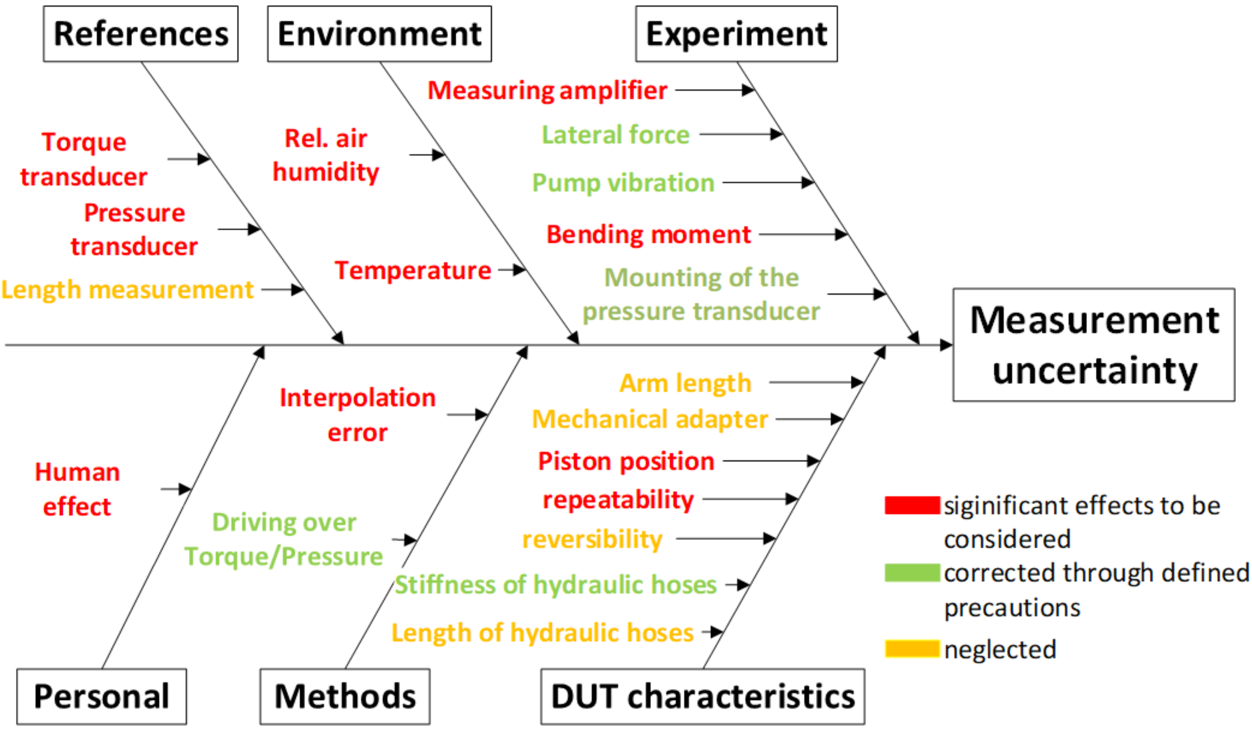


Figure 3: Ishikawa diagram of the uncertainty contribution related to the calibration of hydraulic torque wrenches. The systematic errors are corrected through defined precautions. A sensitivity analysis performed to validate the significance of the non-systematic influences

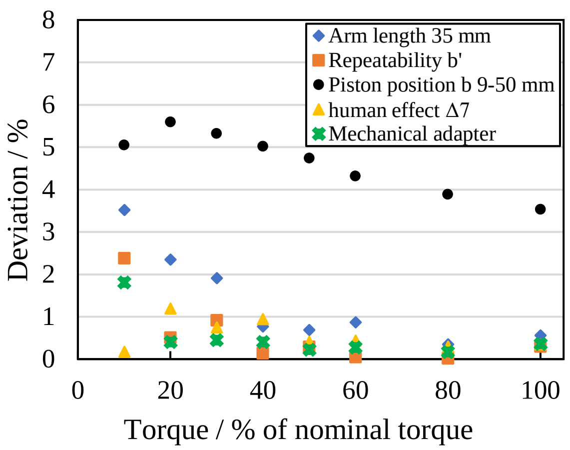


Figure 4: Sensitivity analysis of the main characteristics of the hydraulic torque wrench. The results show the significant effect of the piston position

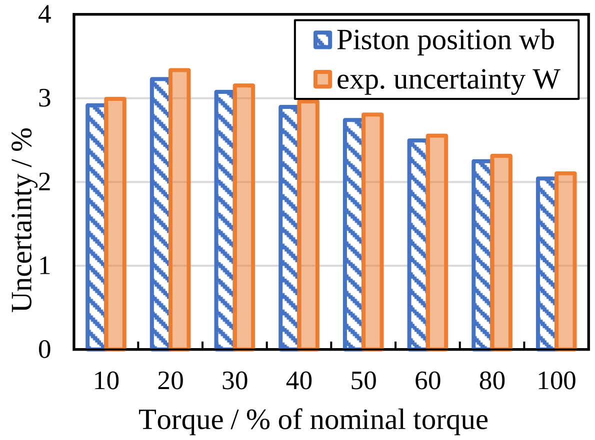


Figure 5: The uncertainty contribution of parameter *b* that corresponds to the piston position to the combined measurement uncertainty of the measurement result

A sensitivity analysis has been performed to investigate the significance of the characteristics of the hydraulic torque wrench. As shown in Figure 4 the variation of the piston position has the dominant uncertainty contribution to the measurement uncertainty. This emphasis the theoretical assumption introduced in section 3. The uncertainty of the variation of the piston position can be evaluated as the reproducibility in the DIN 51309 calibration standard. Three mounting position can be selected; the first position measured where the piston is close to the top dead centre (TDC), the third position where the piston is at the bottom dead centre (BDC), while the second position is measured where the piston lies between the two previous positions. Figure 5 shows typical calibration results where parameter *b* that corresponds to the piston position compared to the combined measurement uncertainty of the measurement result. The experience of DmS shows that this the case of most of the hydraulic wrenches.

The lateral force and the bending moment are considered as parasitic components and must be considered in the design of calibration facility. These influences are having a systematic behaviour and can be eliminated throughout the orientation of the reference torque transducer. The reference torque transducer is a strain-gauge based type where the strain gauges are applied on the plane where the maximum normal strain exists. The connection of the strain gauges may sense other parasitic load rather torsion moment. The torque transducer delivers different lateral force and bending moment sensitivity in the different mounting position. The influence has usually a sine wave shape as shown in Figure 6.

For torque transducer having lower nominal torques the measurement is performed using an air bearing at the measuring side of the torque transducer and a ball bearing to apply the dead weight to the measuring side as shown in Figure 6. The lateral force effect is investigated using the loading of defined load masses, while the bending moment effect is investigated using the shift between the applied load masses to the plane of the strain gauges.

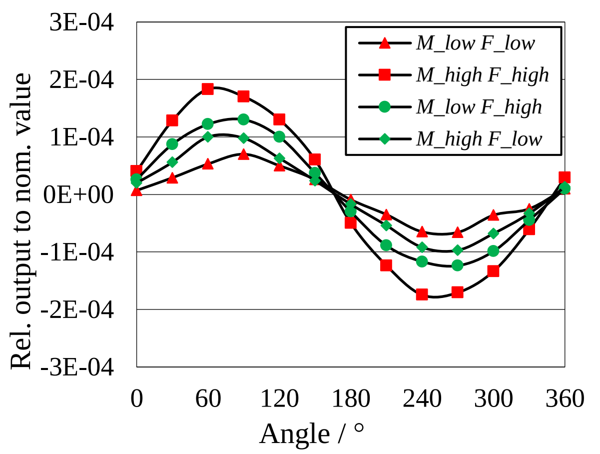


Figure 6: The measurement setup (top) of the investigation of both lateral force and bending moments effects. The curves (bottom) show the relative response of the signal of a 1 kN·m TB2 torque transducer. Two levels of lateral force 140 N, 280 N and a bending moment of 11.5 N·m, 35.5 N·m are applied

The effects of the two loads; lateral force and bending moment, are correlated to each other in the direction and amplitude. Figure 6 shows the results of the different combination of two 2 × 2 ANOVA matrix of two different levels of lateral forces and bending moments. The experience of DmS shows that the torque transducer should be mounted to an angle of ±5° to the minimum lateral effect point, this corresponds to an uncertainty of 0.01 %.

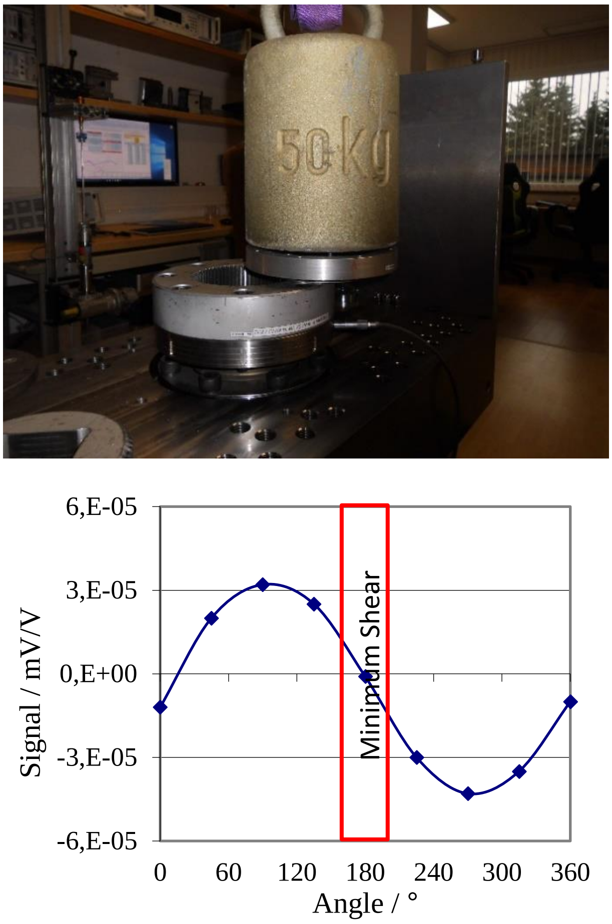


Figure 7: Bottom, the variation of the 20 kN·m reference torque transducer output due to rotating a 50 kg deadweight around its circumference. Top, a photograph of the experiment. The experiment is used to figure out the mounting of the torque transducer where the minimum lateral force effect exposed

For the investigation of the torque transducers of higher torque nominal values like the DmS 20 kN·m reference torque transducer, a 50 kg mass is applied with a distance of 0.1 m to the longitudinal axis of the torque transducer as shown in Figure 7 top. This apply a bending moment of about 49.05 N·m. The results show that the investigated reference torque transducer should be mounted at an angle of about 180°. The signal peak is about 35×10^{-6} mV/V. A 6 kN·m hydraulic torque wrench with an arm length of 0.17 m and span length of 0.13 m will expose bending moment of about 4.5 kN·m. The peak signal will then be of 3.3×10^{-3} mV/V as shown in Figure 7 bottom. This corresponds to a systematic error of 0.55 % if the transducer is oriented to angle of the worst case. The reference of the angle measurement is considered to be the cable output.

6. CALIBRATION PROCEDURE

The calibration procedure shall provide traceability of the applied torque of hydraulic torque wrenches with associated measurement uncertainty. The application of torque in combination with lateral forces leads to some similarity to the known manual-operated torque wrenches, then the decision might lead to the calibration procedure based on DKD-R 3-7. This approach does not quantify the significant influences of the hydraulic torque wrench. This is the piston position rather than the lever arm length or even the mechanical adaptations.

The calibration procedure presented here is the same in DIN 51309. The number of steps and series has not altered. Only the mounting positions differs, the proposed guideline considers the mounting position as the piston position. The proposed guideline does not estimate the hysteresis parameter to compliant with the customer needs and the application field of the hydraulic torque wrench. The hydraulic torque wrenches are normally used to apply torque in the increasing mode without hysteresis.

The estimation of the measurement result and the corresponding uncertainties are considered as case 1 in the DIN 51309 standard. Three preloads to be applied in the first piston position. The calibration procedure is presented in Figure 8. The measurement of creep is not relevant in the application hydraulic torque wrenches.

A calibration example is presented in Figure 9. This shows selected sections from a calibration certificate of a 4.5 kN·m hydraulic torque wrench. The piston positions are set to 9 mm, 27 mm, and 40 mm. The piston position and the interpolation error are the main contributions to the measurement uncertainty.

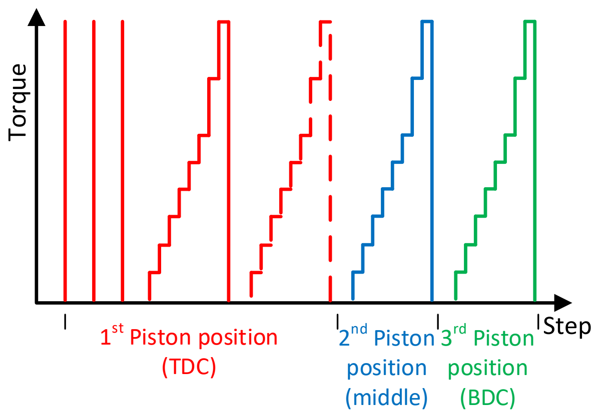


Figure 8: Calibration procedure of the hydraulic torque wrench calibration

8 Auswertung / *Analysis*
8.1 Kalibrierergebnis / *Calibration results*

Dreh-moment / *torque* in N·m	Signal / *signal* in bar	Fall I / *case* I rel. Messunsicherheit / *rel. uncertainty* (*k* = 2) ohne Ausgleichsfunktion / *without interpolation* in %	rel. Messunsicherheit / *rel. uncertainty* (*k* = 2) bei linearer Ausgleichsfunktion / *interpolation* in %
Rechtsdrehmoment / *clockwise torque*			
0	0,0		
450	78,5	2,2	4,0
900	157,1	2,4	4,1
1350	235,9	2,0	3,7
1800	314,8	1,6	3,3
2250	394,2	1,4	2,9
2700	474,4	1,8	2,7
3600	640,6	2,8	2,9
4500	805,9	3,0	3,5

10 Kennwerte nach DIN 51309 / *Classification criteria according to DIN 51309*

	Fall I / *case* I				
M_K in N·m	$\frac{b'}{Y}$ in %	$\frac{b}{Y}$ in %	$\frac{f_0}{Y}$ in %	$\frac{f_{a,\,lin}}{Y}$ in %	r in N·m
4500	0,06	5,17	-	0,92	0,0838
3600	0,20	4,78	-	0,28	0,0838
2700	0,30	2,98	-	-0,98	0,0838
2250	0,25	2,33	-	-1,28	0,0838
1800	0,37	2,63	-	-1,46	0,0838
1350	0,69	3,25	-	-1,54	0,0838
900	0,62	3,94	-	-1,68	0,0838
450	0,60	3,69	-	-1,66	0,0838
0	-	-	-	-	-

12 Darstellung der Ergebnisse in Diagrammen / *Results in diagrams*

Bezugswert / *Reference value:* 798,44 bar

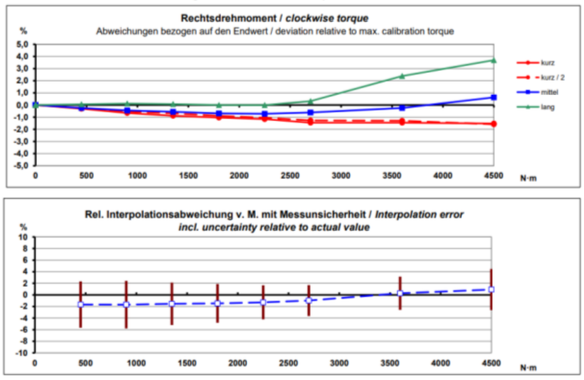


Figure 9: Selected sections from a calibration certificate of a 4.5 kN·m hydraulic torque wrench. The piston positions are set to 9 mm, 27 mm, and 40 mm

7. SUMMARY

In this work a new guideline to the calibration of hydraulic torque wrenches is introduced. the estimation of the calibration result and the measurement uncertainty is performed according to ISO DIN 51309 standard. The guideline is validated according to ISO 17025 requirements. The sensitivity analysis of the different characteristics of the hydraulic torque wrench shows that the piston position has the significant contribution to the measurement uncertainty. The effect of the piston position is considered as parameter *b* according to DIN 51309. The bending moment and lateral force influences are considered in the uncertainty evaluation of the calibration setup. Neglecting these influences can lead to a measurement uncertainty of 1 %.

8. ACKNOWLEDGEMENT

The authors would like to thank Mr Daniel Bozek from PLARAD Torque & Tension Systems for his collaborative work and discussions over the last twenty years in the development of the presented guideline.

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