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INFLUENCE OF CROSS FORCES AND BENDING MOMENTS ON REFERENCE TORQUE SENSORS FOR TORQUE WRENCH CALIBRATION

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Abstract − Effects of disturbing components on reference torque sensors – transducers and torque wrenches – in torque wrench calibration facilities are discussed. Different mounting conditions during the superior calibration of these sensors and their application in the torque wrench calibration machine induce deviations in the sensitivity and affect the best measurement capability of the machines. With standard sensors and mounting situations, methods for investigating and estimating possible effects of cross forces and bending moments are presented.

Keywords: torque wrench calibration, cross force, bending moment, torque reference transducer

1. INTRODUCTION

During the calibration of torque wrenches (figure 1) cross forces and bending moments are important influences (figure 2). The cross forces, at least, act on the torque wrenches under test as well as on the torque transfer wrenches that are used for the calibration of these types of machines according to the guideline DKD-R 3-8 [1]. In order to prevent the torque reference transducers in the machine from being loaded with these additional components, supporting bearings are used. In the best case these are air bearings. But these elements are costly and difficult to operate. Therefore, some laboratories practice torque wrench calibrations without deploying any bearings using special reference transducers. These are then loaded, besides the torque, with cross force and bending moment.

Furthermore, some laboratories work with torque transfer wrenches applied as reference transducers. In this case the change of mounting conditions in the calibration facility compared to the circumstances during the superior calibration of the reference transducers can cause higher uncertainty due to cross force and bending moment influences.

2. REFERENCE TORQUE FACILITIES

Disturbing components like cross forces and bending moments affect the calibration result of torque wrenches. In the guideline DKD-R 3-7 [2], efforts are made to deal with these effects by varying the length of the lever arm.

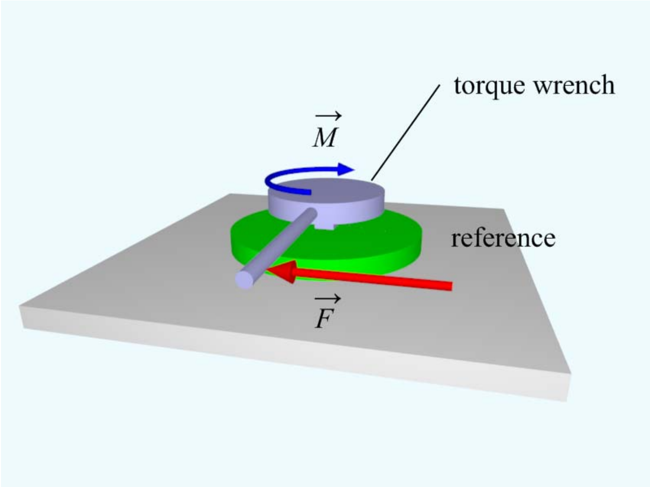

Fig. 1. Force *F* acting on a torque wrench and generating a torque *M.*

The impact of disturbing components on the **reference sensors** is discussed here. These sensors can be reference transducers designed for measuring pure torque, or torque transfer wrenches designed for measuring torque composed of force and length.

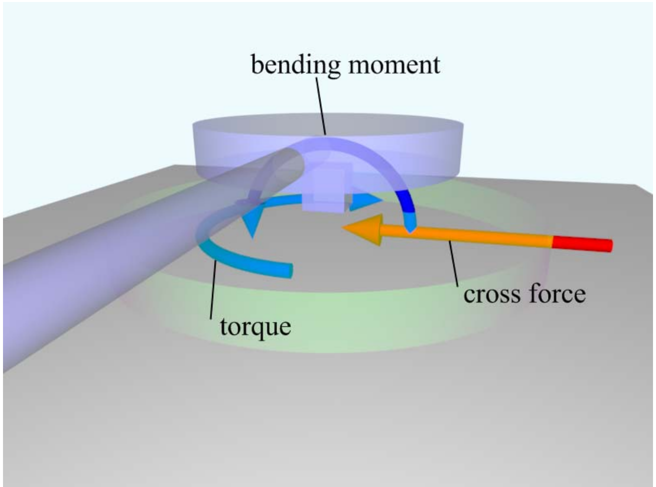

Fig. 2. Forces and moments acting on the reference transducer in a torque wrench calibration facility without supporting bearing.

This distinction is important for calculating the best measurement uncertainty of the calibration machines concerned. Although it is possible to calibrate the facility (i.e. the reference sensor) with superimposed corresponding cross forces, the bending moments can vary when other types of wrenches or (additional) mounting parts are in use (see below).

2.1. Results of an inter-laboratory comparison

The investigations presented here were initiated by the results of an inter-laboratory comparison within the DKD (German calibration service). This comparison was carried out on the basis of the ISO standard 6789:2003 – assembly tools for screws and nuts – Hand torque tools [3].

A precise measuring torque wrench with an electronic display as well as a setting torque wrench were used for the measurements. It was expected that at least the first of the two torque wrenches would produce a good result in the comparison, but this was not the case. Some of the participants delivered values that are not in good agreement with their best measurement capability (b.m.c.). Another effect was a significant difference between clockwise and anti-clockwise torque, although this is not a huge problem, because the overwhelming majority of torque wrench applications are for clockwise torque only.

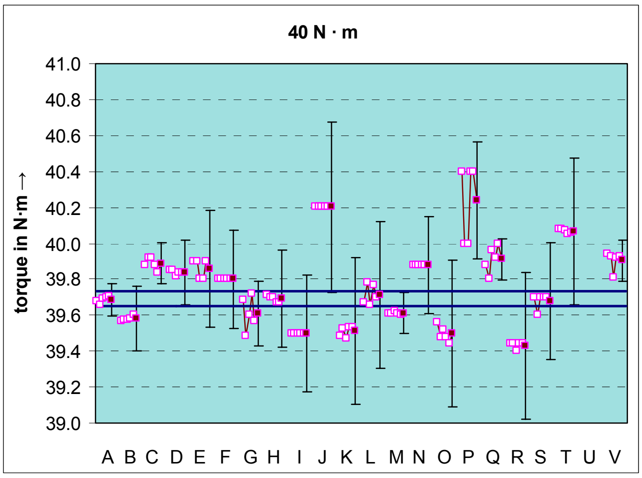

Fig. 3. Anonymous results of an inter-laboratory comparison according to ISO 6789 using a precise measuring torque wrench (torque step 40 N·m, letters: coded participants, A: pilot).

Especially some of the laboratories with a small b.m.c. showed a greater deviation from the reference value (figure 3). The reasons for this are still unknown. A questionnaire was recently sent to the participants in order to gather some additional details about the calibration facility and the measuring procedure.

At the same time, some of the effects which are suspected of contributing to the given deviations were investigated in our laboratory. These effects are strongly related to the use of unsupported reference sensors and are caused by cross forces and bending moments in the calibration setup. In fact we are dealing here with a multi-component load situation (see figure 2).

There is no problem as long as the load situation during the calibration of the facility is reproduced when torque wrenches are calibrated. But in practice there are lots of influences preventing an ideal reproduction of these loads: different dimensions of the torque wrenches, use of additional mounting parts, non-ideal square drive connectors, unknown sensitivities of the reference sensors to disturbing components and others. Some of these factors are investigated here.

2.2. Unsupported reference transducers

The lack of an air bearing in a torque wrench calibration machine exposes the reference transducer to disturbing components which are not included in the sensitivity data gained in a superior calibration of the transducer.

Depending on adaptation conditions, the amount and the impact of these disturbance components can vary.

A facility was constructed that allows the reaction of a standard transducer for unsupported torque wrench calibration to different amounts and orientations of cross force and bending moment to be determined (figure 4).

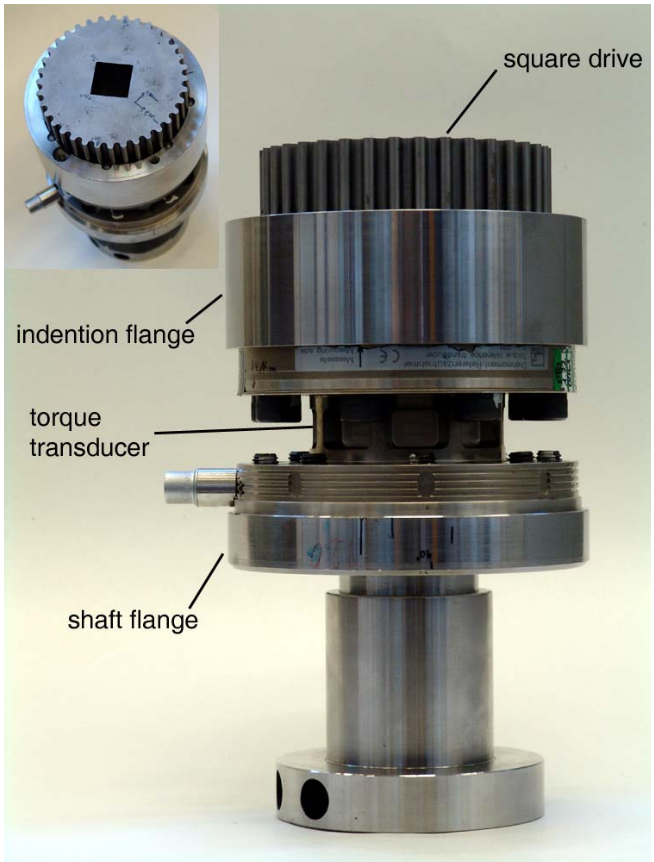

Fig. 4. Facility for determining effects of lateral loading on a torque transducer.

It facilitates the combination of a flange-type torque transducer (HBM TB2, 1000 N·m nominal torque range) with a female square drive adapter of effective (in axial direction) extension length *s*. To one end of the transducer the torque was applied and the other end, with the square drive, was supported using a lever of length *l*.

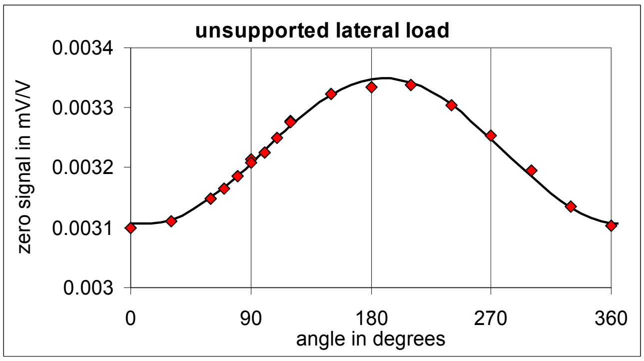

Fig. 5. Zero signal response of an unsupported reference torque transducer to a load lateral to its axis; measurement (dots) and sinusoidal fit (line).

Clockwise torques up to 500 N·m were then applied step by step. The results were compared with a reference measurement for pure torque.

With a preceding test according to an established cross force load procedure [4], loading angles α of minimal lateral sensitivity with $\alpha = 90°$ and $\alpha = 270°$ were found for this transducer (figure 5, “zero” of the sine function).

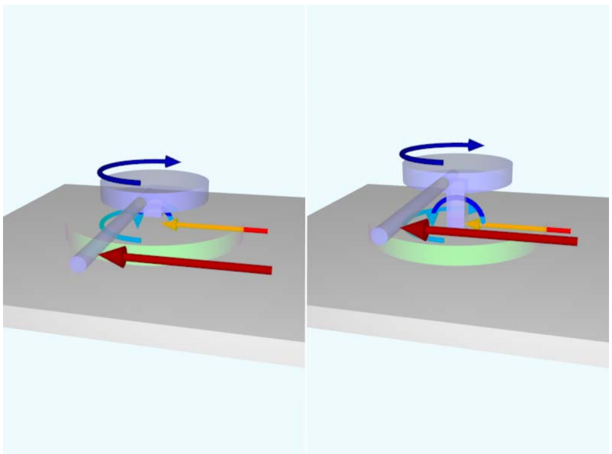

Fig. 6. For the same torque, bending moment increases with increasing axial distance s between torque wrench and reference transducer (from left to right).

According to these results the investigations using the facility were carried out at $\alpha = 90°$. Two effects give cause to an increase of uncertainty at this point. Firstly, the uncertainty of the angular adjustment has a maximum at the zero points of the sine function, because of the maximal inclination of the sinusoidal curve at these points. Secondly, due to the elastic compliance of the mechanical setup the angle changes when the load increases.

Depending on the stiffness especially of the lever, this angular deviation can amount to about 10 degrees. On the whole, a mismatch of α from optimum value was found to cause a relative signal deviation of up to 0.03 % in our example.

To detect the influence of lateral loads, the extension length s was altered from 105 mm to 220 mm (distance measured from the centre of the transducer to the centre of the lever, figure 6), which affects the bending moment. In addition, the lever length l was altered from 750 mm to 1500 mm, which affects both cross force and bending moment (figures 6 and 7). The result of these measurements is shown in figure 8. Each of the three curves was obtained at constant s but with decreasing l (1500 mm, 1250 mm, 1000 mm and 750 mm, dots in the curves from left to right, figure 7) at 500 N·m.

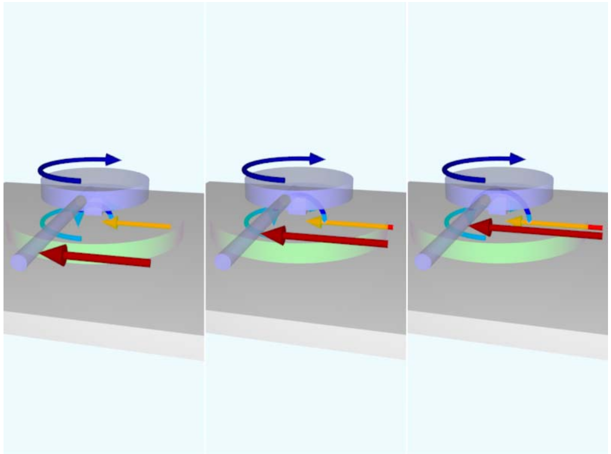

Fig. 7. For the same torque, cross force and bending moment increase with decreasing lever arm length (from left to right).

This parameter field is typical for calibrations. Here, the relative deviation of the sensitivity increases with increasing cross force and bending moment in the range from 0.01 % up to 0.07 %.

Hence for torque wrench calibrating laboratories with an unsupported reference transducer like this, it should take a great effort to get a best measurement capability U_{bmc} (expanded uncertainty, $k = 2$) better than 0.2 %. Since the examined transducer has a flat flange-type design and a high stiffness against bending, the presented result should be a minimum estimation of the effects linked to torque wrench calibration in an unsupported setup.

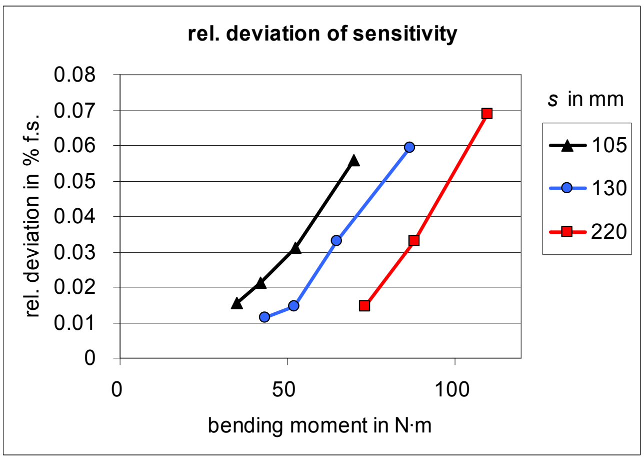

Fig. 8. Sensitivity deviation of a torque transducer relative to a pure torque measurement as a function of the bending moment for different axial extension lengths s.

2.3. Reference torque wrenches

Torque transfer wrenches are calibrated according to the guideline DKD-R 3-7 before being applied as a reference in a torque calibration machine. Usually they are mounted in the calibration facility without their lever arm although the superior DKD-R 3-7 calibration was performed with it. In this mounting, the head of the transfer wrench is fixed to the calibration machine via the housing of the inner sensing disk. Although the fixing is not in the centre (fixing length $l_f = 300$ mm), the effective lever length of such a fixing is zero, because the connection is tight and able to transfer the torque as a vector.

To determine the effects of deviating mountings, special adaptations were manufactured which allowed calibrations without the lever of the wrench to be performed. In figure 9 the setup is shown. Although the perspective of this picture suggests it, there is no direct axial connection between the torque drive axis and the head of the torque wrench. For generating the counter-torque, a lever with variable length and axial distance ("supporting lever") was connected via a square drive to the wrench. Because the support of the lever at the calibration machine is designed as a hinge, it is not able to transfer a torque vector. So here the torque is acting as a combination of force and lever arm.

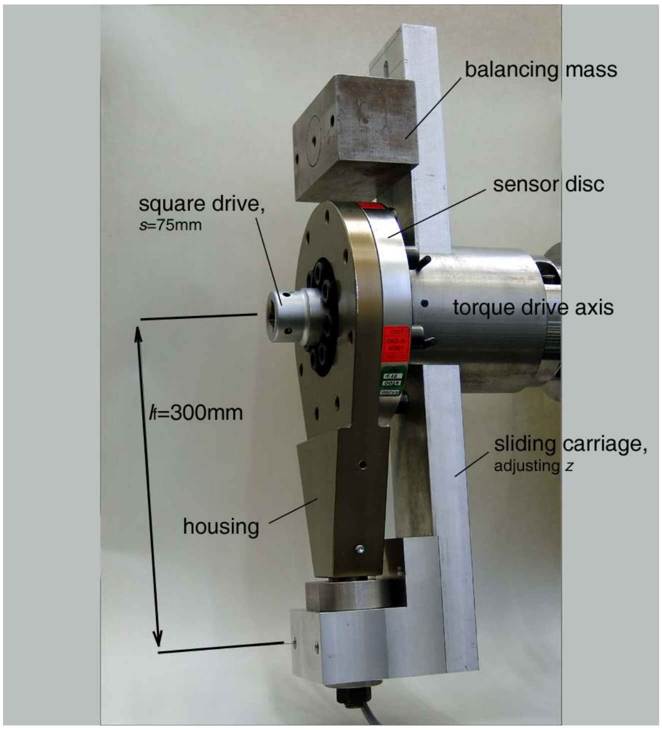

Fig. 9. Torque wrench adaptation for mounting without lever (fixing distance $l_f = 300$ mm), adjustable z and alterable square drives for different values of s.

These investigations were performed with a 1000 N·m torque wrench (HBM TB1) calibrated according to DKD-R 3-7 at a lever arm length l of 1000 mm and an extension length s of 75 mm as a datum reference. In the special adaptation the head of the wrench can be rotated relative to the supporting lever by 360°. In this way the response of the wrench to different loading angles can be determined relative to the reference calibration at which the loading angle was 180° (figure 10).

As seen in figure 5, the measured points can be fitted to a sinusoidal function, which shows that the wrench head is not mounted into the housing with the optimum orientation. At normal use with $\alpha = 180°$ the lateral sensitivity is far from minimum. The zero points are found at about $\alpha = 20°$ and $\alpha = 200°$. Because the curve is slightly asymmetrical with respect to the zero line, the expected deviation from the reference at $\alpha = 0°$ is smaller than at $\alpha = 180°$. Thus it was decided to use the orientation $\alpha = 0°$ for the further measurements.

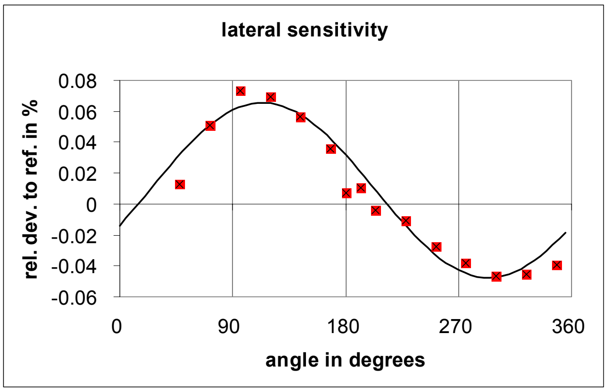

Fig. 10. Relative sensitivity deviation of a torque wrench head mounted without lever at different loading angles; measurement (dots) and sinusoidal fit (line).

To determine the effects of cross force and bending moment on the wrench head, the length of the supporting lever l and the axial extension length s were varied. Furthermore, the influence of an eccentric mounting of the wrench with respect to the measuring axis was demonstrated by increasing the eccentricity z from $z < 0.05$ mm to $z = 10$ mm.

The effect of the eccentric mounting ($z = 10$ mm) is shown in figure 11. The amplitude of the sensitivity deviation is more than 10 times greater compared with $z < 0.05$ mm. The maximum values are obtained at $\alpha = 0°$ and $\alpha = 180°$.

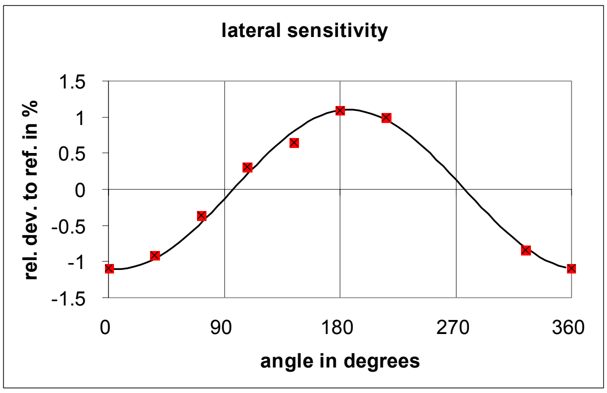

Fig. 11. Relative sensitivity deviation of a torque wrench due to eccentric mounting with $z = 10$ mm as a function of loading angle; measurement (dots) and sinusoidal fit (line).

This is a straight geometrical effect, given by the ratio between the eccentricity and the lever length. The ratio of 10 / 1000 equals 1 % and is the value of the deviation amplitude in figure 11. As easily as this can be corrected with knowledge of *z*, this effect is a great contribution to the uncertainty of torque wrench measurements with improper square drives of unknown *z* [5].

In figure 12, the deviation of the sensitivity of the torque wrench relative to the reference calibration due to cross force and bending moment as a function of bending moment is shown. In each curve, the dots represent measurements at decreasing lever lengths from left to right. The linear run of the curves prove that the deviation of sensitivity is proportional to the reciprocal value of lever length.

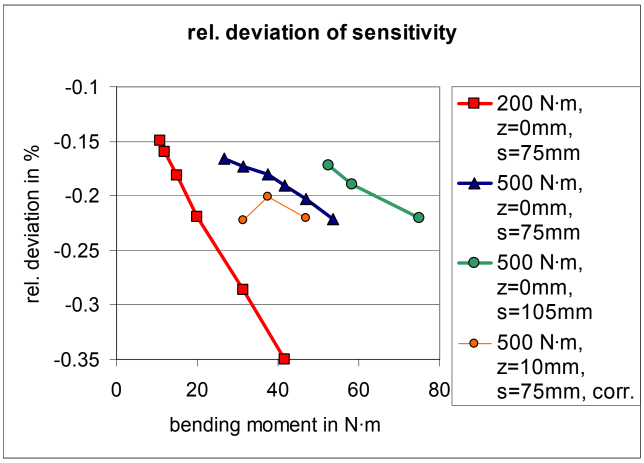

Fig. 12. Relative sensitivity deviation of a torque wrench mounted without lever as a function of the bending moment at different torque values, eccentricities *z* and axial extension lengths *s*.

Although the relative sensitivity deviation depends on the length of the supporting lever *l*, in practical use of a calibration facility this length is given by the torque wrench under test and is, therefore, not variable.

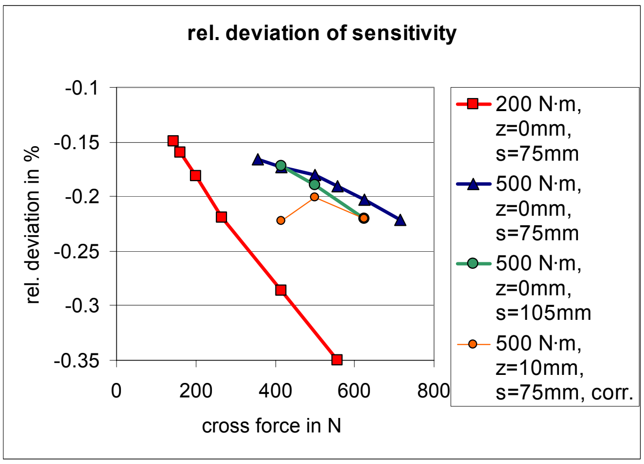

Fig. 13. Relative sensitivity deviation of a torque wrench mounted without lever as a function of the cross force at different torque values, eccentricities *z* and axial extension lengths *s*, same data as in figure 12.

For this reason, the laboratory concerned has to take into account the influence of the supporting lever's length very carefully, because relative deviations up to 0.35 % as given in figure 12 are not negligible for a lot of accredited laboratories.

Increasing the extension length *s* results in higher bending moments, but there is nearly no effect on the relative deviation of sensitivity. Therefore, the measured torque wrench can be said to be much more sensitive to cross forces than to bending moments. This is confirmed by the presentation of the same data as a function of cross force (figure 13). Here the curves for 500 N·m are very close together and the measurements at a similar cross force are associated to similar relative deviations regardless of their different bending moment.

After correcting the geometrical effect, the relative deviation of the measurements with $z = 10$ mm was reduced from about 1 % as shown in figure 11 by factor 10 (figure 12, orange curve) and is then very close to the corresponding measurements with $z < 0.05$ mm (figure 12, blue curve). This confirms the idea of a geometrical effect in this context.

2.4. Reference torque wrenches with $l \rightarrow \infty$

When increasing *l* towards infinity the cross force at the torque wrench decreases towards zero.

This situation complies with a torque wrench used as a reference transducer for torque transducer calibrations according to DIN 51309 [6]. Some laboratories wanted to use this method. Therefore, investigations of the reference torque wrench with varying lever lengths towards infinity were performed (figure 14).

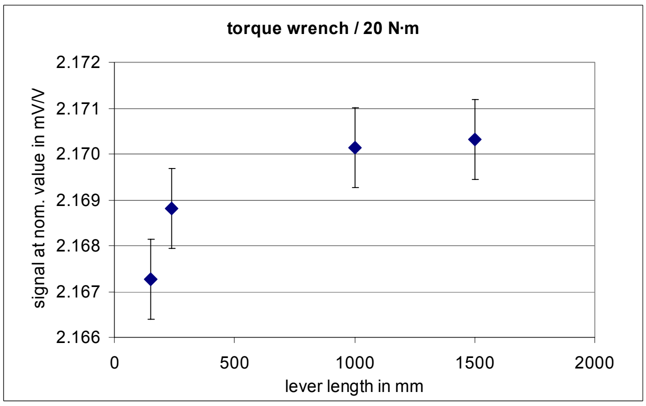

Fig. 14. Example of a torque wrench calibration with increasing lever length for the determination of the sensitivity at infinite lever length.

It was found that with increasing lever length, the sensitivity of the wrench achieves a limit value in an asymptotic way. Therefore, an estimation of the sensitivity and its uncertainty for an infinite lever can be found with measurements at increasing length by fitting them with an asymptotic curve. The relative expanded uncertainty of this method is about 0.03 % (k=2).

3. CONCLUSIONS

Investigations on the influence of cross force and bending moment are important for the calculation of the best measurement capability of reference-type torque wrench calibration machines.

With special facilities these influences were determined for torque sensors and mounting situations, which are typical in DKD laboratory use.

The importance of a careful adjustment of the reference transducer's orientation was demonstrated. Even then, uncertainty of angle measurement and the torque-induced angular shift can cause relative sensitivity deviations of 0.03 %.

In the chosen examples, bending moments and cross forces in the usual ranges produce relative deviations of up to 0.07 % for torque transducers and up to 0.35 % for torque wrenches.

The use of a torque wrench as a reference in an orientation different to that in the superior calibration can cause relative deviations up to 0.1 %.

Eccentric mounting of the sensor axis of the reference torque wrench causes relative deviations given by the ratio z / l. The effect of lateral load on reference torque wrenches is proportional to $(1 / l)$.

These results represent an important contribution to confirming quality management in torque wrench calibrating laboratories.

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