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A GERMAN TORQUE COMPARISON FROM 20 N · m TO 200 N · m AND ITS RESULTS

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Abstract: In October 2009, the members of the German DKD Torque Committee (FA 10) agreed to carry out a comparison of torque calibrations according to the German torque calibration standard DIN 51309:2005-12 in the range from 20 N · m to 200 N · m using very stable torque transducers as travelling standards. The pilot laboratory was the torque working group at PTB. Thirteen accredited laboratories from Germany, together with another German laboratory without accreditation and an Austrian laboratory, participated in this comparison. All measurements were carried out in 2010 and 2011, and the first results were discussed in 2012. The report on the comparison was expected to be published later in 2013.

This paper summarizes the results for discussion in the international community. In general, there was very good agreement between the results of the participants and the pilot laboratory.

Keywords: torque, DKD, DIN 51309, 200 N · m, comparison.

1. INTRODUCTION

During a meeting of the Torque Committee (FA 10) of the German Calibration Service (DKD) in October 2009, the members decided to carry out a 200 N · m torque comparison with torque transducers (not torque wrenches). The aim was to compare the calibration results and issued certificates of laboratories accredited in this range. The comparison was open to participants without accreditation.

PTB's torque working group prepared the technical protocol of the comparison, including the timetable. The set of transducers and additional equipment to be sent to the participants were defined. The laboratories had to carry out the measurements and fill in Excel worksheet templates with their measured data, thus allowing a faster data processing by the pilot.

The pilot laboratory investigated the stability of the travelling standards, evaluated the data submitted by the participants, applied corrections to this data for the amplifier deviations and calculated final E_n values.

It is interesting that while the comparison was running, the old DKD (it was dealing with accreditations of calibration laboratories until the end of 2009) became a part of the new German Accreditation Body (DAkkS) in 2010. The DKD was newly founded on 3rd May, 2011 as a PTB panel for the cooperation between Germany's national metrology institute PTB and accredited laboratories.

2. PARTICIPANTS AND DATES

Table 1 shows the 16 laboratories participating in the comparison: one from Austria, all others from Germany.

Abbreviation Accred. number	Company name location
HBM D-K-12029-01	Hottinger Baldwin Messtechnik GmbH Darmstadt
Ford D-K-15088-01	Ford-Werke GmbH Köln
Schatz D-K-17572-01	Schatz AG Remscheid
GTM D-K-15106-01	Gassmann Testing and Metrology GmbH Bickenbach
DSM D-K-15152-01	DSM Messtechnik GmbH Aalen
Kopp D-K-15180-01	Kalibrierdienst Kopp GmbH Wiesloch
Kistler D-K-17650-01	Kistler Lorch (formerly Dr. Staiger, Mohilo + Co. GmbH) Lorch
Lorenz D-K-17603-01	Lorenz Messtechnik GmbH Alfdorf
Atlas Copco D-K-17447-01	Atlas Copco (formerly TBB Industrial Tools Services GmbH) Dingolfing
DmS Dr. Peschel D-K-15165-01	DrehmomentService Dr. Peschel Wendeburg, OT Neubrück
MPA DA D-K-11048-01	Staatliche Materialprüfanstalt Darmstadt Institut für Werkstoffkunde, TU Darmstadt Darmstadt
Q-direct D-K-15001-01	Q-direct GmbH Loiching-Kronwieden
Deprag DKD-K-51101	DEPRAG SCHULZ GmbH u. CO. Amberg
TÜV AT without	TÜV Austria Services GmbH Vienna / Austria
Porsche without	Porsche AG Weissach
PTB without	Physikalisch-Technische Bundesanstalt WG 1.22 „Realization of Torque " Braunschweig

3. TRAVELLING STANDARDS

The following equipment was sent to the participants:

Torque transducer 1:
- type TB2 (with fixed adaptors)
- capacity: 200 N · m
- make: Hottinger Baldwin Messtechnik, Germany
- serial number: #080830117
- dimensions: Ø 103 mm × 253 mm (with adaptors)
- interface: Ø 50h7 mm × 80 mm shaft ends
- mass: 5.7 kg (with adaptors)
- packaging: in plastic bag inside a transportation box
- sensor type: strain gauge
- cable: TB2 LEMO 06-1.22, 6 wires, length 3 m
- connectors: Lemo FGG6 (transducer) – DB-15

Torque transducer 2:
- type TT1
- capacity: 200 N · m
- make: Raute Precision Oy, Finland
- serial number: 36077-00, bridge M1
- dimensions: Ø 57 mm × 224 mm
- interface: Ø 30h7 mm × 60 mm shaft ends
- mass: 1.4 kg
- packaging: in plastic bag inside a transportation box
- sensor type: strain gauge
- cable: K010-1.22, 6 wires, length 3 m
- connectors: DB-15 (transducer) – DB-15

Additional equipment:
Bridge calibrator K148
- make: Hottinger Baldwin Messtechnik, Germany
- type: K148
- serial number: K148-0100
- dimensions: 330 mm × 270 mm × 75 mm
- mass: 3.5 kg with power supply unit
- cable: K148-single channel

Data logger
- make: MSR Electronics, Switzerland
- type: MSR 145
- serial number: 302434
- dimensions: 70 mm × 40 mm × 22 mm
- mass: 0.1 kg

Serial RS-232 cable.

The comparison was of a combined ring-star design. A ring consisted of a maximum of two participants and began as well as ended with at least a stability measurement in the pilot laboratory. The pilot end measurement of one loop was the start measurement for the following loop. These loops formed the "rays" of the star. There were 9 of these loops, and within each loop the measurements were carried out first on the machine with the lower uncertainty.

Fig. 1 shows an example of a measurement result in the pilot laboratory: the deviation in parts per million is calculated for each mounting position in relation to the mean result from all mounting positions. It is a good indicator for the reproducibility of the generated torque and the alignment of the machine axes.

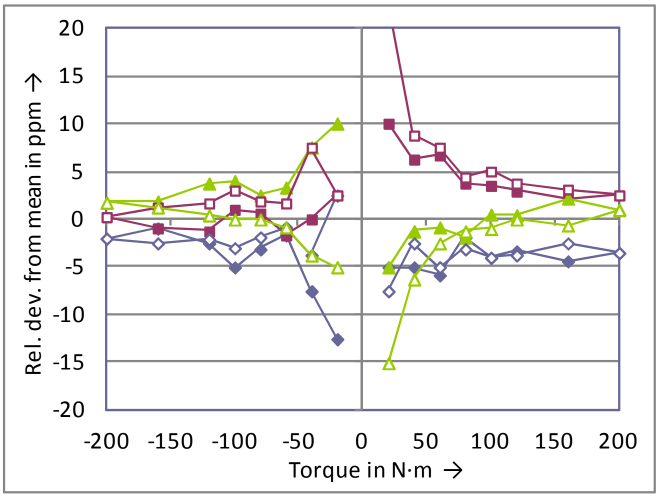

Figure 1: Example of a measurement result in the pilot laboratory

4. STABILITY OF THE STANDARDS

The stability of the **travelling standards** is essential for a good result of the comparison. A much better indicator for the long-term stability of the transducer is the deflection, the signal at nominal torque reduced by the indication at zero torque. Fig. 2 shows the measured deflection of the TT1 transducer at 200 N · m over a period of 16 months. The dashed red lines indicate an interval with a (relative) width of 3×10^{-5}.

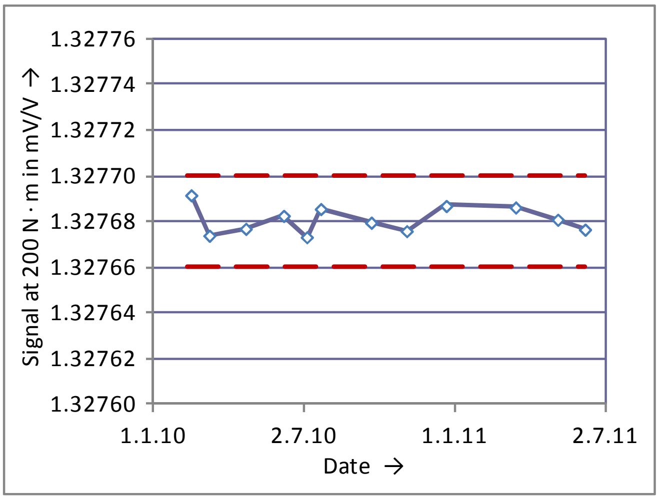

Figure 2: Stability of the TT1 transducer over 16 months

The bridge calibrator K148 (accuracy lever of 0.0025%) was used by the participants to check their own **amplifiers**. For comparisons of torque standard machines at a level of a few 10^{-5}, usually a DMP40 is used together with a high-end bridge standard BN100. In this comparison, the best relative measurement uncertainty of a participant's machine is 10^{-4}. For this purpose the K148 was sufficient. The DMP40 amplifier (accuracy lever of 0.0005%) of the pilot laboratory was calibrated each time when the transducers came back. Over the whole period of the comparison, the absolute deviation between amplifier and bridge standard was between -20 nV/V and +80 nV/V with a maximum span of ±10 nV/V at the maximum deviation. The deviation between the amplifiers used by the pilot and by the participant was taken into account by means of correction factors that were applied to the data.

The data logger MSR 145 was used to record the environmental conditions temperature and relative humidity during transportation and measurements in the loops. It was found that nearly all laboratories work under very stable environmental conditions; only one participant had a problem with the air conditioning. The temperature was between 20°C and 23°C, the relative humidity between 25% rH and 50% rH.

5. TYPES OF TORQUE CALIBRATION MACHINES

The participants use different kinds of **torque calibration machines** in their laboratories: deadweight machines, pendulum-weight machines, jockey-weight machines and reference machines; the latter with vertical or horizontal axis. The uncertainties of measurement achievable with these machines depend on the design: deadweight machines are usually more accurate than reference machines utilizing a calibrated reference torque transducer. Air bearings offer a lower uncertainty than other types of bearing or suspension.

Four of the participants (pilot not counted) operate a **deadweight** torque machine similar to that of the pilot laboratory. The principle of operation is shown in Fig. 3.

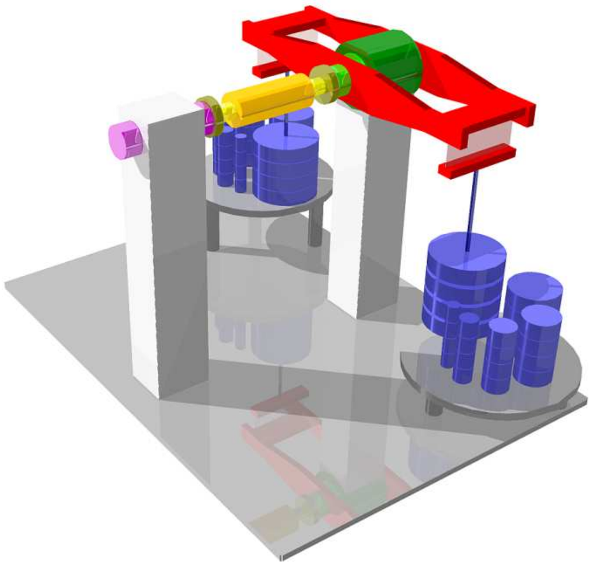

Figure 3: Deadweight torque machine

In the following figures, the same colour scheme is used for similar parts: the weights are blue, the lever is red, the bearing is green, the transducer under test is yellow, the reference transducer is pink and the torque drive is orange. The counterdrive in Fig. 3 is magenta. It has no direct function for torque generation but it is used to ensure the horizontal position of the lever during the calibration. Otherwise the elastic deformation along the torque axis can lead to a change of the acting torque due to a displacement of the lever's centre of gravity resulting in an additional countertorque, or due to a shorter length of the lever arm.

The best measurement capability ($k = 2$) for which the four laboratories are accredited is 1×10^{-4}.

The second type of machine using a deadweight is the **pendulum-weight** machine (Fig. 4). Here, a drive is necessary to generate a rotation of the weight around the torque axis. The centre of gravity of the weight will then move along a circular line. The weight force is always directed vertically towards the centre of the Earth and a torque is generated when the centre of gravity of the weight is not exactly below the torque axis (rotational axis of the bearing). For the calculation of the torque value it is necessary to know the horizontal distance between the force acting line going through the centre of gravity of the weight and a line parallel to it going through the torque axis. The torque is then the product of the found distance and the acting weight force.

In a real setup, the above distance cannot be found easily, since the real position of the weight's centre of gravity is unknown. The pendulum weight can be calibrated using a horizontally positioned two-armed lever and well-known weights at precisely defined distances in a free setup, where no other parts are connected to the pendulum. In the measurement, the torque is calculated from the rotational angle of the pendulum which itself is measured using an angular encoder.

One laboratory is accredited with this type of machine and the best measurement capability ($k = 2$) is 1×10^{-4}.

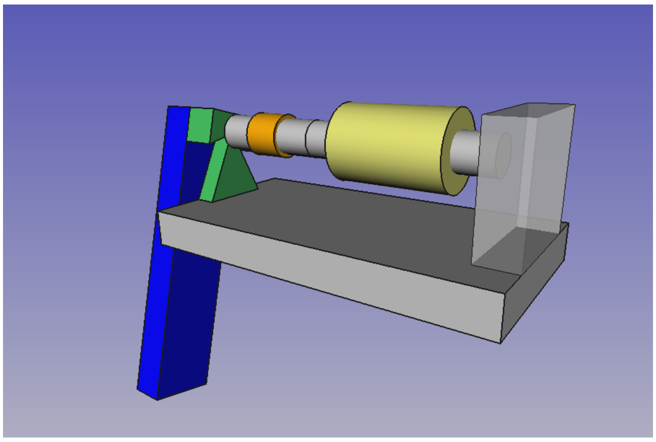

Figure 4: Pendulum-weight torque machine

There is a third type of machine using a dead-weight: the **jockey-weight** type. Here, a weight is moved along the horizontally positioned lever (Fig. 5). As described above, the torque is determined by the product of the horizontal distance between the weight's centre of gravity and the torque axis with the acting weight force.

Again, it is not easy to define the exact position of the centre of gravity. Other influences are caused by the driving mechanism that is necessary for moving the weight. One solution for this problem is the calibration of these machines using torque transfer transducers. Thus there is no direct traceability to mass, length and acceleration. As a result, the uncertainty is slightly higher, but on the other hand, this method is much simpler and cheaper.

Two laboratories are accredited with this type of machine and the best measurement capability ($k = 2$) is 2×10^{-4}.

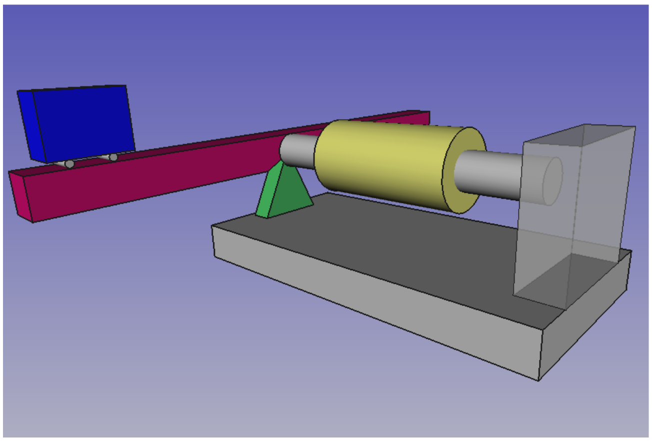

Figure 5: Jockey-weight torque machine

The remaining eight laboratories operate **reference** torque calibration machines: six of them with a vertical axis (Fig. 6), another two with a horizontal axis (Fig. 7).

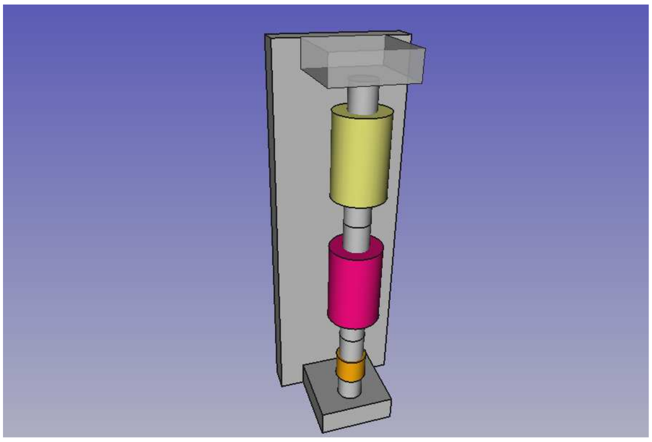

Figure 6: Reference torque machine (vertical axis)

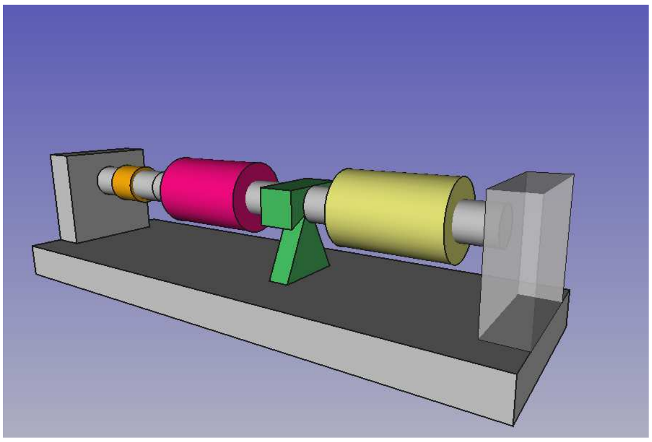

Figure 7: Reference torque machine (horizontal axis)

The principle of operation is quite simple: reference transducer and transducer under test are mounted in line. A drive (orange part in the figures) generates a torque in the system. The torque is measured by the reference transducer and this value is usually used for the control of the machine, and it is recorded together with the indication of the transducer under test.

The accredited expanded uncertainties ($k = 2$) with this type of machine are 2×10^{-4} (one), 1×10^{-3} (five) and 2×10^{-3} (two laboratories).

6. FURTHER DETAILS OF THE COMPARISON

The measurements were carried out according to DIN 51309 (three mounting positions at each 120°, one repeated incremental series at 0°, both clockwise and anti-clockwise torque directions) between February 2010 and June 2011. One participant measured at 90° positions due to the square drive adaptation. The pilot laboratory performed 12 measurements in total on each of the two transducers; most of them were short stability measurements. According to the first version of the protocol, the comparison was to be finished at the end of 2010. One participant could not perform the measurements according to this first schedule because of problems with unstable environmental conditions in the laboratory. The measurements were therefore conducted in 2011. Two other laboratories joined the comparison after the first schedule was agreed upon. These participants carried out their measurements also in 2011. After all data had been received by the pilot, a first version of the evaluation was discussed in October 2011 during a meeting of the DKD’s Torque Committee FA 10. The data showed that there is obviously an influence of the machine’s misalignment on the results. At the next meeting it was decided to also measure the sensitivity of both transducers to cross forces and bending moments by applying a well-defined force (deadweight) acting perpendicular to the axis of the transducers at a known distance (measured along the axis) from its centre. The transducers were rotated about their axes in order to obtain the dependence of the output signal on the direction of cross force and bending moment. According to the setup of this measurement, both quantities were applied in superposition; it was not possible to apply a pure bending moment or a pure cross force. One of the participants (D-K-15165-01) agreed to carry out these measurements.

Last but not least, not only were the measurement results compared but also the calibration certificates issued by the participating laboratories were evaluated. These certificates were checked for completeness and formal requirements. It was also checked whether correct results and uncertainties were calculated.

7. RESULTS

The E_{n} value calculated according to the common formula (1)

$$E_n = \frac{X_{\text{Lab}} - X_{\text{Ref}}}{\sqrt{U_{\text{Lab}}^2 + U_{\text{Ref}}^2}} \qquad (1)$$

has a disadvantage: a poor misalignment of a machine that has to be compared with other machines of the same type and better alignment usually yields a higher expanded measurement uncertainty U_{Lab} associated with the measurement result X_{Lab}. This will reduce the absolute value of E_n, thus improving the result of this laboratory. In order to minimize this influence, a stricter version of (1) was used in this comparison. Instead of using the expanded measurement uncertainties U_{Lab} found in the calibration, the best measurement capability ($U_{\text{Lab,bmc}}$) of the participating machines was taken for the calculation according to:

$$E_n = \frac{X_{\text{Lab}} - X_{\text{Ref}}}{\sqrt{U_{\text{Lab,bmc}}^2 + U_{\text{Ref,bmc}}^2}} \quad (2)$$

The misalignment was investigated for each participant by evaluating the results of each mounting position similar to the result shown in Fig. 1 for the pilot laboratory.

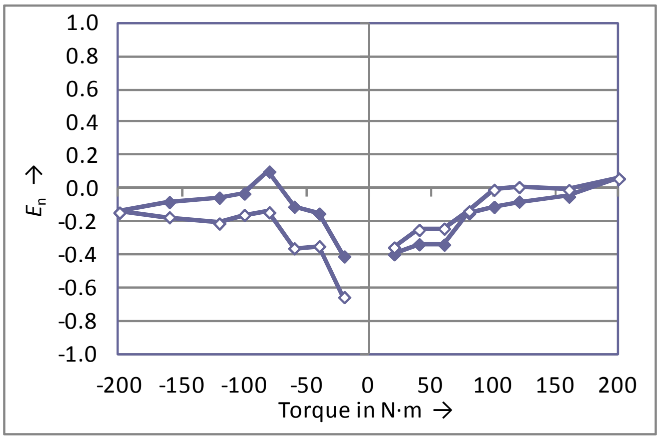

Figure 8: Example: E_n values for a measurement with TT1, deadweight machine, b.m.c.: 1×10^{-4}, (full symbols: incremental torque, empty symbols: decremental torque)

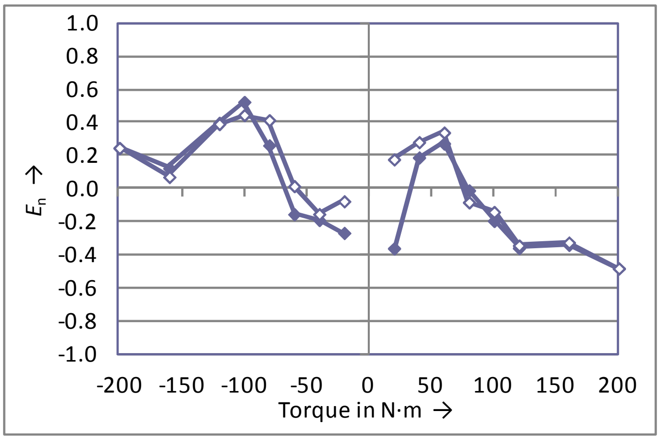

Figure 9: Example: E_n values for a measurement with TB2, pendulum-weight machine, b.m.c.: 1×10^{-4}, (full symbols: incremental torque, empty symbols: decremental torque)

In general, the vast majority of the E_n values calculated according to (2) lies in the range between -1 and 1. Some examples are given in Figs. 8 through 10.

One participant had a problem with one of the two transducers; the results of the second one was excellent. This one measurement was repeated later on and the problem did not occur anymore. Three participants had a very small number (one up to three out of 60, i.e. 2% to 5%) of E_n values that fall slightly outside the above range, often values calculated for decremental torque. The reason can be friction in the driving components. One participant used square drive connectors which were not covered by the scope of this comparison. In this case 12, out of 60 E_n values were below the interval with a minimum of -1.4. This participant increased the b.m.c. value after the comparison.

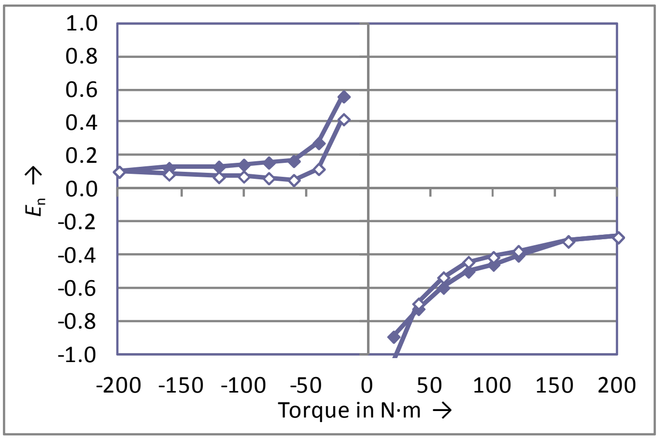

Figure 10: Example: E_n values for a measurement with TT1, jockey-weight machine, b.m.c.: 2×10^{-4}, (full symbols: incremental torque, empty symbols: decremental torque)

Figs. 11 and 12 show the results of the cross force/bending moment test of the two transducers.

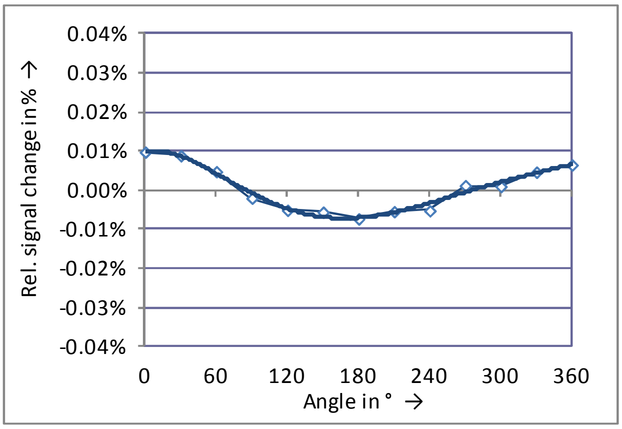

Figure 11: Relative change in the output signal of the TT1 torque measuring bridge related to the signal at full load, where a cross force of 102 N and a bending moment of 11.2 N · m are applied and the transducer is rotated around its horizontally directed axis (symbols: measured values, line: fitting function)

As expected, the dependence of the output signal on the rotational angle follows a sine function. Due to the different mechanical design, the TB2's cross force/bending moment sensitivity is higher than that of the TT1. But this cannot explain all of the results since some of the participants got better results with their TT1 measurement, others with their TB2 calibration. It is possible that the transducers and the machines must be investigated separately with pure bending moment and pure cross force to reveal the underlying effects.

The examination of the calibration certificates revealed some minor formal mistakes. Most of them were corrected immediately after they became known to the participants or on the occasion of laboratory assessments.

All results will be published in the Report [2].

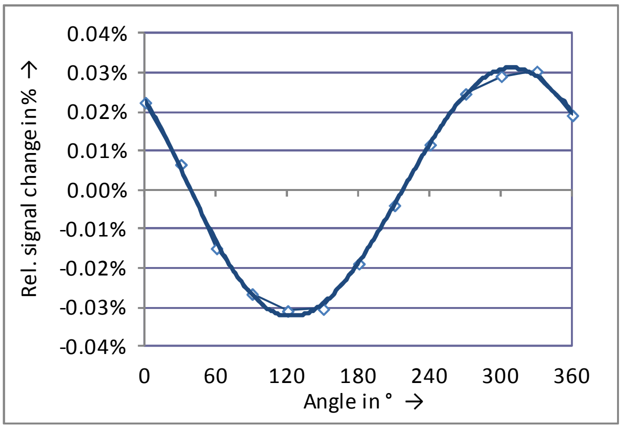

Figure 12: Relative change in the output signal of the TB2 torque measuring bridge related to the signal at full load, where a cross force of 158 N and a bending moment of 18.2 N · m are applied and the transducer is rotated around its horizontally directed axis (symbols: measured values, line: fitting function)

8. CONCLUSIONS

The comparison showed very good agreement between the results of the 15 participants and the pilot laboratory. It supports the claimed uncertainties of measurement for the calibration laboratories. The examination of the calibration certificates was helpful for improving these documents from both formal and objective points of view.

9. REFERENCES

[1] D. Röske, Technisches Protokoll des DKD-Ringvergleiches nach DIN 51309:2005-12, 20 N·m bis 200 N·m (Technical Protocol of the DKD round robin comparison according to DIN 51309:2005-12: 20 N·m to 200 N·m), (DKD FA10 document, not published, in German)

[2] D. Röske, DKD-E 10.1 Bericht über den DKD-Ringvergleich nach DIN 51309:2005-12: statische Drehmomente von 20 N·m bis 200 N·m (Report on the DKD round robin comparison according to DIN 51309:2005-12: static torques from 20 N·m to 200 N·m), Draft (in German)