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THE INFLUENCE OF MISALIGNMENT ON TORQUE TRANSDUCERS

A. Brüge, D. Peschel and D. Röske
Physikalisch-Technische Bundesanstalt, Bundesallee 100
D-38112 Braunschweig, Germany

Abstract: Misalignment during the mounting of torque transducers in calibration devices can cause parasitic bending inside the transducers. Flexible couplings allow the contribution of misalignment to the measurement uncertainty to be reduced to a negligible amount.
Keywords: torque, calibration, misalignment, flexible coupling

1 INTRODUCTION

Torque transducers using strain gauges are designed so as to detect the torque by sensing the deformation in mechanical devices such as massive shafts, hollow shafts or arrangements of bars (lanterns). Misalignment of the transducer in the setup may lead to a parasitic bending inside the devices. Compensating techniques using mechanical and electrical means are able to reduce the bending effects. However, the remaining bending sensitivity may cause problems in setups where the degree of misalignment is higher.

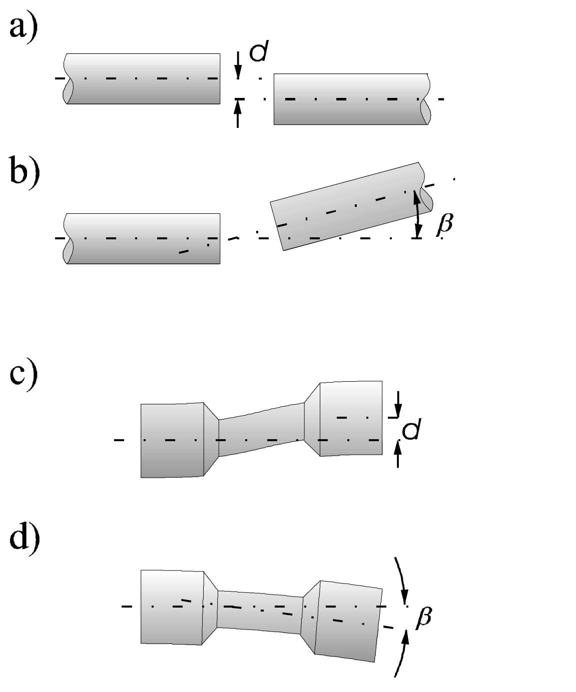

Figure 1. Basic types of misalignment in torque transducer calibrations:
a) radial displacement *d* of the setup shafts,
b) angular displacement *b* of the setup shafts,
c) and d) corresponding displacements of the transducer

2 MISALIGNMENT

The typical mounting of torque transducers in a setup is between two shaft ends of the setup using concentric clampings. Two basic types of misalignment can be distinguished: radial displacement *d* and angular displacement *b* in both, the setup and the transducer (figure 1).

In addition to these pure mounting errors, any combinations of errors are possible so that some errors can interfere negatively or positively at certain mounting angles a , which is the angle of rotation between setup and transducer, the main sensitivity axis of the transducer being the axis of rotation. Due to these varying mechanical conditions the calibration result may depend on a.

A calibration according to DIN 51309 [1] therefore consists of three parts: calibration at a =0°, a =120° and a =240°. The average of the three positions is in general considered to be free from mounting effects, and the maximum difference of the three positions at given bending moments is a measure of the bending sensitivity of the transducer. Figure 4 shows an example of the influence of different transducer positions a on the sensitivity of a torque transducer.

Another mounting setup frequently used is the square drive connection. Here the problems of misalignment are more complicated. Because of clearance and mismatch between square drive and square nut, bending can be different whenever connection is repeated and at increasing torque. Square drives are therefore not used for high precise transducers [2], and they are not the subject of this paper. In spite of these difficulties, square drives are commonly used with torque wrenches because the flexible and fast mounting of this connection is of advantage here.

3 FLEXIBLE COUPLINGS

Coupling elements which are highly flexible for bending but very stiff for torsion - known as flexible couplings - are able to balance radial displacements d by up to several millimetres and angular displacements b by up to several degrees when they flank the transducer in the setup. Typical examples are stacks of thin metal discs (multiple disc coupling), metal bellows and cardan joints. The PTB's torque laboratory uses flexible couplings for torque from 1 N·m to 20 kN·m, multiple disc couplings being preferred because of their relatively low stiffness for bending.

As the use of flexible couplings permits larger deviations from optimum alignment, mounting is faster and the results obtained are more reliable.

Torque laboratories using hydraulic clampings must install flexible couplings in order to fulfil the needs of this clampings. Only with excellent alignment of the setup is it possible to combine the coupling with shafts and bushings. For the tests with flexible couplings locked and $d > 0{,}1$ mm described below the radial displacement was brought about after shafts and hydraulic clampings had been connected.

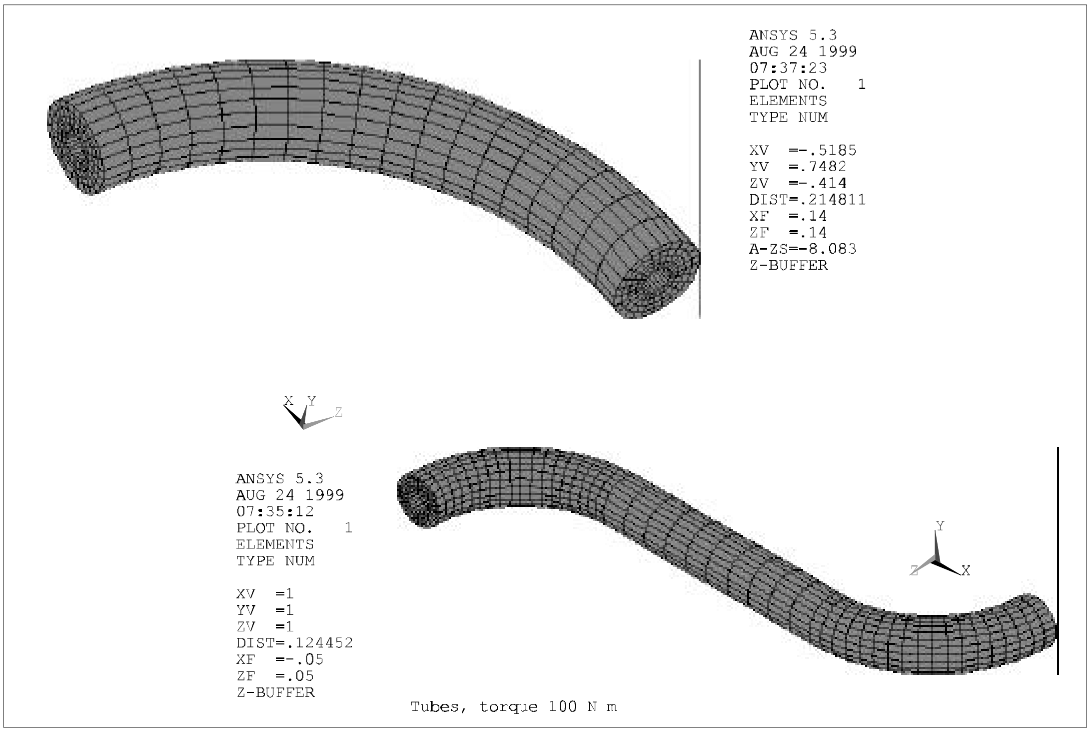

Figure 2. FEM-models for simulation of torque deflection with different tubes.

In some discussions the view was taken that a torque M which is deflected through an angle j is reduced to M·cos j for geometrical reasons. In this case, the use of flexible couplings could cause a considerable change in torque for higher values of j. Following this argument, a torque deflection through j = 90° (cos 90° = 0) should be impossible. To test this angular dependence, a simulation of a 90° torque deflection, based on the finite element method (FEM), was carried out (figure 2). Two tube models were generated, one in the form of a quarter ring (upper part in the figure, ring radius: 250 mm, tube inner radius: 10 mm, tube outer radius: 30 mm) and the other as a combination of two quarter rings with a linear connecting tube (lower part in the figure, ring radius: 50 mm, tube inner radius: 5 mm, tube outer radius: 10 mm, straight length between the two bended parts: 100 mm). One of the model ends was fixed, a torque of 100 N·m was applied at the other end using multiple couples of force tangential to the perimeter in the cross-sectional area. For the first model (quarter ring) and in the case of steel material, 33,5% of the applied static torque was transmitted through the tube and changed the direction by 90°! Even 38,2% of the applied torque can be transmitted when the same tube is made of Plexiglas, thus showing the dependence of the effect on the elastic properties of the material. The result also depends on the geometry of the elastic body considered. For the second model of a tube with two 90° bows at the ends, the transmitted static torque was also greater than 30% for steel. Hence, as a matter of principle, an orthogonal deflection and even a transverse displacement of a static torque is possible for non-rigid bodies.

4 MEASUREMENTS

A first test with maximum radial displacement was performed at the 1 kN·m torque calibration machine of the PTB. This direct loading machine is equipped with a 6-degrees-of-freedom counter bearing which was used to apply a radial displacement of 9 mm to a high quality reference transducer (massive shaft). This misaligned setup was then compared with a setup in optimum alignment. The 9 mm displacement leads to a compensating angle *j* of about 1,5° in the flexible couplings. At this angle, the relative repeatability error (span) *b* in different positions α increases from 0,003% to 0,015%. Theoretically, this change is caused by disturbing signals due to a combination of residual transverse forces and bending moments transmitted by the flexible couplings to the transducer.

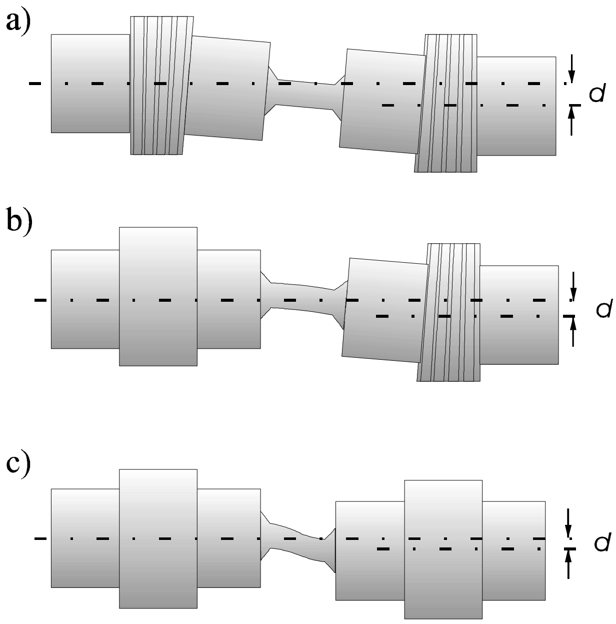

Figure 3. Transducer mounted in a setup with radial displacement *d* and
a) flexible couplings unlocked
b) one coupling locked
c) both couplings locked .

Despite this, the relative change of the sensitivity as the average of three positions is by $2 \cdot 10^{-5}$ only and, therefore, in the range of measurement uncertainty of the calibration device.

Using another high quality reference transducer (massive shaft), the effects of the radial displacement to a setup with unlocked flexible couplings, only a single coupling locked and both couplings locked were examined using the 2 kN·m torque calibration machine of the PTB (figure 3). This machine, designed for the comparison method, makes radial shifting of the counter bearing by up to 5 mm from the reference axis possible. In the case of optimum adjustment, the alignment errors are *d* < 0,1 mm and *b* < 0,003°. In figure 4 two right-hand torque calibrations of the same transducer are shown, which were performed in this well-aligned state, with and without flexible couplings. The possible relative deviation of sensitivity without flexible couplings amounts to 0,02% of full scale.

Figures 5, 6 and 7 show the influence of increasing radial displacement on some important transducer parameters. In the setups with at least one coupling locked, full radial displacement could not be achieved because the maximum transverse force of the air bearing, integrated between reference transducer and test object was reached here at smaller displacements.

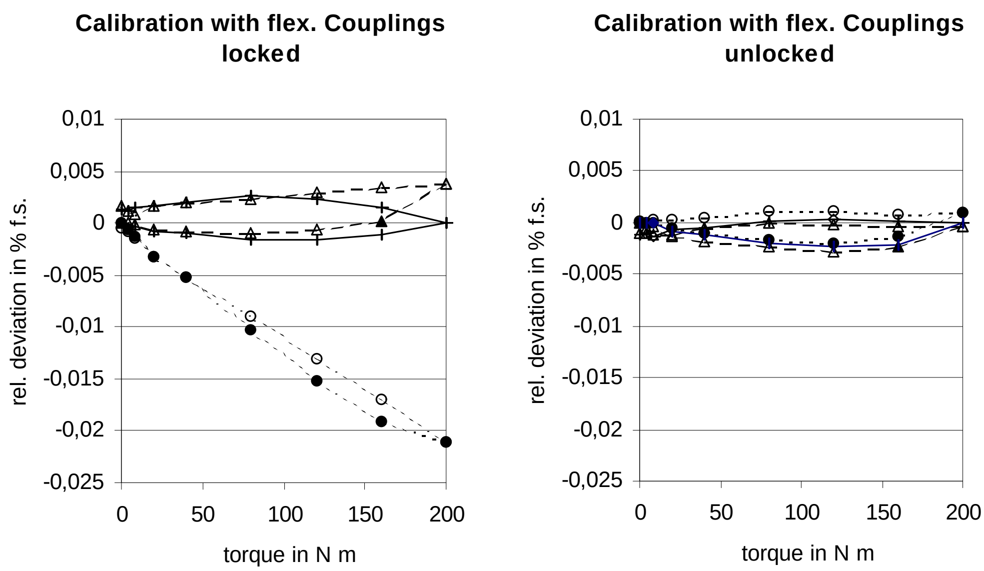

Figure 4. Relative deviation from linear approximation in % of full scale of a right-hand torque calibration with flexible couplings locked (left) and unlocked (right)
(◆: *a*=0°, ▲: *a*=120°, ●: *a*=240°; solid symbols: upstairs, open symbols: downstairs calibration).

With flexible couplings locked, sensitivity (as the average of three positions), span and hysteresis are highly dependent on *d*. Surprisingly, in this case the span decreases with increasing *d*. Probably a compensation takes place here of an initial misalignment caused by the transducer shape and the amounts of *d* and *b* in the well-aligned state.

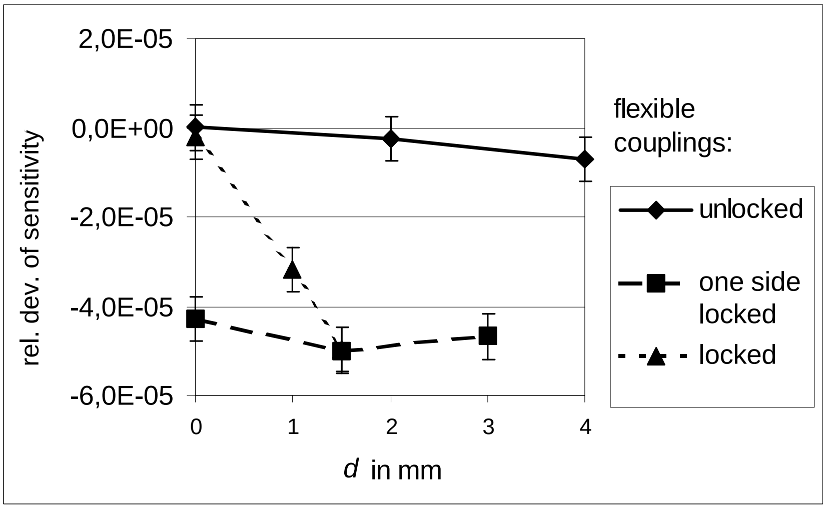

Figure 5. Relative deviation of sensitivity depending on radial displacement *d*.

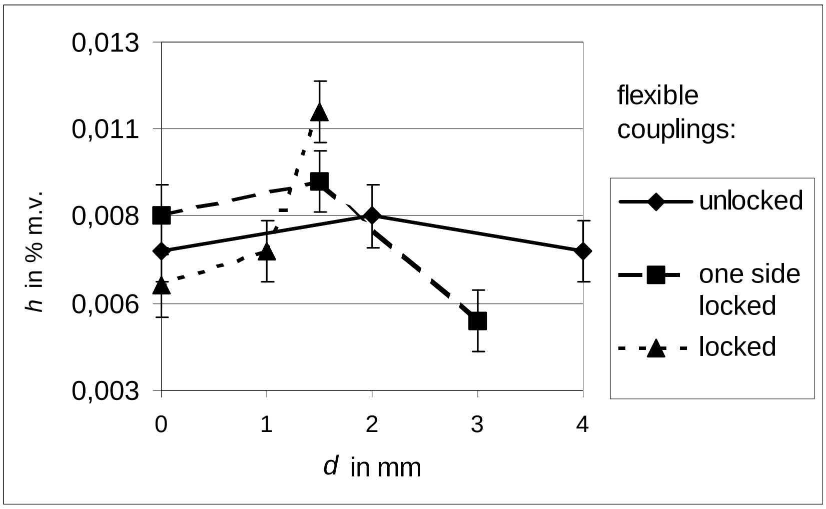

Figure 6. Hysteresis *h* at 40% of full scale torque depending on radial displacement *d*.

With only a single flexible coupling locked, the values of span and sensitivity deviate from those obtained with unlocked. This, too, points to an initial misalignment in the setup and to the necessity of using flexible couplings to avoid this effect.

The differences in the results obtained for the setup with one coupling locked and the setup with both couplings locked may be caused by the interaction between the different types of bending expected for these situations (figure 3b and 3c), the design of the torsion body and strain gauge application to the transducer.

With both flexible couplings unlocked, the influence of the radial displacement on the three parameters is very small. For *d* = 4 mm, the relative change in the sensitivity is only $1{\cdot}10^{-5}$. In agreement with the result in the first test this change is within the measurement uncertainty of highly precise torque calibration machines. Hysteresis and span show no measurable effect in this range of radial displacement. The flexible couplings used in this test can therefore be considered to be suitable for compensating radial displacements by up to 4 mm for high-precision torque measurement. An alignment in this range should be possible without great effort in every high-quality torque calibration machine.

In the range of $d \approx 1$ mm, which can be supposed to be typical of alignments made without special tools, the use of flexible couplings has no effect on the hysteresis but causes a reduction by more than the factor 6 of the span and more than the factor 30 of the relative deviation of the sensitivity (average of three positions), compared with the setup without flexible couplings.

Despite these factors the consequences which the change in sensitivity has for calibrations are moderated as the average over three positions. The validity of the span measurement is of a qualitative nature only, as long as the bending moments involved are not known. Much more problems than for transfer standard calibration are to be expected for such applications of transducers where the measurement cannot be performed in three positions. The absence of flexible couplings can then cause a relative sensitivity deviation by more than $1{\cdot}10^{-4}$ as is shown in the example in figure 4.

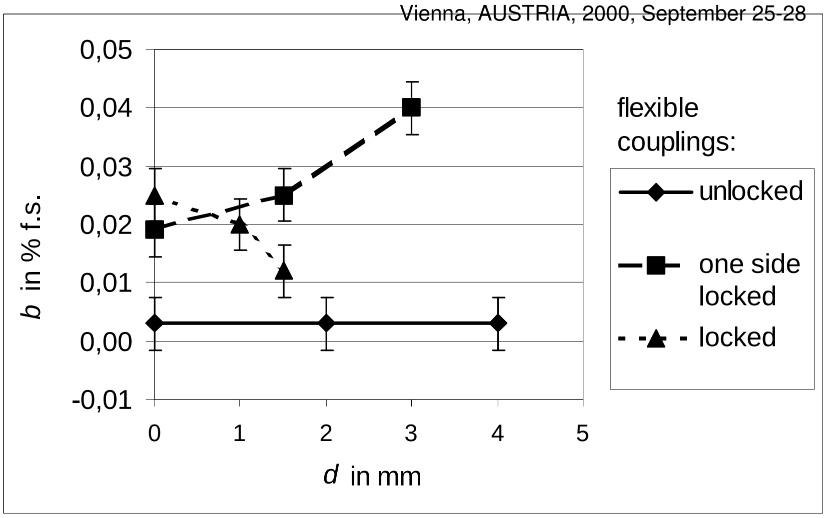

Figure 7. Span *b* at full scale torque depending on radial displacement *d*.

To get quantitative information about the span it will be necessary to apply a well-defined bending moment to the transducer during calibration. With the adjustable counter bearings of the PTB's calibration machines such application should in principle be possible. The topical question is how to calculate the appropriate radial displacement in order to produce a certain bending moment in interaction with all elements involved, such as clampings, shafts, bearings and couplings.

5 CONCLUSIONS

The result of the investigations is of essential importance for the establishment of the technical requirements for the adjustment of mechanical assembly groups of torque calibration devices. When flexible couplings are used, the adjustment of test transducers must fulfil only normal technical requirements; without couplings, the requirements must be much stricter, especially if hydraulic clampings are applied. Through the use of flexible couplings disturbing signals are limited to calculable ranges. The results of the calibrations can be transferred to practical applications.

Without flexible couplings, the system is statically overdetermined and the disturbing signals are undefined and not assessable.

This is valid in particular if transducers are directly joined using square drives. Even with optimum alignment of the calibration device axis, the deviations of the geometrical shape of the square drives lead to elastic deformations of the total setup and to unknown disturbing signals.

REFERENCES

[1] DIN 51309:1998-02 "*Calibration of static torque measuring devices*", DIN Deutsches Institut für Normung e. V., Beuth Verlag GmbH, Berlin

[2] D. Röske, Investigation of the influence of disturbing components on the torque measurement, *Proceedings of the 16th International Conference on Force, Mass and Torque Measurements* (IMEKO TC3, Taejon, 14-18 September 1998), KRISS Taejon, Korea, 1998, p. 280-285.

AUTHORS: Andreas BRÜGE, D. PESCHEL and D. RÖSKE, Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany, Phone Int. +0531 592-1226
Fax Int. +0531 592-1105, E-mail: andreas.bruege@ptb.de