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Report on the DKD interlaboratory comparison according to DIN 51309:2005-12: Static torques from 20 N·m to 200 N·m

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Deutscher Kalibrierdienst (DKD)

Since its foundation in 1977, calibration laboratories of industrial enterprises, research institutes, technical authorities, inspection and testing institutes were joined together in the DKD. On 3 May 2011, the DKD was reestablished as a *technical body* of the PTB and the accredited laboratories.
Bearing the name 'Deutscher Kalibrierdienst' (*German Calibration Service* – DKD), this body is under the direction of the PTB. The guidelines and guides elaborated by the DKD represent the state of the art in the respective technical areas of expertise and can be used by the DAkkS (the German accreditation body – *Deutsche Akkreditierungsstelle GmbH*) for the accreditation of calibration laboratories.
The accredited calibration laboratories are now accredited and monitored by the DAkkS (German Accreditation Body) as legal successor of the accreditation body of the DKD. They carry out calibrations of measuring devices and measuring standards for the measured values and measuring ranges defined during accreditation. The calibration certificates issued by these laboratories prove the traceability to national standards as required by the family of standards DIN EN ISO 9000 and DIN EN ISO/IEC 1702.

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TABLE OF CONTENTS

Page

Foreword

DKD comparison reports aim to disclose the results of comparison measurements organized, carried out or evaluated by the German Calibration Service. They contain a lot of information regarding the measurement capabilities of the participating calibration laboratories and the comparability of the measurements. The DKD comparison reports reflect the views of the respective authors which do not necessarily represent in detail the perspective of the Board of the DKD or that of the Technical Committees.

The DKD comparison reports are aimed at presenting the examined aspects and results of the calibration and shall be made available, both nationally and internationally, to the big community of calibration laboratories through publication by the DKD.

The present DKD Comparison Report was approved by the Board of the DKD in May 2014.

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REPORT

on the DKD interlaboratory comparison according to DIN 51309:2005-12: Static torques from 20 N·m to 200 N·m

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Abstract

At the 15th meeting of the DKD Technical Committee "Torque" on 7 and 8 October 2009 in Rüper, a decision was taken to carry out a DKD comparison according to the calibration standard DIN 51309:2005-12. The aim of the interlaboratory comparison was to compare the calibration procedures applied by the participating calibration laboratories, as well as to compare the reference standards used and the reports on the results (calibration certificates), to demonstrate compliance with the requirements for calibration laboratories for the quantity of torque or to determine deviations and, if necessary, to introduce corrective measures.

As a result, it can be stated that the interlaboratory comparison showed an excellent agreement of the measurement results of the 15 participants, and can thus be considered a very good confirmation of compliance with the measurement uncertainties the laboratories are designated or accredited for.

Abbreviations used

abs. - absolute
DAkkS - Deutsche Akkreditierungsstelle (German National Accreditation Body)
DIN - Deutsches Institut für Normung (German Institute for Standardization)
DKD - Deutscher Kalibrierdienst (German Calibration Service)
FV - Full scale value (calibration result with maximum amount of torque)
MV - Mean value (arithmetic mean value derived from a number of measured values)
PTB - Physikalisch-Technische Bundesanstalt
rel. - relative
rel. dev. - relative deviation
b/a - before/after mounting
bmc - best measurement capability

1. General information about the interlaboratory comparison

At the 15th meeting of the DKD Technical Committee "Torque" on 7 and 8 October 2009 in Rüper, a decision was taken to carry out a DKD comparison according to the calibration standard DIN 51309:2005-12. The PTB Working Group 1.22 "Realization of Torque" has drawn up a technical protocol that is available on the website of the Technical Committee on the Internet.
The aim of the interlaboratory comparison was to compare the calibration procedures applied by the participating calibration laboratories, as well as to compare the reference standards used and the results reports (calibration certificates), to demonstrate compliance with the requirements for calibration laboratories for the quantity of torque or to determine deviations and, if necessary, to introduce corrective measures.
In this report, the numbers of the DKD abbreviations or the company markings are used to designate the participants.

2. Measurement range

A measurement range of 200 N·m was agreed upon, with 8 torque steps being measured, starting at 20 N·m in steps of 20 N·m and omitting the steps 140 N·m and 180 N·m. The measurements were to be performed for three mounting positions, each rotated by 120°.

3. Participants

Table 1 shows the 15 participants and PTB as pilot laboratory. It includes all laboratories accredited for this measuring range and standard (for which participation in the comparison is mandatory) as well as other interested parties who possess the appropriate calibration capabilities. If a laboratory had several different devices able to cover the measuring range, then the one with the best measurement capability was to be chosen. On a voluntary basis, the participants could also carry out measurements on different machines.

Table 1: Participants of the DKD interlaboratory comparison 200 N·m with DKD number valid at that time (in brackets: DAkkS number)

Company, laboratory DKD No. (DAkkS No.)	**Contact person, address**	
HBM DKD-K-00101 (D-K-12029-01-00)	**Hans-Jörg Fraiss** E-Mail dkdcal@hbm.com Tel. (06151) 803-436 Fax (06151) 803-590	Hottinger Baldwin Messtechnik GmbH Kalibrierlaboratorium Im Tiefen See 45 64293 Darmstadt
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KDK DKD-K-24801 (D-K-15180-01-00)	**Dr. Gerald Jahn** E-Mail gerald.jahn@kdkgmbh.de Tel. (06222) 305 38-0 Fax (06222) 305 38-18	Kalibrierdienst Kopp GmbH In den Ziegelwiesen 25 69168 Wiesloch
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Lorenz DKD-K-37801 (D-K-17603-01-00)	**Dr. Wilfried Krimmel** Ab Januar 2013: **Alfred Botscher** E-Mail info@lorenz-messtechnik.de Tel. (07172) 93730-0 Fax (07172) 93730-22	Lorenz Messtechnik GmbH Obere Schlossstraße 131 73553 Alfdorf
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Deprag DKD-K-51101 (D-K-18255-01-00)	**Carsten Rosenkranz** E-Mail cal-lab@deprag.de Tel. (09621) 371-0 Fax (09621) 371-199	Kalibrierlaboratorium der DEPRAG SCHULZ GmbH u. CO. Kurfürstenring 12 - 18 (jetzt: Carl-Schultz-Platz 1) 92224 Amberg
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When calling from abroad, use the international call prefix plus country code (00 49 for Germany) and omit the zero in the area code.

4. Comparison scheme and schedule

Table 2: Detailed schedule of the DKD interlaboratory comparison 20 N·m - 200 N·m

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2010																															
Feb.	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su			
						PTB1									Week 7					HBM											
Mar.	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We
	Week 9					PTB2									Week 11					GTM									Week 13		
Apr.	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Th	We	Th	Fr	
		DSM									Week 15					PTB3									Week 17						
May	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo
	Schatz									Week 19					Ford									Week 21					PTB4		
Jun.	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	
	PTB4						Week 23					Staiger									Week 25					PTB5					
Jul.	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa
	PTB5				Week 27					Lorenz									Week 29							Week 30					
Aug.	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu
		Week 31					PTB6									Week 33							Week 34							TBB-	
Sept.	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	
	ITS				Q-direct								Week 37					PTB7									Week 39				
Oct.	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su
		MPA DA									Week 41					Deprag									Week 43					PTB8	
Nov.	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	
	PTB8							Week 45					DmS Dr. Peschel									Week 47					TÜV AT				
Dec.	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr
	TÜV AT					Week 49					PTB9									Porsche, KDK, PTB in 2011											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Measurement in the pilot laboratory	Shipping of the standards	Measurement in the participant's laboratory

A combined ring-star design was chosen for this interlaboratory comparison in order to reduce the transport and calibration efforts for the pilot laboratory. The adopted schedule is shown in Table 2. After being used by a maximum of two participants, the instruments were sent back to the pilot laboratory where they were subjected to a short intermediate calibration. The pilot laboratory itself took part at the beginning and at the end of the comparison, both times carrying out a full calibration.

5. Transfer standards used

The following transfer standards were used:

200 N·m, Type TB2 (with fixed adapters providing cylindrical shaft ends)

- Manufacturer Hottinger Baldwin Messtechnik GmbH, Germany
- Serial number #080830117
- Dimensions Ø 103 mm x 253 mm (with adapters)

- Interface	Ø 50_{h7} mm x 80 mm (Adapter to cylindrical shaft ends at both ends)
- Mass	5,7 kg (with adapters)
- Packaging	in a plastic bag inside a transportation box
- Type of sensor	strain-gauge transducer
- Cable	TB2 LEMO 06-1.22, 6 wires, Lemo FGG6 (transducer) – DB-15,3 m

200 N·m, Type TT1

- Manufacturer	Raute Precision OY, Finland
- Serial number	36077-00, bridge M1
- Dimensions	Ø 57 mm x 224 mm
- Interface	Ø 30_{h7} mm x 60 mm cylindrical shaft ends at both ends
- Mass	1,4 kg
- Packaging	in a plastic bag inside a transportation box
- Type of sensor	strain-gauge transducer
- Cable	K010-1.22, 6 wires, DB-15 (transducer) – DB-15, 3 m

Additional devices:

Bridge calibrator K148

- Manufacturer	Hottinger Baldwin Messtechnik GmbH, Germany
- Type	K148
- Serial number	K148-0100
- Dimensions	330 mm x 270 mm x 75 mm
- Mass	3,5 kg with power supply unit
- Cable	K148-single channel, power supply unit with power cord

Data logger

- Manufacturer	MSR Electronics, Switzerland
- Type	MSR 145
- Serial number	302434
- Dimensions	70 mm x 40 mm x 22 mm
- Mass	0,1 kg

Serial Cable RS-232	without number

The data logger MSR145 served for recording temperature and relative humidity during transport. During the measurement, it had to be stored near the transducer being calibrated.

6. Stability of the standards

The long-term stability of the transfer standards is essential to achieve conclusive results. The results in the pilot laboratory showed that the stability was sufficiently good. Over a period of 16 months, a total of 12 measurements were carried out at PTB, using both transducers in each measurement.

In the following, the results are displayed in two-column sections. The Figures on the left show the results of the TT1 transducer, the Figures on the right the results of the TB2 transducer. The same is valid for diagrams that extend over the entire width of the page, i.e. first the TT1 is shown, then the TB2.

Figures 1 and 2 show a qualitative evaluation based on the example of the measurement PTB07. The evaluations have been carried out for all measurements. The relative deviations of the tared individual results for each measurement series from its associated mean value are a measure of the influence of rotation and thus of the quality of the alignment of the machine or of the sensitivity of the transducer for this influence. The dispersion of the values is sufficiently small for both transducers, so that both the standard measuring device and the transducers appear to be suitable for comparison. Figures 3 and 4 show the relative deviations of the results of the individual measurements (mean value over the three mounting positions, only quantitatively increasing torque) in the pilot laboratory from their corresponding average. The values show the reproducibility of the measurements over a longer period, and thus the **long-term stability**.

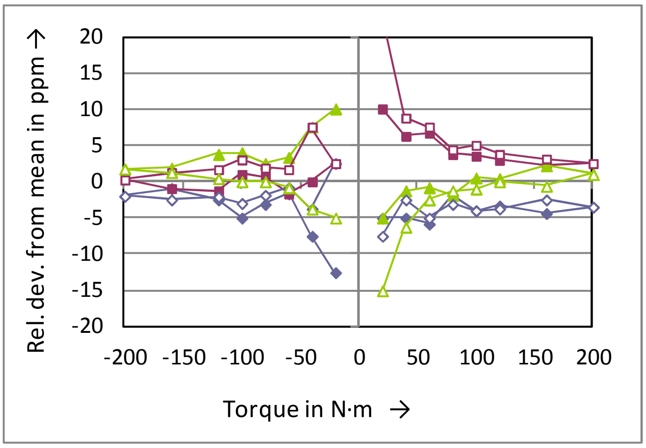

Figure 1: Measurement PTB07 – Example of the qualitative evaluation of a measurement result of the TT1 in the pilot laboratory: Relative deviations of the results of the three series of measurements, related to their common mean value, (mounting positions: 1 – diamond, 2 – square, 3 – triangle, filled symbols: increasing series, blank symbols: decreasing series)

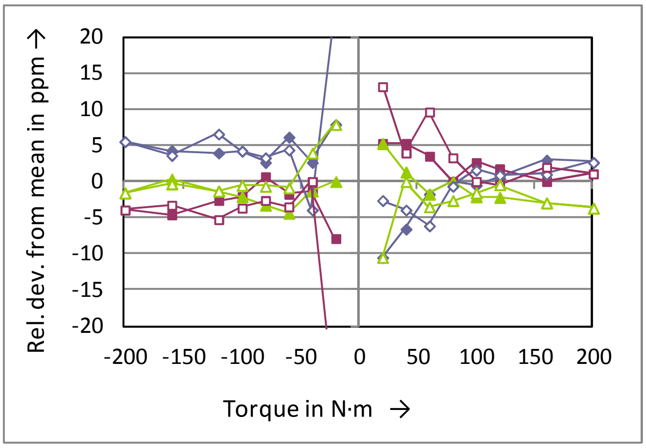

Figure 2: Measurement PTB07 – Example of the qualitative evaluation of a measurement result of the TB2 in the pilot laboratory: Relative deviations of the results of the three series of measurements, related to their common mean value, (mounting positions: 1 – diamond, 2 – square, 3 – triangle, filled symbols: increasing series, blank symbols: decreasing series)

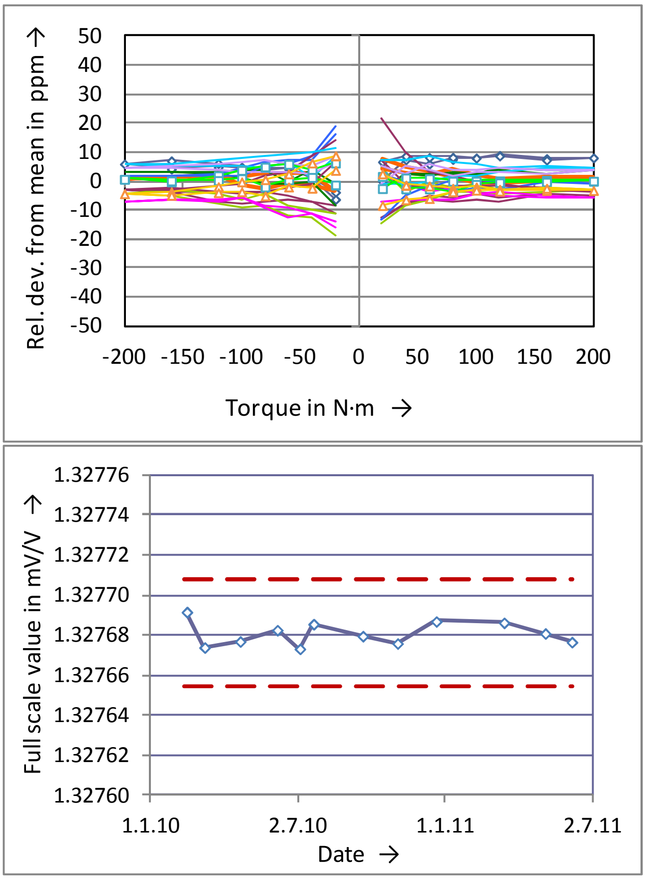

Figure 3: Long-term stability of the TT1:
Top: Relative deviations of the results of the different calibrations (average of the three series of measurements, only increasing amount of torque) in the pilot laboratory, related to their common mean value
Below: Measured value at a torque of 200 N·m during the twelve measurements in the pilot laboratory, dashed line: mean value · (1 ± 0,002%)

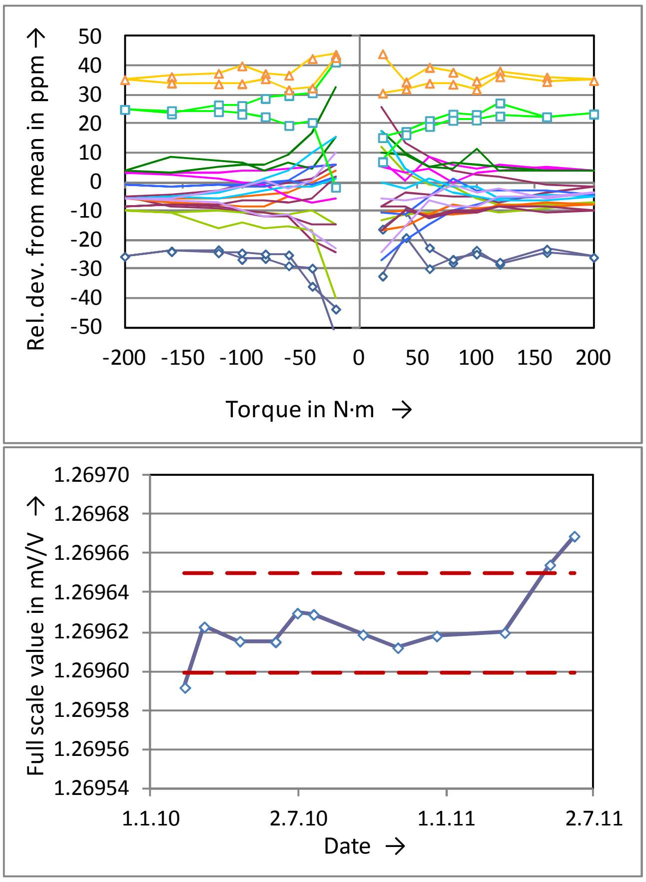

Figure 4: Long-term stability of the TB2:
Top: Relative deviations of the results of the different calibrations (average of the three series of measurements, only increasing amount of torque) in the pilot laboratory, related to their common mean value
Below: Measured value at a torque of 200 N·m during the twelve measurements in the pilot laboratory, dashed line: mean value · (1 ± 0,002%).

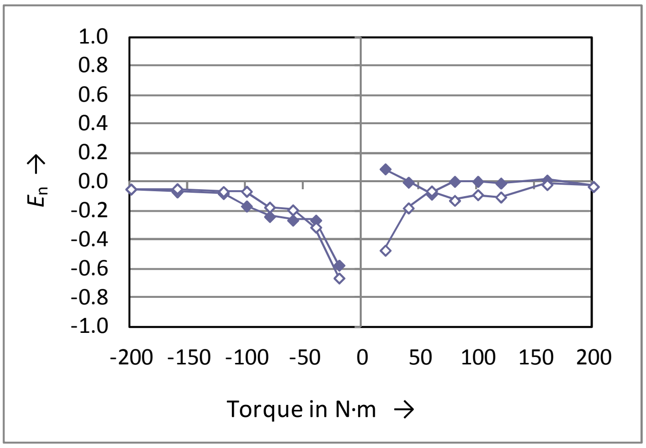

Figure 5: Measurement PTB07 – Example of the qualitative evaluation of a measurement result of the TT1 in the pilot laboratory: E_n factor of the individual measurement (mean value of the tree series of measurement) related to the mean value of all measurements in the pilot laboratory (Symbols: filled – increasing series, blank – decreasing series)

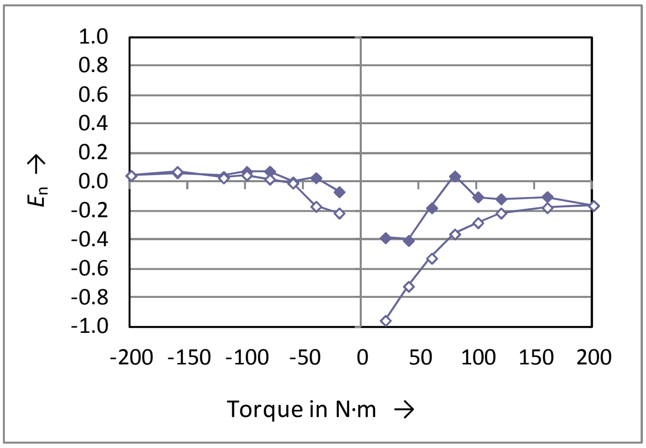

Figure 6: Measurement PTB07 – Example of the qualitative evaluation of a measurement result of the TB2 in the pilot laboratory: E_n factor of the individual measurement (mean value of the tree series of measurement) related to the mean value of all measurements in the pilot laboratory (Symbols: filled – increasing series, blank – decreasing series)

Above, Figure 4 shows a rather strong deviation of the first (diamond) and the last two measurements (square and triangle) from the other results. In the lower part, the history of the characteristic values is plotted. Here too, it can clearly be seen that the first and the last two measurements deviate relatively strongly from the mean value. This behaviour could not be detected in case of the TT1 transducer (the respective curves are shown in the above charts with identical symbols), so one can assume that the deviation is caused by an unknown influence of the transducer, probably by a drift. As the largest deviations were observed exactly at the beginning and end of the comparison, and since the impact on the laboratories with very small measurement capabilities should be kept to a minimum, the above-mentioned measurements were not taken into account in the determination of the reference value for the comparison. Apart from that, the transfer standards used showed a very good long-term stability. During the entire period of the comparison, all deviations of the TT1 transducer shown in Figure 3 did not exceed ±22 ppm, equivalent to $\pm 2.2 \cdot 10^{-5}$. The measurements PTB2 to PTB10 of the TB2 transducer lie between ±37 ppm, equivalent to $\pm 3.7 \cdot 10^{-5}$. This stability is sufficient for a comparison measurement at a level of $1 \cdot 10^{-4}$ at the best. To minimize the effects of a single measurement on the reference value of the comparison, the mean values were defined as reference values for the evaluation of the participants' results.

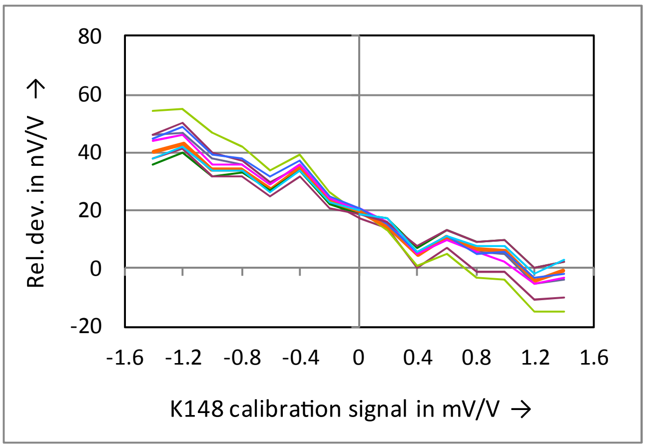

Figure 7: Stability of the amplifier used in the pilot laboratory in combination with the bridge standard K148 over a period of eleven months (calibration before measuring the TT1 transducer)

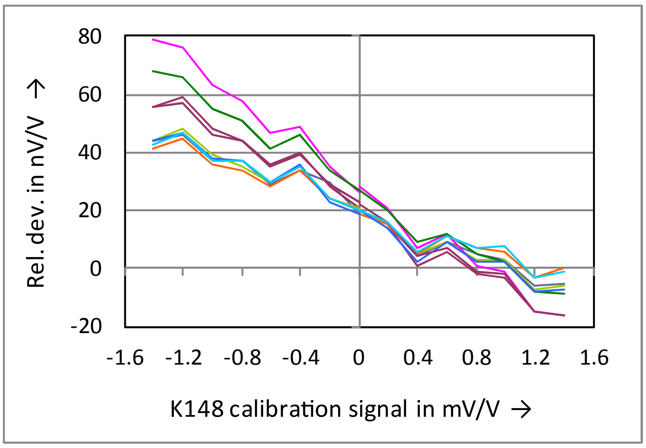

Figure 8: Stability of the amplifier used in the pilot laboratory in combination with the bridge standard K148 over a period of eleven months (calibration before measuring the TB2 transducer)

The measuring amplifiers used were calibrated by means of the bridge calibrator K148 which was included in the delivery. The focus was not primarily on the absolute calibration of the amplifiers but rather on establishing comparability of the instruments used by the participants. This calibration was performed twice, once for each of the two transducers. The stability of the K148 and the DMP40 used at PTB were checked during the measurements performed at PTB. Figures 7 and 8 show the absolute deviations of the DMP40 compared to the K148 during nine intermediate measurements at PTB over a period of eleven months. Although in extreme cases the deviations could amount to 75 nV/V, they were nonetheless very well reproducible (range of interval usually well below 50 nV/V).

Stability at the participants' laboratories

The stability of the transfer standards was evaluated based on the history of the zero signals, as measured by the participants before and after installation in the measurement device. These signals may provide information regarding possible overloads, a strain or extreme environmental influences.

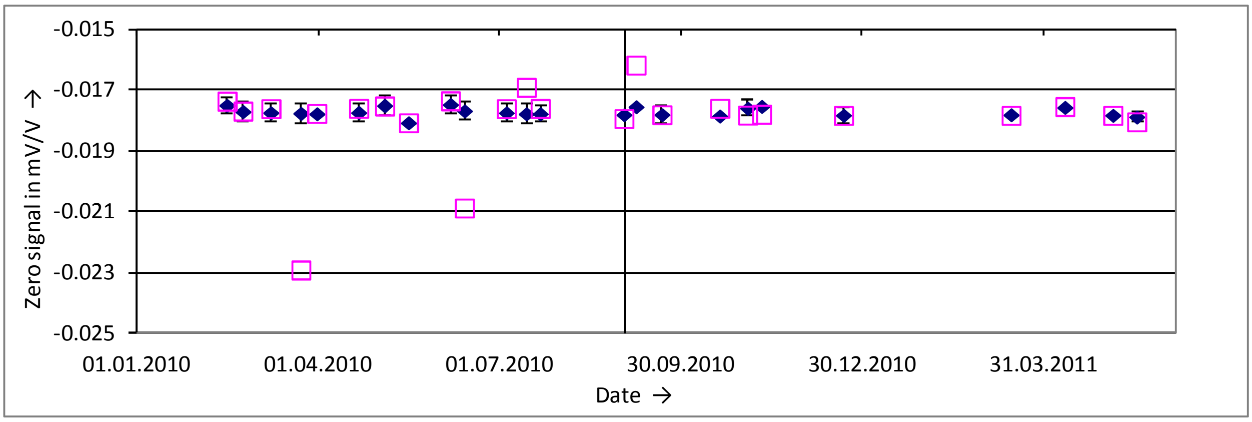

Figure 9: History of the zero signals of the TT1: the zero signals determined before (diamond) and after (blank square) installation; the error bars represent the measured remanences (not determined for laboratories having delivered tared values)

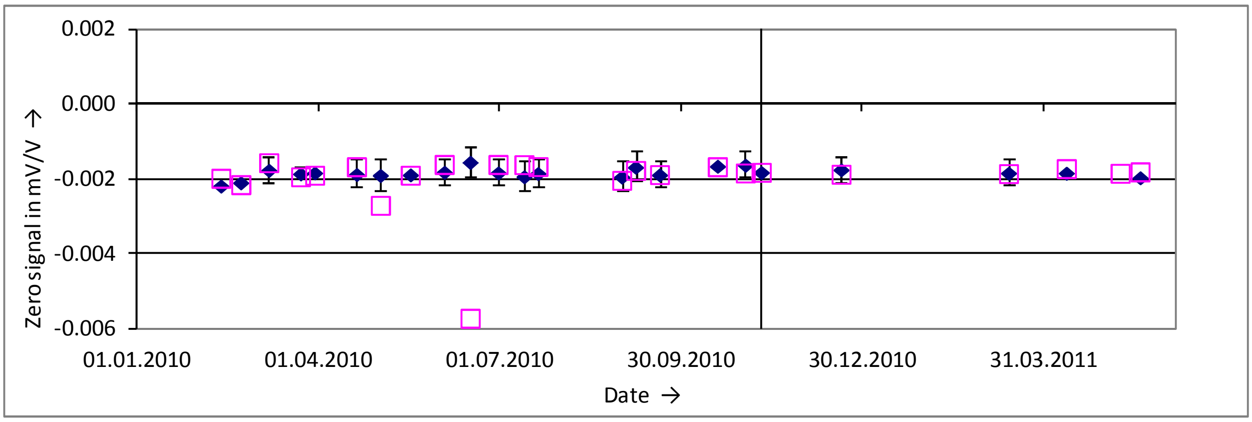

Figure 10: History of the zero signals of the TB2: the zero signals determined before (diamond) and after (blank square) mounting; the error bars represent the measured remanences (not determined for laboratories having delivered tared values)

As can be seen from Figures 9 and 10, the zero signals are subject to change due to the installation in some devices (10401, 37701) which may exceed the values of the remanence by a multiple, but are still small referred to the full scale value (0.3% ... 0.4%). This may be caused by corresponding preloads or a non-optimal alignment. Attention must also be paid to the changes of the zero signals (max-min) across the different mounting positions (see Tables 3 and 4). All in all, there was no indication of a drift or a leap of the **zero signals**.

The **remanence** reflected in the diagrams was calculated for the laboratories that had delivered appropriate values; it was in good agreement with the values determined by PTB. Only 41401 produced a higher value, by a factor of about 100 for TT1 and a factor of about 70 for TB2. At Porsche (TT1) and in laboratory 37701 (TB2), the values of the remanence are only about half as large; it would be appropriate to examine how the corresponding zero signals were measured.

The above-mentioned values, together with further data such as the ambient conditions stated by the laboratories, are summarized in Tables 3 and 4. Here and hereinafter, the participants (except for the pilot laboratory) were sorted in ascending order according to the best measurement capability (bmc). In case of equal values for best measurement capability, the laboratories were sorted by ascending DKD number. The different specifications regarding resolution and stability derived from the fact that some participants had used different measuring amplifiers (19801: DMC, 24801: NI 9237).

It turned out that the strict requirements regarding the ambient conditions have not been met everywhere and, of course, there is a correlation with the desired measurement uncertainty, i.e. very tight tolerances are only needed for the smallest measurement uncertainties of 0.01% and 0.02%. Here, the low humidity values in the laboratories 09301 (only TT1) and 49301 or the relatively high temperatures in laboratory 09301 are especially striking.

Table 3: Compilation of some measurement values and results for the TT1 transducer

		bmc	Date	TT1	TT1	Zero signal b/a		Rel. dev.	max-min	Remanence	Resolution	Stability
				T in °C	*rH* in %	in mV/V	in mV/V	of FV	in mV/V	in mV/V	in mV/V	in mV/V
00101	HBM	0.0001	23.02.2010	21.2	44.2	-0.017677	-0.017660	0.001%	0.000052	0.000327	0.000001	0.000001
09301	Schatz	0.0001	05.05.2010	22.3	27.2	-0.017480	-0.017490	-0.001%	0.000053	0.000335	0.000001	0.000003
37801	Lorenz	0.0001	15.07.2010	22	44.9	-0.017750	-0.016880	0.067%	0.000061	0.000302	0.000001	0.000002
49301	MPA DA	0.0001	11.04.2011	20.5	25	-0.017542	-0.017511	0.002%	-	-	0.000001	0.000002
10401	GTM	0.0002	27.03.2010	22	40	-0.017734	-0.022880	-0.396%	0.000497	0.000315	0.000001	0.000000
37701	Staiger	0.0002	14.06.2010	20	50	-0.017655	-0.020842	-0.245%	0.000038	0.000294	0.000001	0.000001
41401	TBB-ITS	0.0002	02.09.2010	21.5	40	-0.017780	-0.017910	-0.010%	0.000045	0.026851	0.000001	0.000002
47801	DmS	0.0002	10.11.2010	21.2	45	-0.017511	-0.017763	-0.019%	-	-	0.000001	0.000003
08001	Ford	0.0010	17.05.2010	21	48	-0.018045	-0.018046	0.000%	-	-	0.000001	0.000005
19801	DSM	0.0010	01.04.2010	23	43	-0.017750	-0.017740	0.001%	-	-	0.000025	0.000010
51101	Deprag	0.0010	20.10.2010	21.2	40.5	-0.017823	-0.017571	0.019%	-	-	0.000001	0.000004
-	Porsche	0.0010	17.05.2011	22.5	42	-0.017850	-0.018010	-0.012%	0.000420	0.000147	0.00001	0.00004
-	TÜV-AT	0.0010	01.12.2010	23.0	30	-0.01785	-0.01786	-0.001%	0.000040	0.000277	0.00001	0.00001
24801	KDK	0.0020	27.04.2011	20.0	-	0.000000	-0.000600	-0.046%	-	-	0.00001	0.00002
50601	Q-direct	0.0020	08.09.2010	21	46	-0.017520	-0.016150	0.105%	-	-	0.000001	0.000002
	PTB		Mean value	21.2	41.9	-0.017678	-0.017648	0.002%	0.000118	0.000286	0.000001	0.000001

Table 4: Compilation of some measurement values and results for the TB2 transducer

		bmc	Date	TB2	TB2	Zero signal b/a		Rel. dev.	max-min	Remanence	Resolution	Stability
				T in °C	*rH* in %	in mV/V	in mV/V	of FV	in mV/V	in mV/V	in mV/V	in mV/V
00101	HBM	0.0001	22.02.2010	21.2	44.7	-0.002073	-0.002122	-0.004%	0.000424	0.000419	0.000001	0.000001
09301	Schatz	0.0001	03.05.2010	22.4	35.2	-0.001877	-0.002675	-0.061%	0.000506	0.000412	0.000001	0.000003
37801	Lorenz	0.0001	14.07.2010	21.9	45	-0.001910	-0.001590	0.025%	0.000441	0.000388	0.000001	0.000002
49301	MPA DA	0.0001	12.04.2011	20.5	29.6	-0.001816	-0.001694	0.009%	-	-	0.000001	0.000002
10401	GTM	0.0002	24.03.2010	22	38	-0.001835	-0.001911	-0.006%	0.001883	0.000395	0.000001	0.000000
37701	Staiger	0.0002	17.06.2010	20	50	-0.001527	-0.005689	-0.320%	0.001749	0.000165	0.000001	0.000010
41401	TBB-ITS	0.0002	01.09.2010	21.5	40	-0.001920	-0.002010	-0.007%	0.000160	0.025761	0.000001	0.000002
47801	DmS	0.0002	10.11.2010	21.2	45	-0.001799	-0.001793	0.000%	-	-	0.000001	0.000003
08001	Ford	0.0010	18.05.2010	22	47	-0.001865	-0.001867	0.000%	-	-	0.000001	0.000005
19801	DSM	0.0010	31.03.2010	22.9	42	-0.001810	-0.001870	-0.005%	-	-	0.000025	0.000010
51101	Deprag	0.0010	19.10.2010	21.3	41	-0.001634	-0.001644	-0.001%	-	-	0.000001	0.000004
-	Porsche	0.0010	19.05.2011	22.5	42	-0.001940	-0.001780	0.012%	0.001060	0.000403	0.00001	0.00004
-	TÜV-AT	0.0010	02.12.2010	23.0	30	-0.00183	-0.00190	-0.005%	0.000050	0.000350	0.00001	0.00001
24801	KDK	0.0020	20.04.2011	20.0	-	0.000000	0.000100	0.008%	-	-	0.00001	0.00002
50601	Q-direct	0.0020	08.09.2010	21	46	-0.001660	-0.001740	-0.006%	-	-	0.000001	0.000002
	PTB		Mean value	21.1	41.7	-0.001780	-0.001703	0.006%	0.000295	0.000352	0.000001	0.000001

7. Measurement results and evaluation

The measured values determined on the measuring amplifiers at the laboratories by means of the bridge standard K148 as well as the values for temperature and relative humidity, which had been locally recorded by means of the accompanying data logger MSR145, were evaluated and graphically displayed in order to enable the comparison of the measurement values. The respective results are shown in Figures 11 to 100, together with the corresponding measurement values of the participants.

As can be deduced from the data, the **amplifiers** generally show a rather good agreement. However, to achieve optimum results, the deviations of the measuring amplifiers from the DMP40 used in the pilot laboratory were taken into account in the measurement values of the participants by applying a correction. It was calculated to what extent the individual amplifiers show different slopes of the characteristic curves. This difference was taken into account for each transducer by applying a correction factor to the tared and averaged measurement values of the participants. There was no adjustment of the associated measurement uncertainties.

For the majority of the participants, the influences of the **ambient conditions** on the results of the comparison are negligible. The reference conditions for temperature and relative humidity were adhered to by the participants. Major deviations were only to be found at the laboratories 0931, 49301 and TÜV AT. In these cases, the tared and averaged measurement values were corrected with regard to the deviating temperature and relative humidity. The procedure corresponded to that of the international interlaboratory comparison CCM.T-K1. It is described in [1]. The parameters of temperature and humidity dependence were also taken from the measurements in the context of this international comparison, since the same types of transducers (TB2 and TT1) were used. For temperature, they amounted to 0.8 (nV/V)/K (TB2) and 1.5 (nV/V)/K (TT1) as final values, and for humidity, the parameters for the final value were at 0.2 (nV/V)/$\%_{\mathrm{rF}}$ (TB2) and -5.1 (nV/V)/$\%_{\mathrm{rF}}$ (TT1). In contrast to CCM.T-K1, however, there was no adjustment of the associated measurement uncertainties.

The **measurement results** of each participant were subjected to a qualitative evaluation according to Figures 1 and 2 in order to detect influences caused by the adjustment of the devices. The scaling was adjusted to the best measurement capability, deviations are highlighted in red and bold type.

The measurement values, which had been corrected with regard to the amplifier and – where necessary – also with regard to the ambient conditions, were finally used to calculate the E_n values. These are generally calculated according to (1):

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

In this comparison, however, the properties of the transfer transducer were neglected in the sense that the accredited bmc values were used as measurement uncertainties in the denominator of the formula, so that a slightly sharper criterion (2) with $U_{\mathrm{Lab,bmc}} < U_{\mathrm{Lab}}$ was applied:

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

The reason for this is that a large measurement uncertainty of the calibration result, inter alia by insufficient adjustment of the measuring device, facilitates the fulfilment of the criterion $|E_n| < 1$, and thus tends to favour the laboratory in question.

The E_n values were determined and graphically represented for all measuring points, i.e. for increasing and decreasing torque amounts.

00101 – HBM (DAkkS No.: D-K-12029-01-00)

Type of measuring device: dead weight with supported lever
Measurement axis: horizontal
Best measurement capability (k = 2): $1 \cdot 10^{-4}$

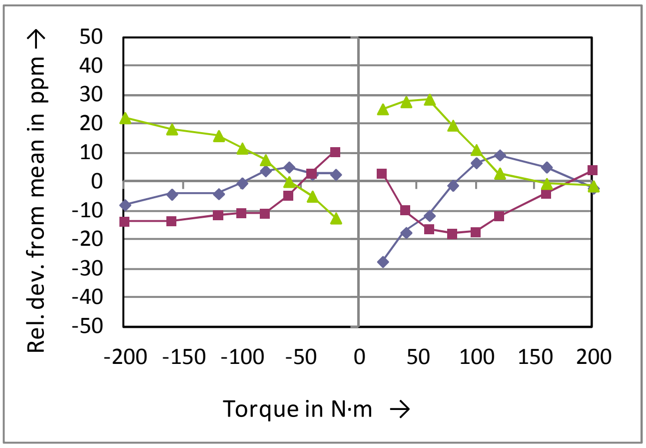

Figure 11: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

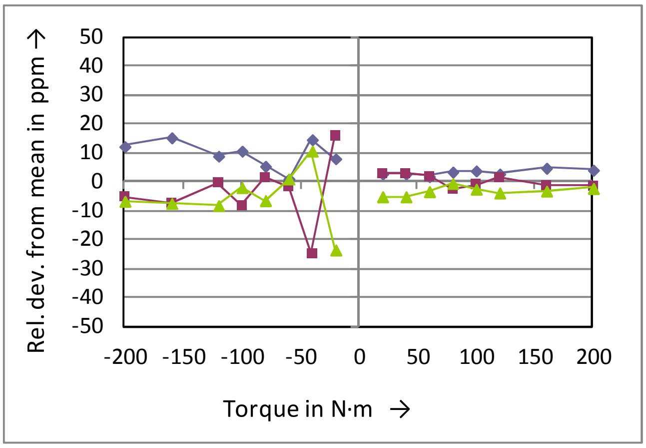

Figure 12: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

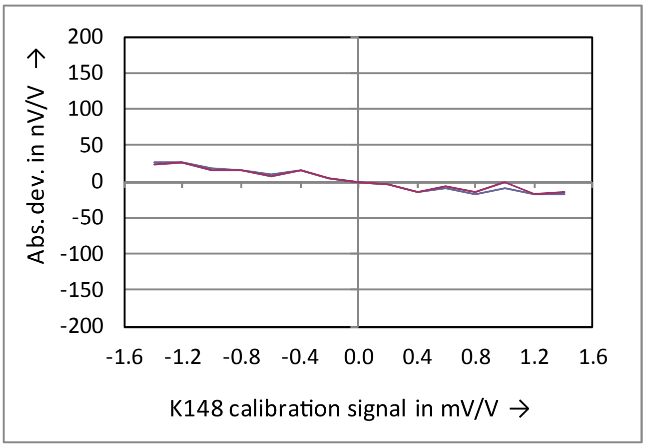

Figure 13: Absolute deviations of the signals of the amplifier used (DMP40) from the calibration signals of the bridge standard K148, one measurement for each of the two transfer standards

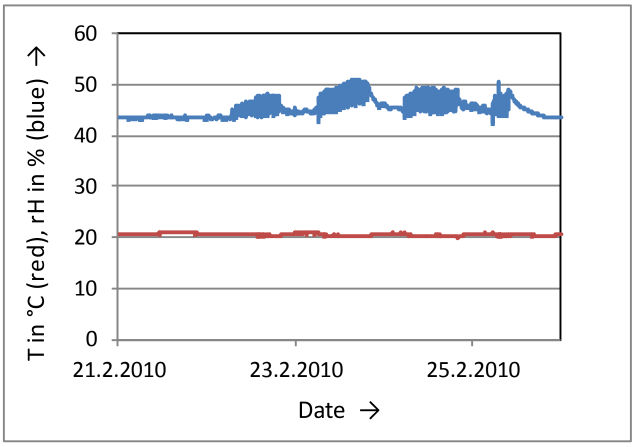

Figure 14: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

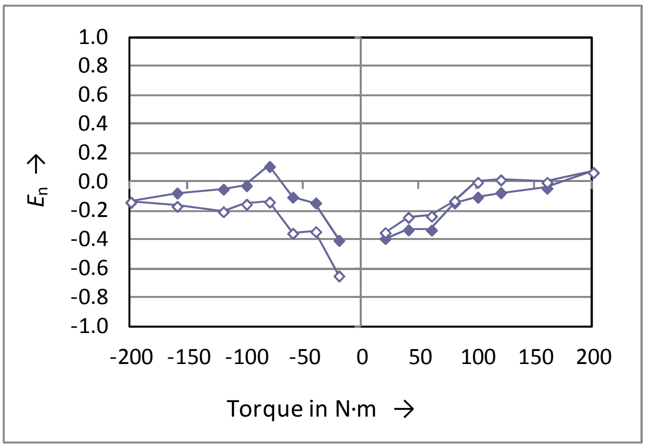

Figure 15: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

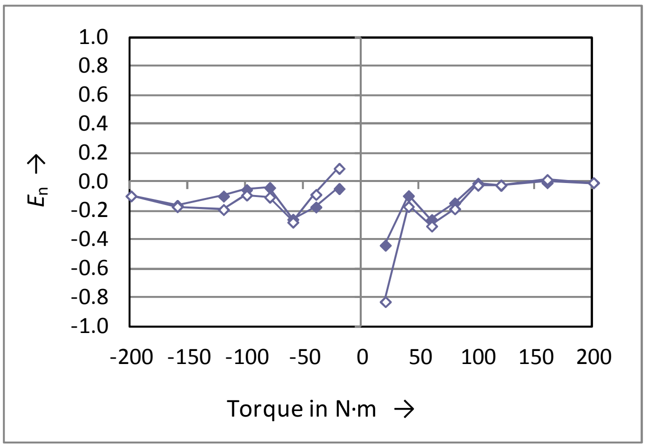

Figure 16: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

09301 – Schatz (DAkkS No.: D-K-17572-01-00)

Type of measuring device: dead weight with supported lever
Measurement axis: horizontal
Best measurement capability (k = 2): $1 \cdot 10^{-4}$

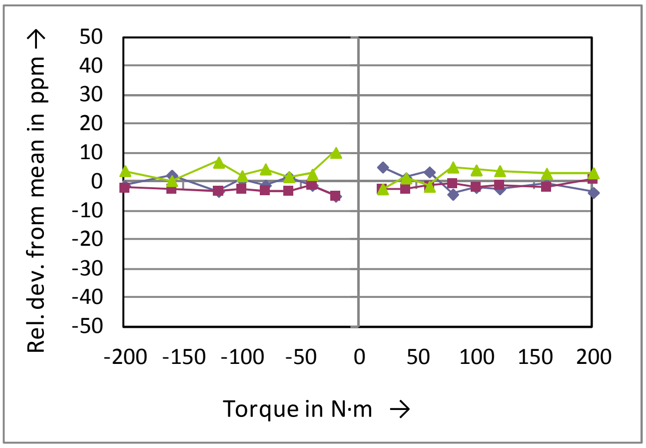

Figure 17: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

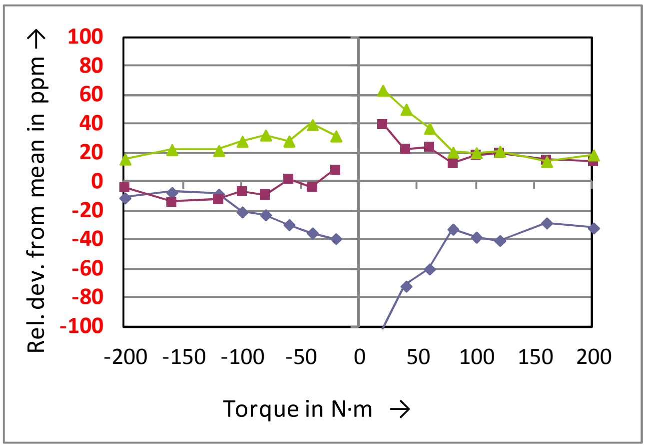

Figure 18: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

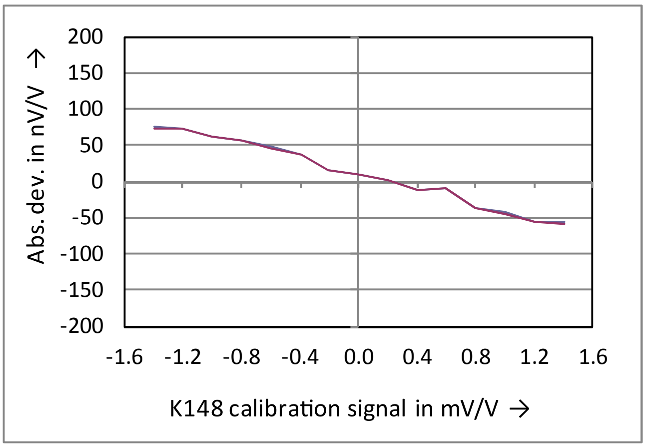

Figure 19: Absolute deviations of the signals of the amplifier used (MGCplus with ML38) from the calibration signals of the bridge standard K148, one measurement for each of the two transfer standards

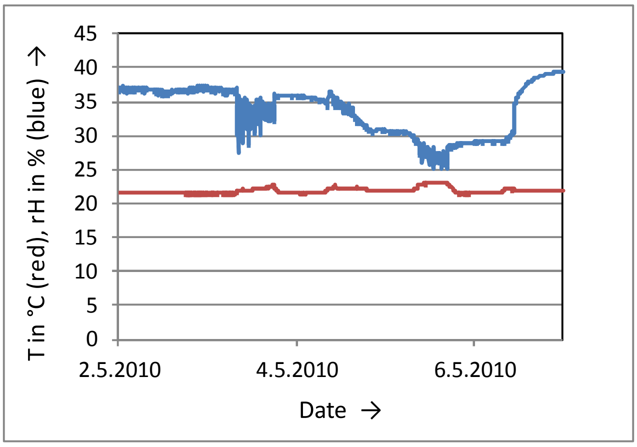

Figure 20: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

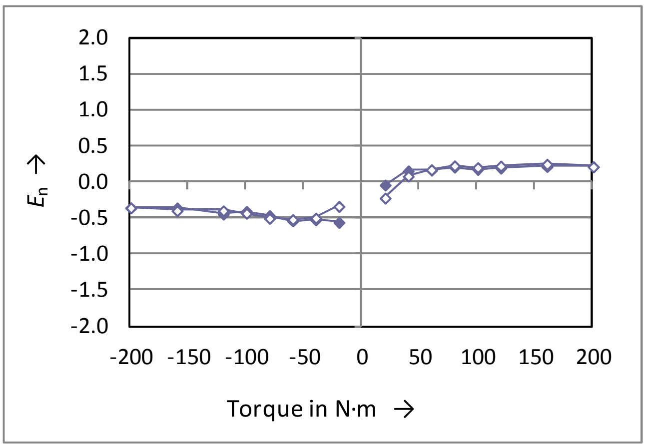

Figure 21: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

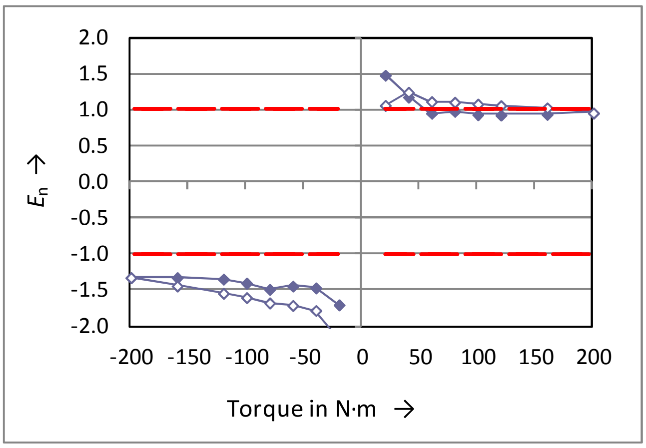

Figure 22: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

37801 – Lorenz (DAkkS No.: D-K-17603-01-00)

Type of measuring device: dead weight with supported lever
Measurement axis: horizontal
Best measurement capability (k = 2): $1 \cdot 10^{-4}$

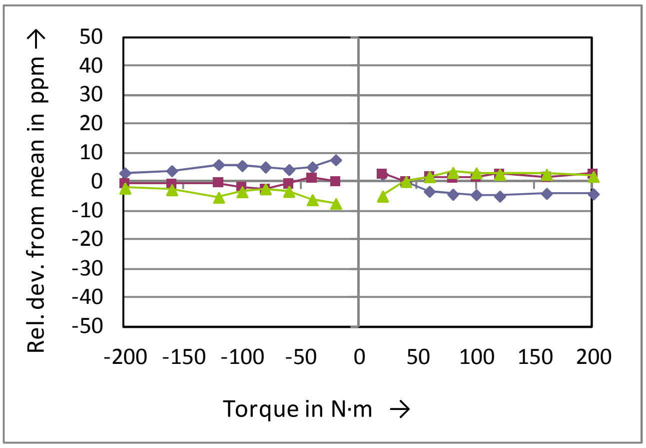

Figure 23: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

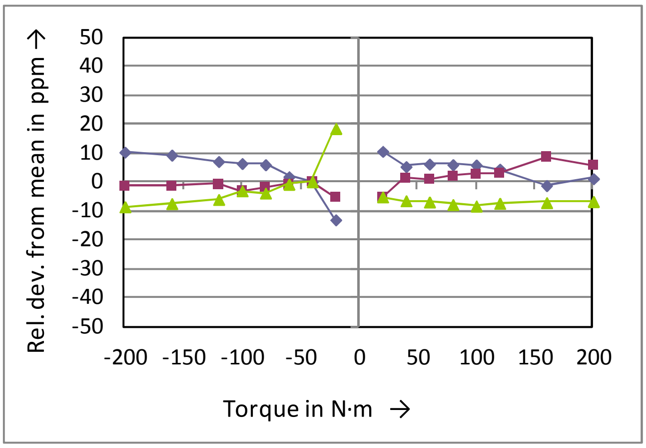

Figure 24: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

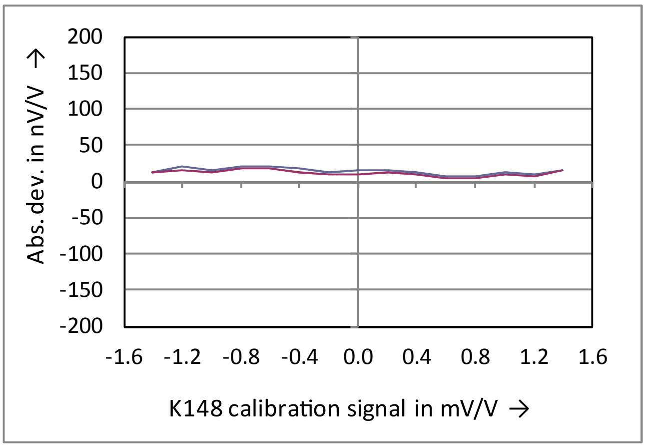

Figure 25: Absolute deviations of the signals of the amplifier used (MGCplus with ML38) from the calibration signals of the bridge standard K148, one measurement for each of the two transfer standards

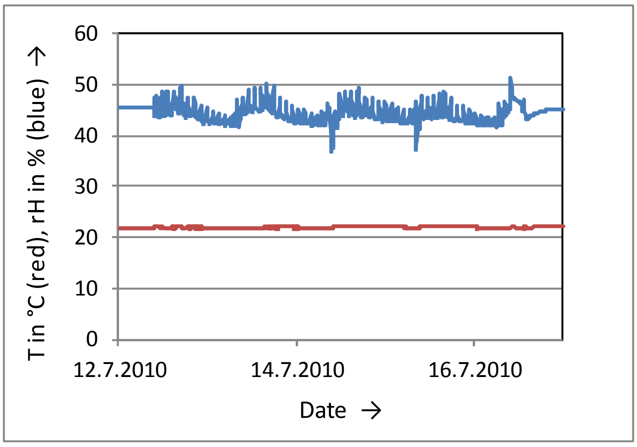

Figure 26: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

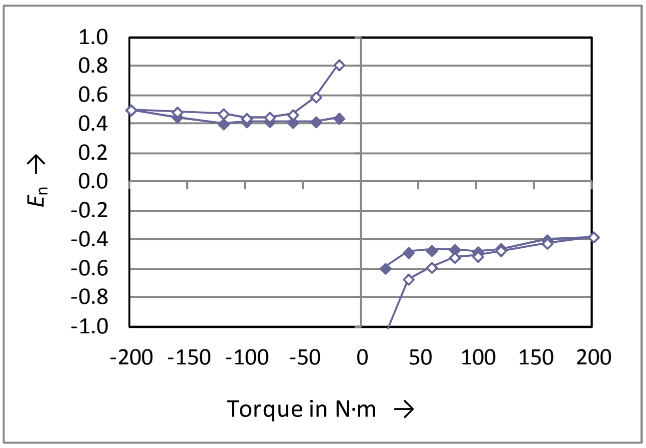

Figure 27: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

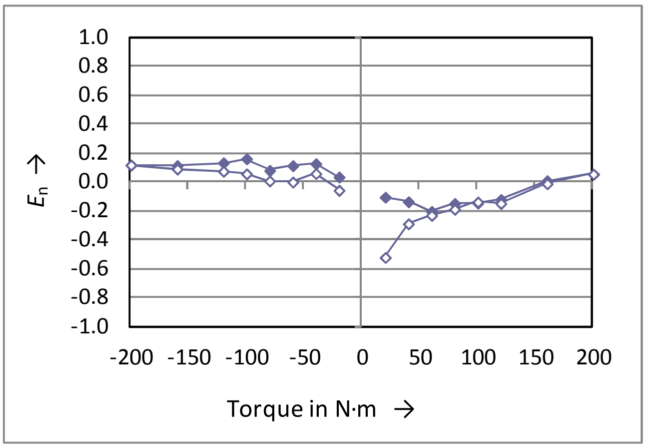

Figure 28: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

49301 – MPA DA (DAkkS No.: D-K-11048-01-00)

Type of measuring device: pendular mass
Measurement axis: horizontal
Best measurement capability (k = 2): $1 \cdot 10^{-4}$

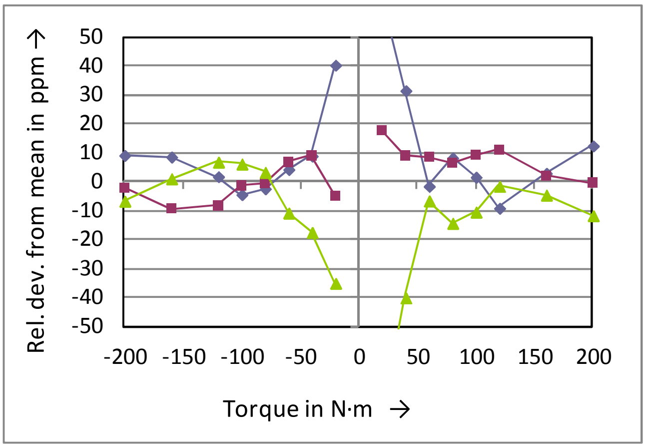

Figure 29: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

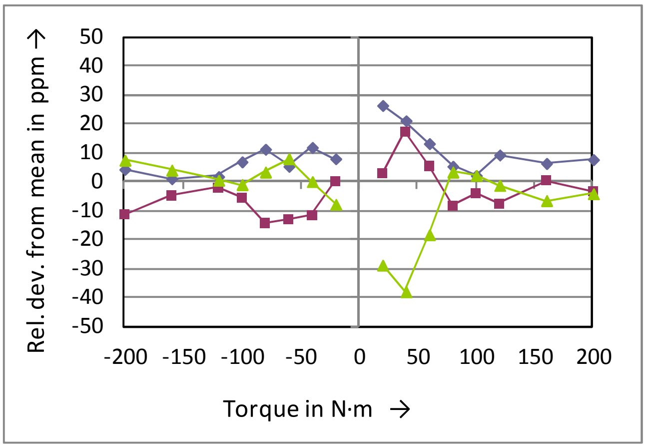

Figure 30: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

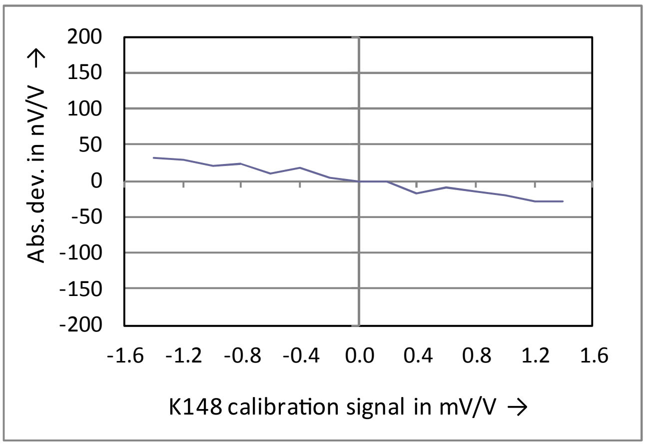

Figure 31: Absolute deviations of the signals of the amplifier used (DMP40) from the calibration signals of the bridge standard K148, only one measurement

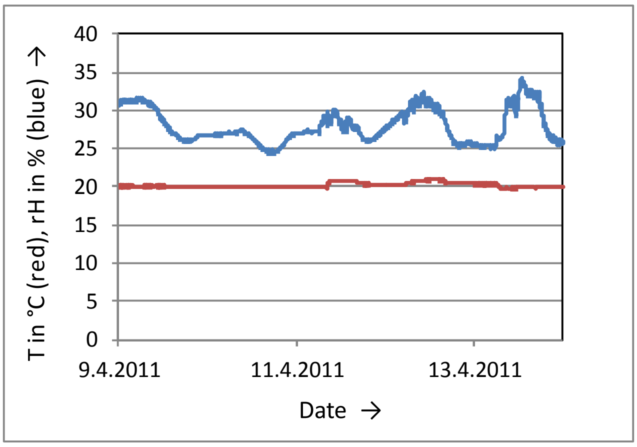

Figure 32: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

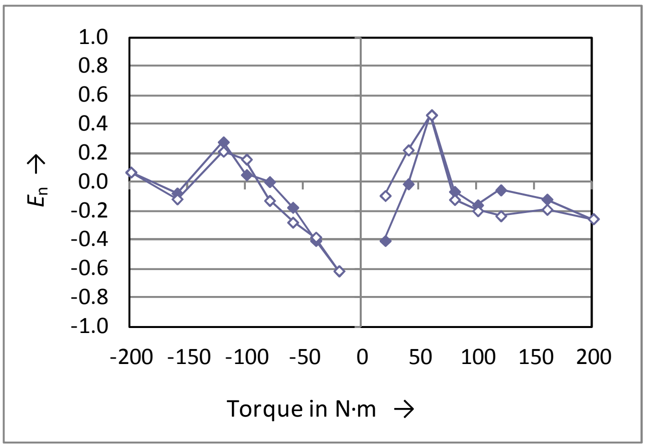

Figure 33: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

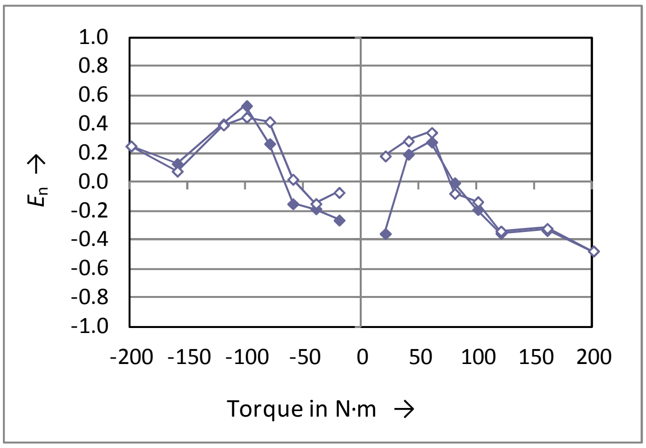

Figure 34: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

10401 – GTM (DAkkS No.: D-K-15106-01-00)

Type of measuring device: jockey weight
Measurement axis: horizontal
Best measurement capability ($k = 2$): $2 \cdot 10^{-4}$

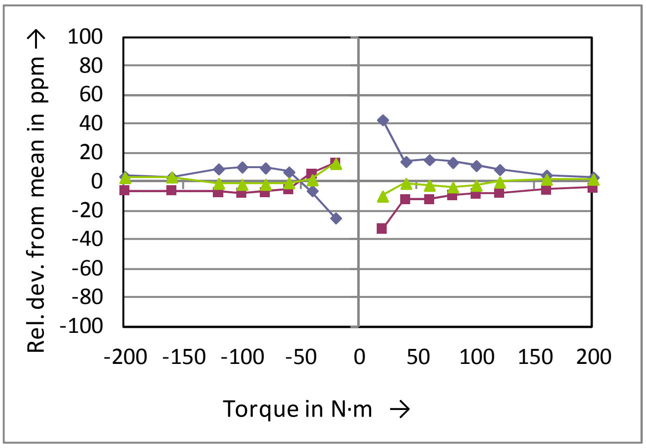

Figure 35: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

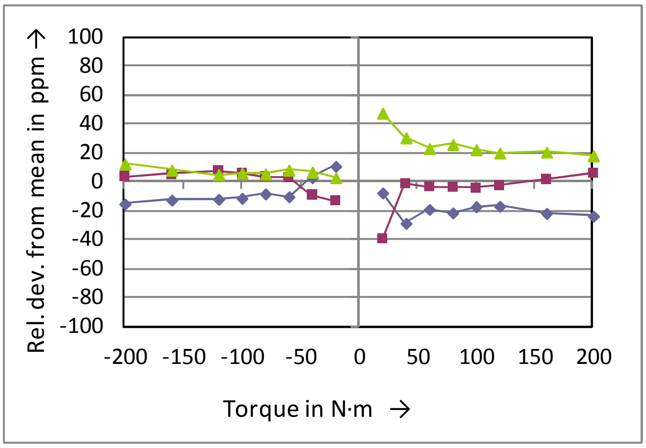

Figure 36: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

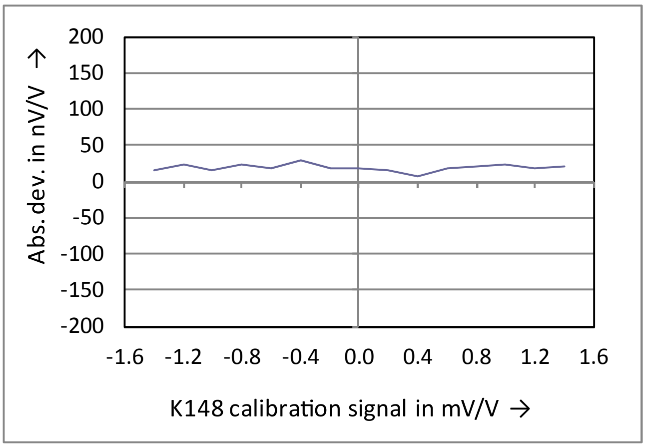

Figure 37: Absolute deviations of the signals of the amplifier used (DMP40) from the calibration signals of the bridge standard K148, only one measurement

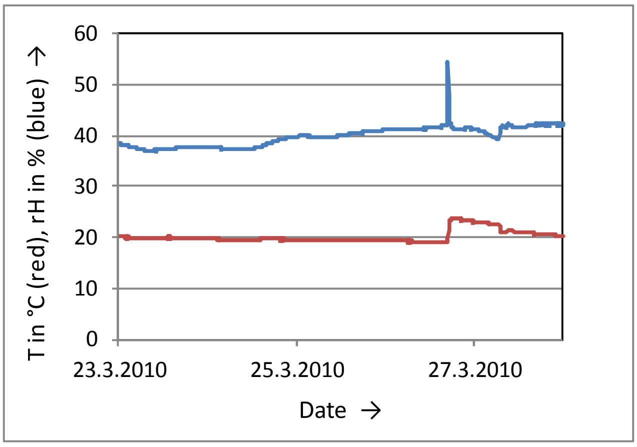

Figure 38: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

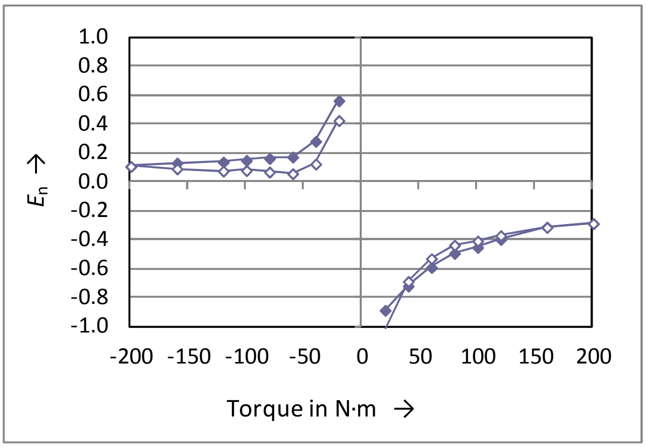

Figure 39: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

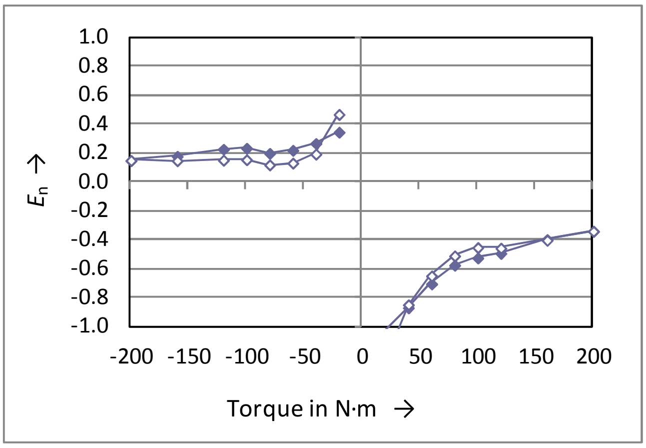

Figure 40: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

37701 – Staiger (now: Kistler Lorch, DAkkS No.: D-K-17650-01-00)

Type of measuring device: jockey weight
Measurement axis: horizontal
Best measurement capability (k = 2): $2 \cdot 10^{-4}$

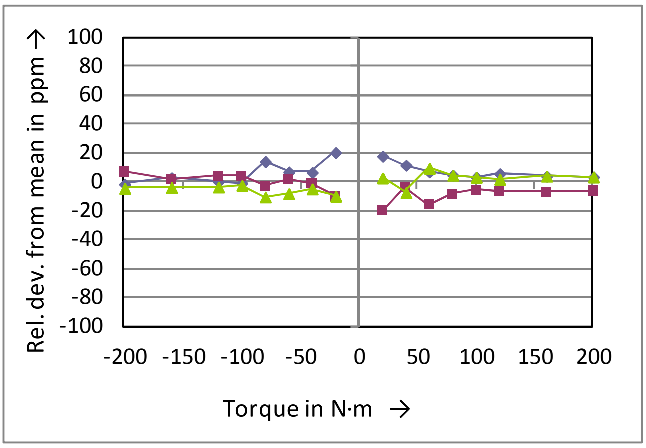

Figure 41: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

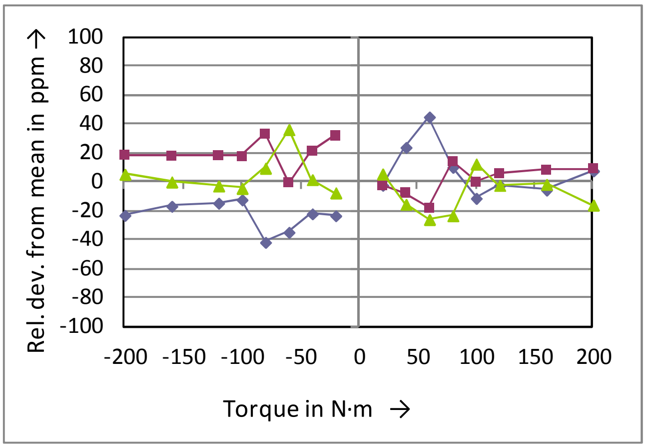

Figure 42: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

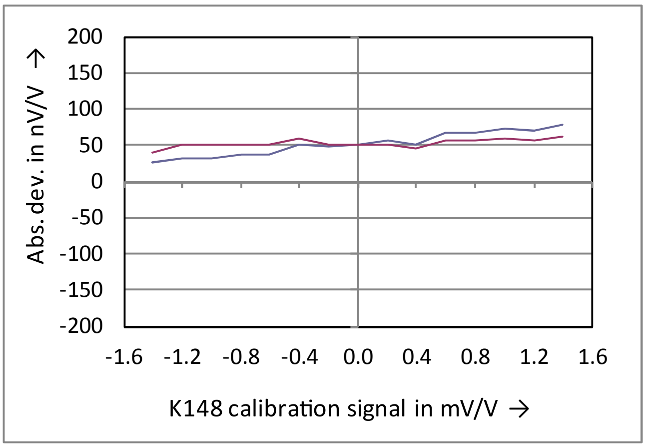

Figure 43: Absolute deviations of the signals of the amplifier used (MGCplus with ML38) from the calibration signals of the bridge standard K148, one measurement for each of the two transfer standards

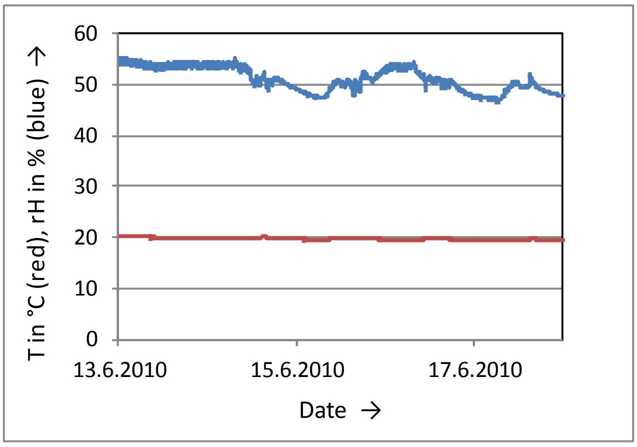

Figure 44: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

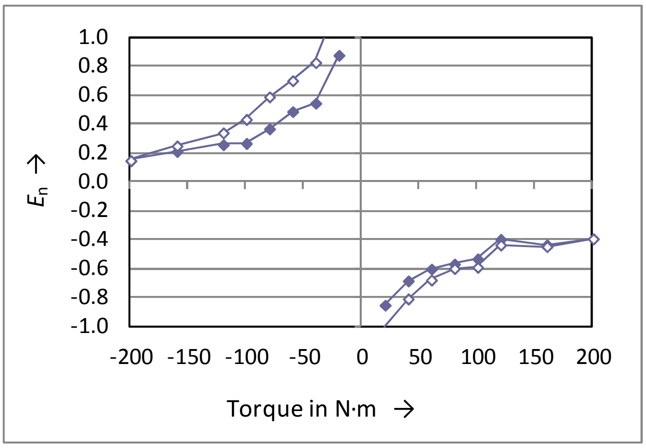

Figure 45: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

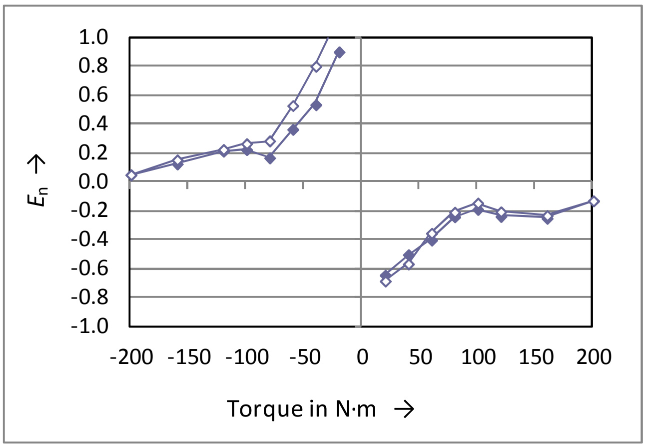

Figure 46: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

41401 – TBB-ITS (now: Atlas Copco, DAkkS No.: D-K-17447-01-01)

Type of measuring device: dead weight with supported lever
Measurement axis: horizontal
Best measurement capability (k = 2): $2 \cdot 10^{-4}$

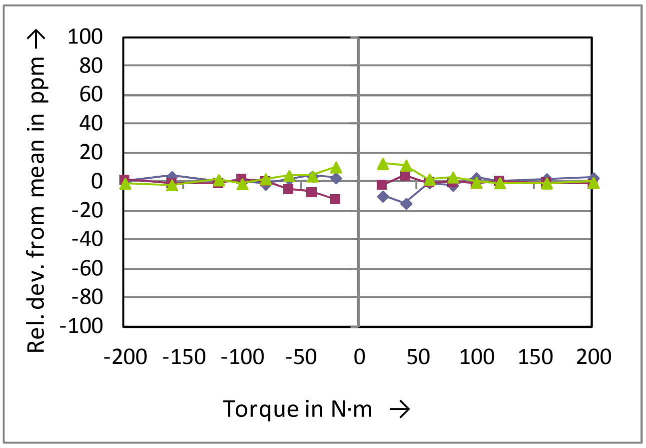

Figure 47: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

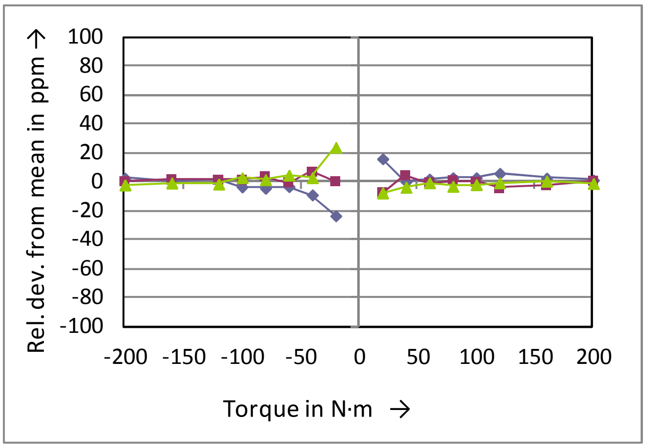

Figure 48: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

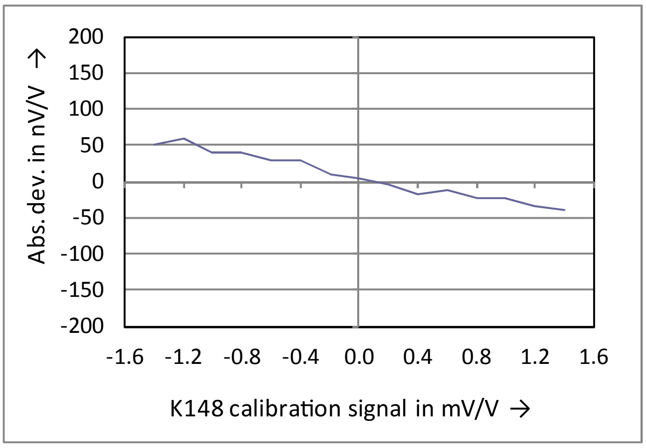

Figure 49: Absolute deviations of the signals of the amplifier used (MGCplus with ML38) from the calibration signals of the bridge standard K148, only one measurement

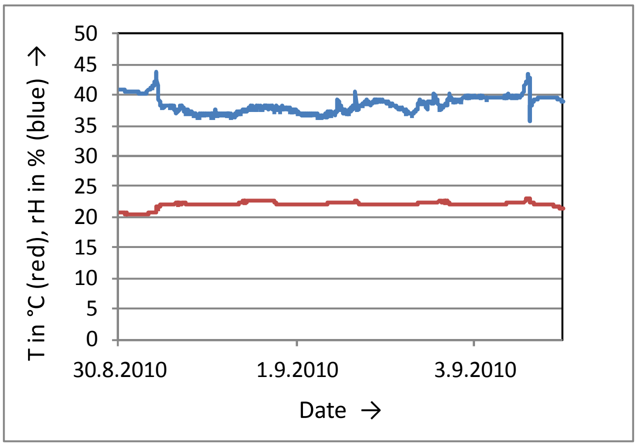

Figure 50: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

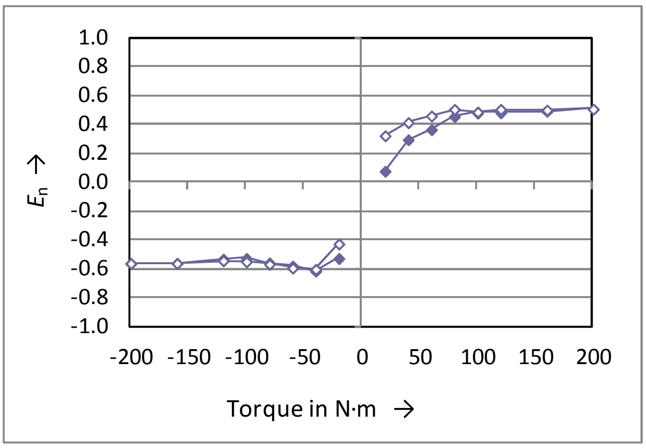

Figure 51: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

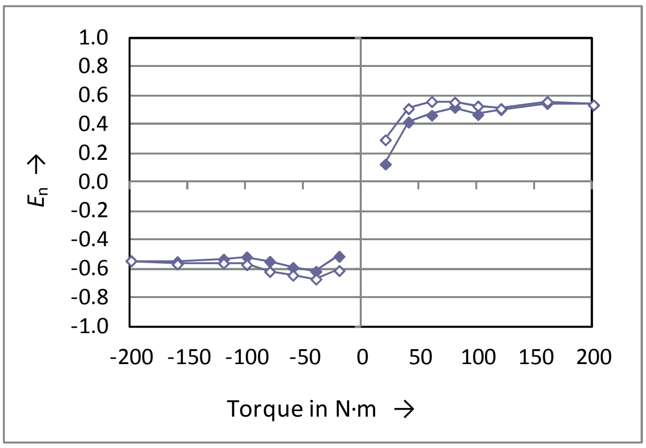

Figure 52: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

47801 – DmS (DAkkS No.: D-K-15165-01-00)

Type of measuring device: reference
Measurement axis: vertical
Best measurement capability (k = 2): $2 \cdot 10^{-4}$

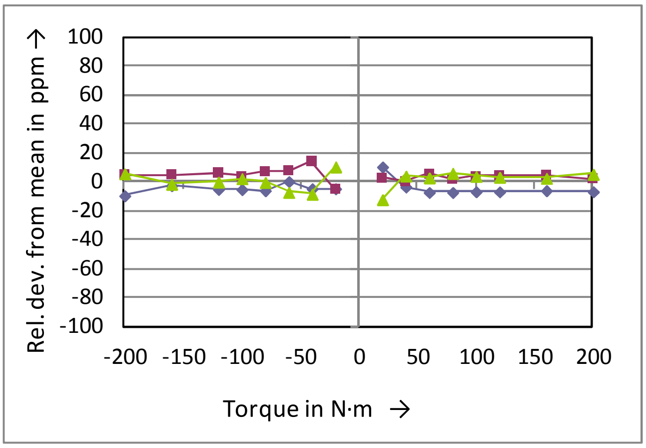

Figure 53: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

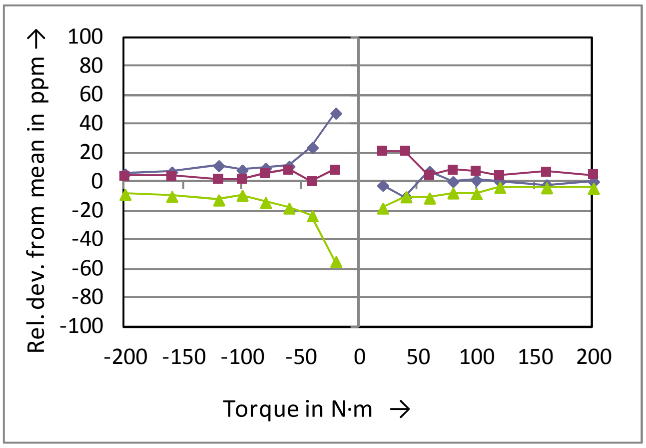

Figure 54: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

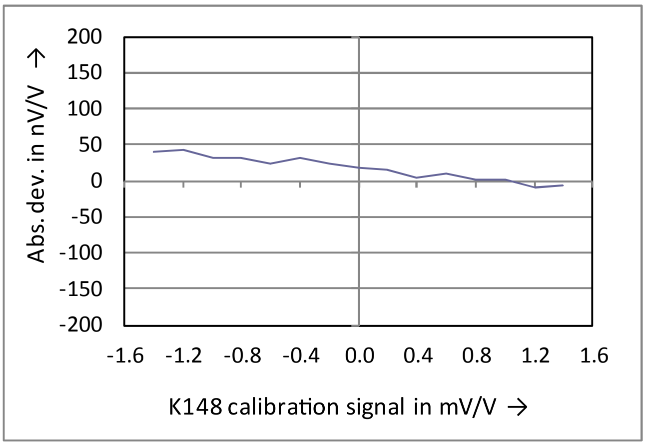

Figure 55: Absolute deviations of the signals of the amplifier used (DMP40) from the calibration signals of the bridge standard K148, only one measurement

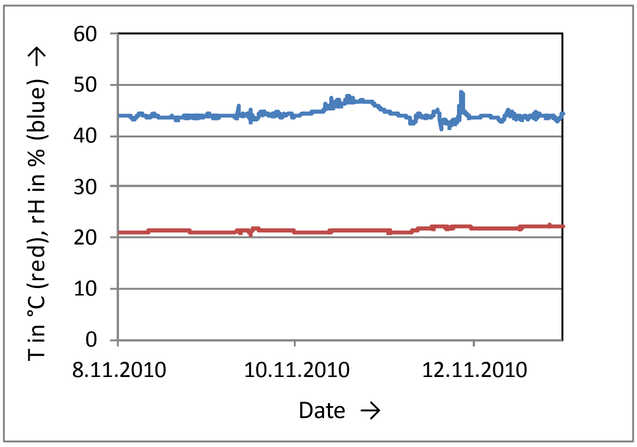

Figure 56: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

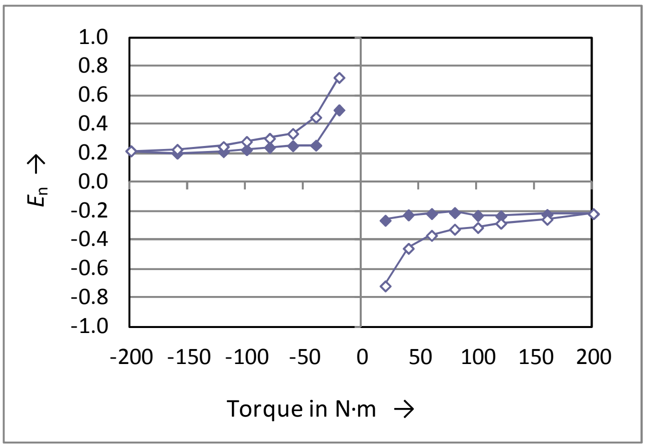

Figure 57: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

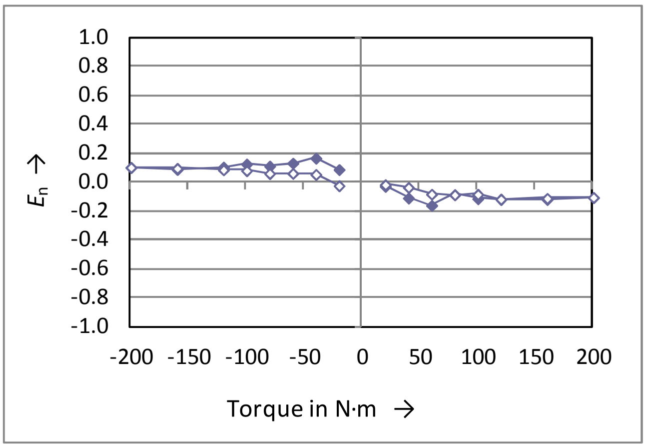

Figure 58: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

08001 – Ford (DAkkS No.: D-K-15088-01-00)

Type of measuring device: reference
Measurement axis: vertical
Best measurement capability (k = 2): $1 \cdot 10^{-3}$

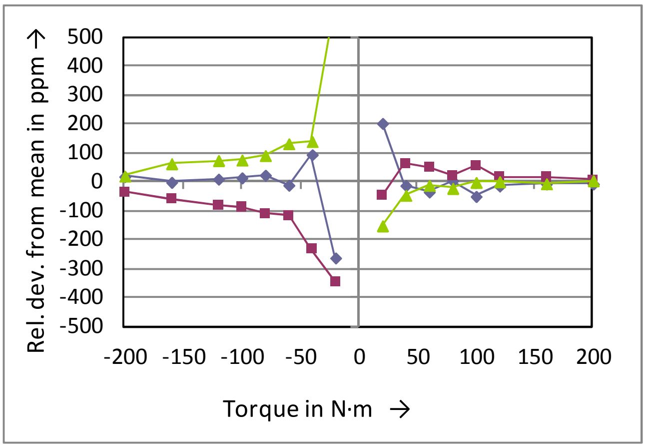

Figure 59: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

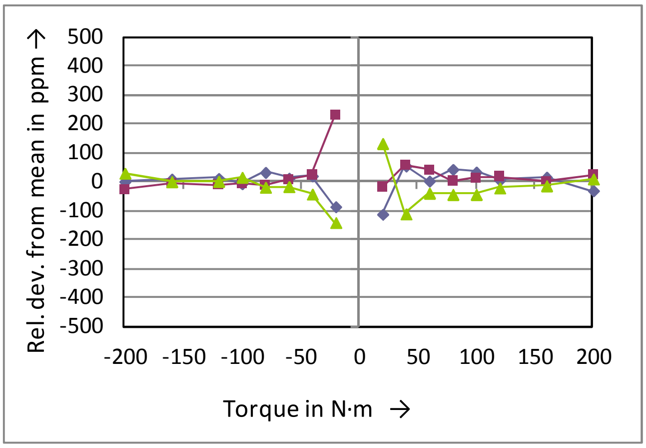

Figure 60: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

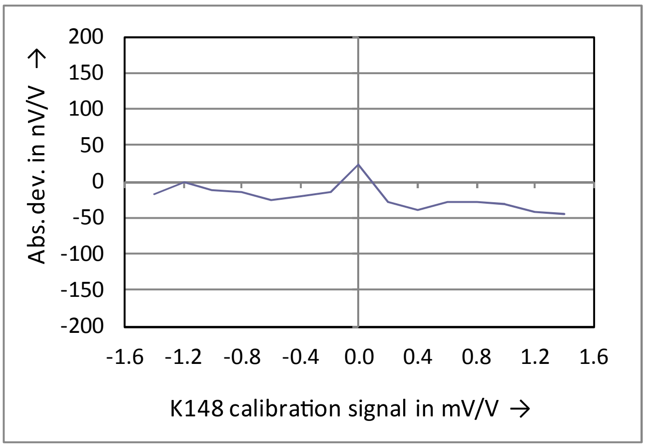

Figure 61: Absolute deviations of the signals of the amplifier used (MGCplus with ML38) from the calibration signals of the bridge standard K148, only one measurement

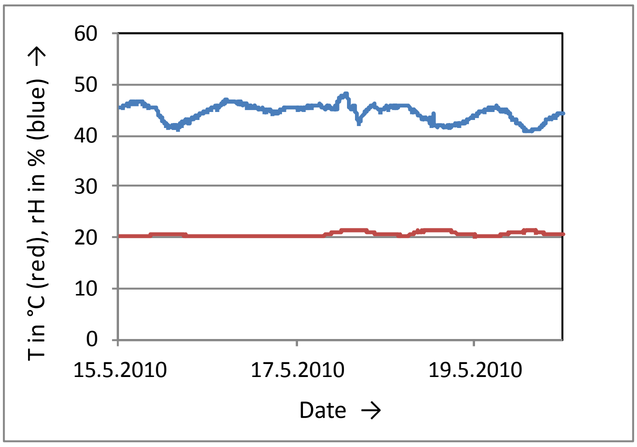

Figure 62: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

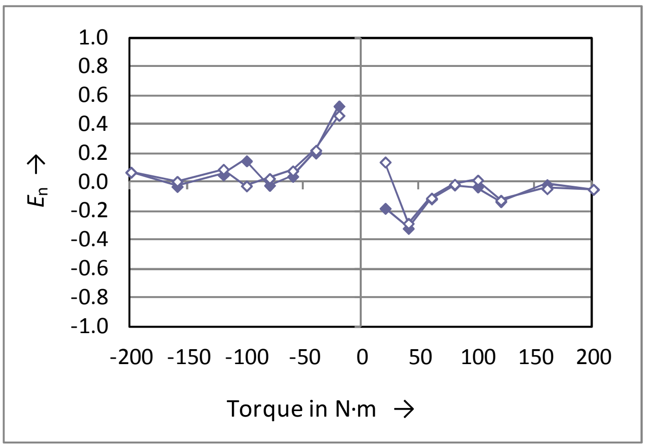

Figure 63: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

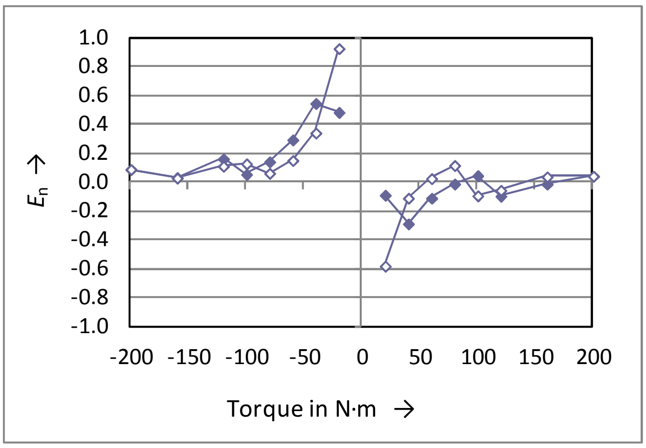

Figure 64: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

19801 – DSM (DAkkS No.: D-K-15152-01-00)

Type of measuring device: reference
Measurement axis: vertical
Best measurement capability (k = 2): $1 \cdot 10^{-3}$

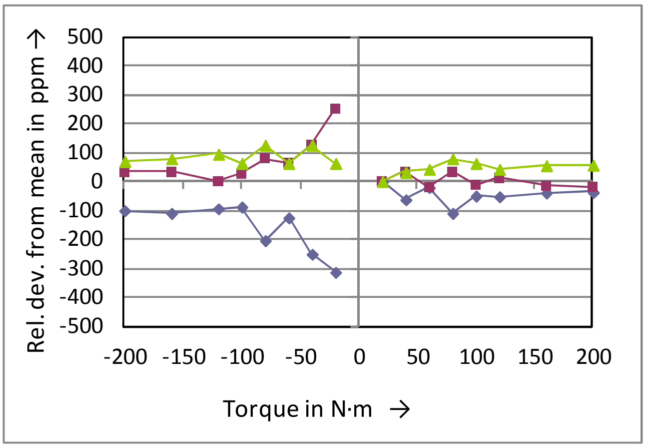

Figure 65: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

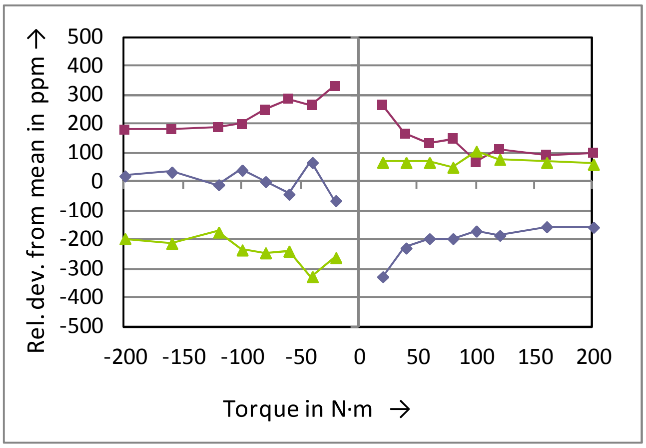

Figure 66: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

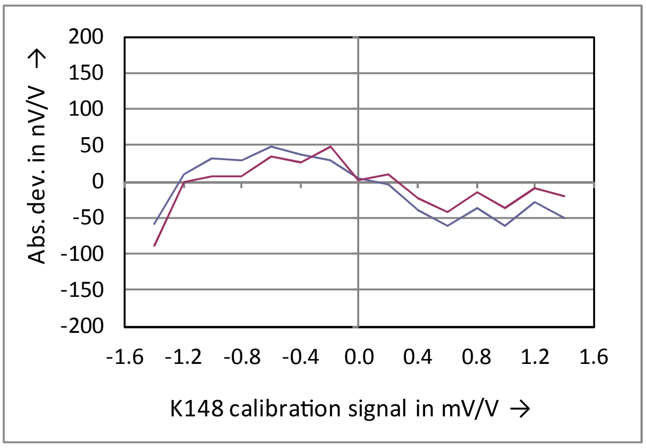

Figure 67: Absolute deviations of the signals of the amplifier used (DMCplus with DV30) from the calibration signals of the bridge standard K148, one measurement for each of the two transfer standards

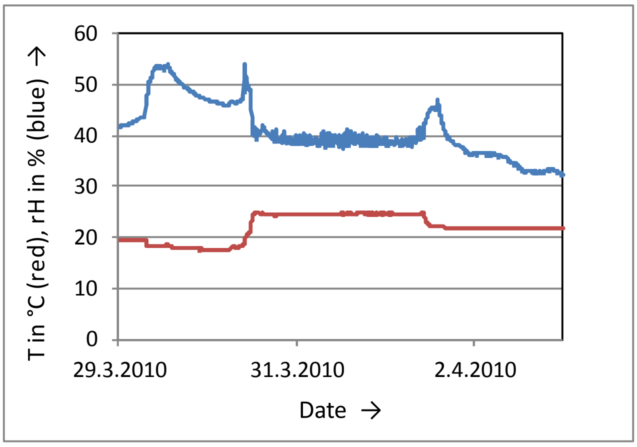

Figure 68: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

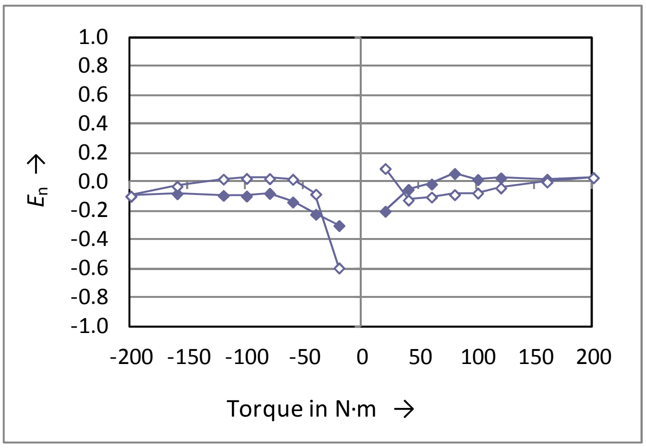

Figure 69: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

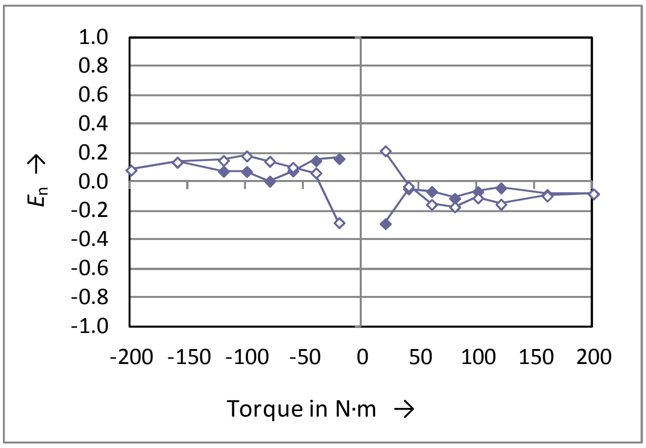

Figure 70: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

51101 – Deprag (DAkkS No.: D-K-18255-01-00)

Type of measuring device: reference
Measurement axis: vertical
Best measurement capability (k = 2): $1 \cdot 10^{-3}$

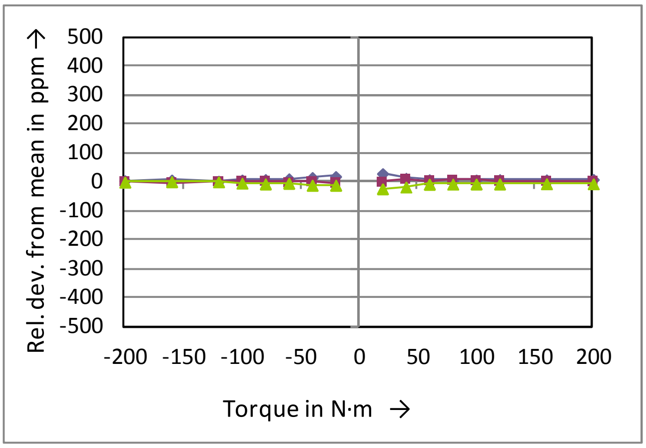

Figure 71: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

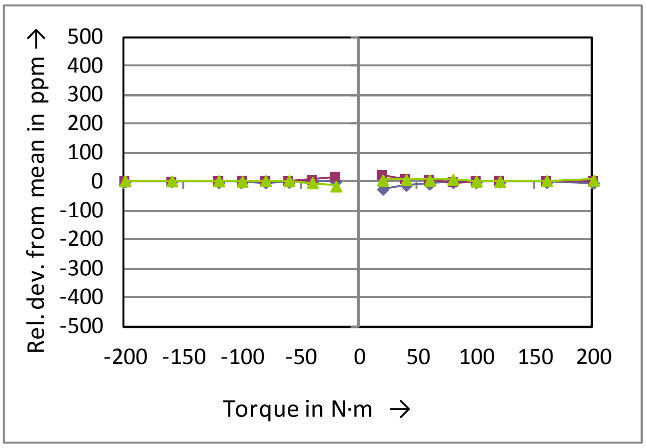

Figure 72: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value
(mounting positions: 1 – diamond, 2 – square, 3 – triangle)

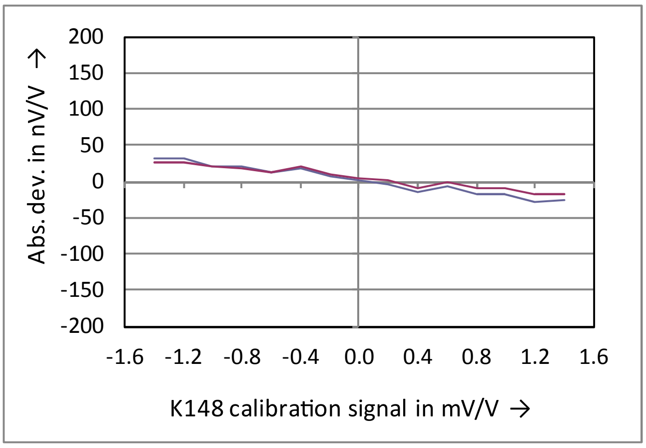

Figure 73: Absolute deviations of the signals of the amplifier used (MGCplus with ML38) from the calibration signals of the bridge standard K148, one measurement for each of the two transfer standards

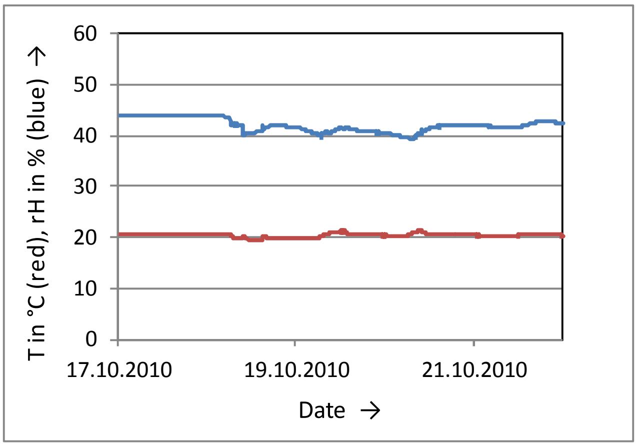

Figure 74: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

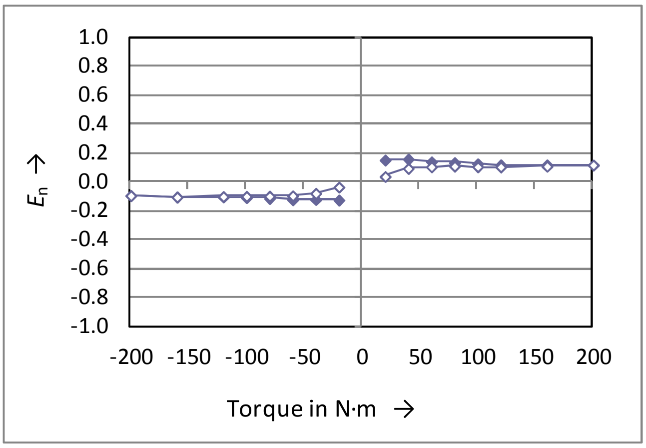

Figure 75: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

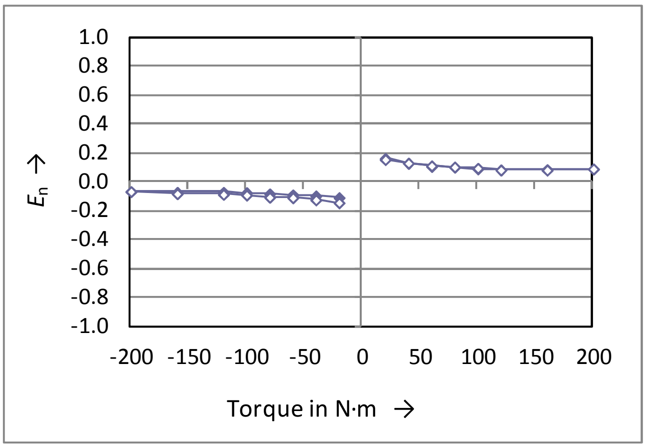

Figure 76: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

Porsche

Type of measuring device: reference
Measurement axis: horizontal
Best measurement capability (k = 2): $1 \cdot 10^{-3}$

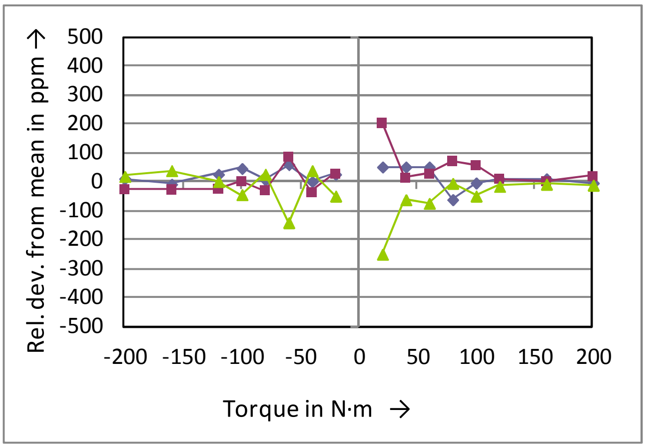

Figure 77: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

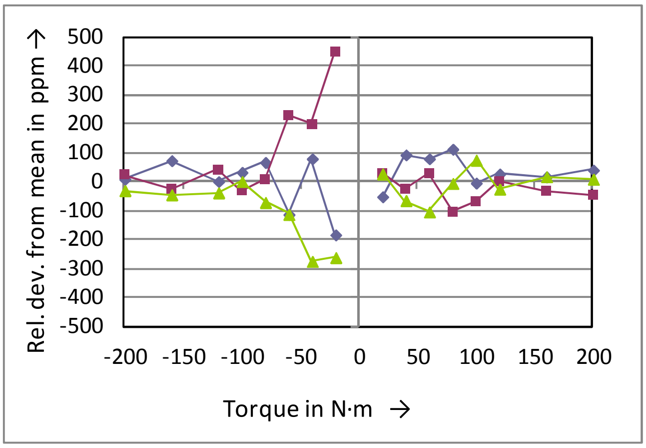

Figure 78: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

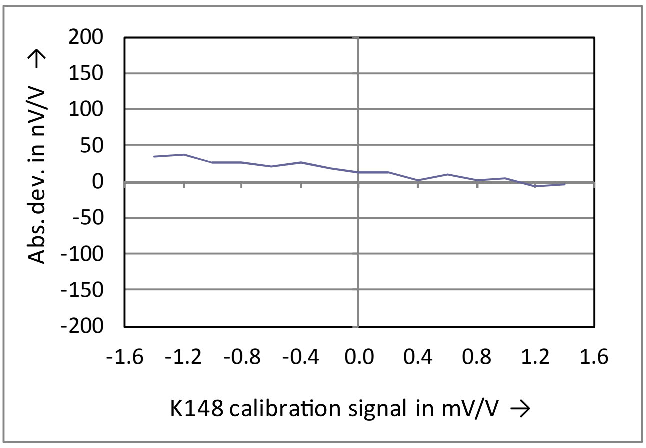

Figure79: Absolute deviations of the signals of the amplifier used (MGCplus with ML38) from the calibration signals of the bridge standard K148, only one measurement

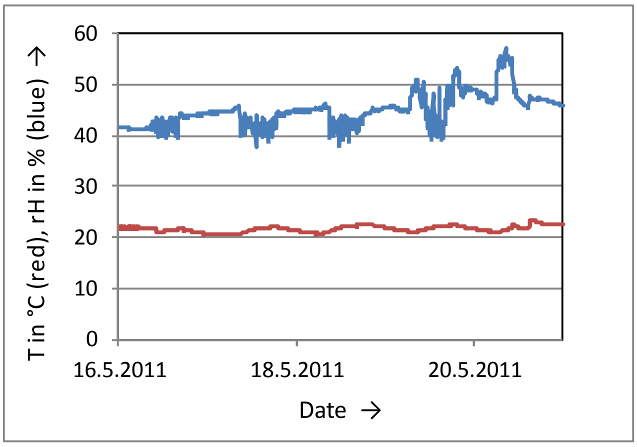

Figure 80: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

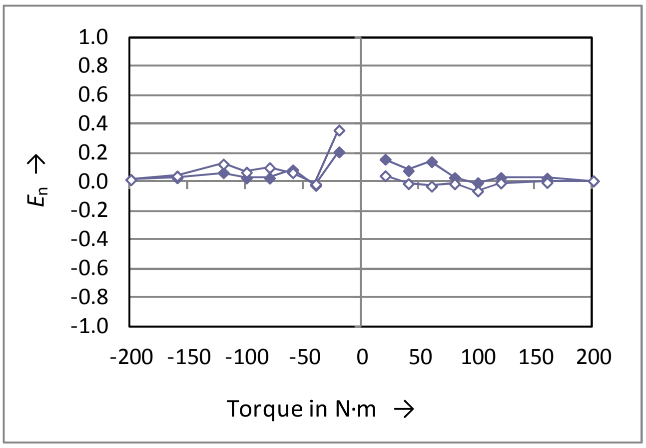

Figure 81: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

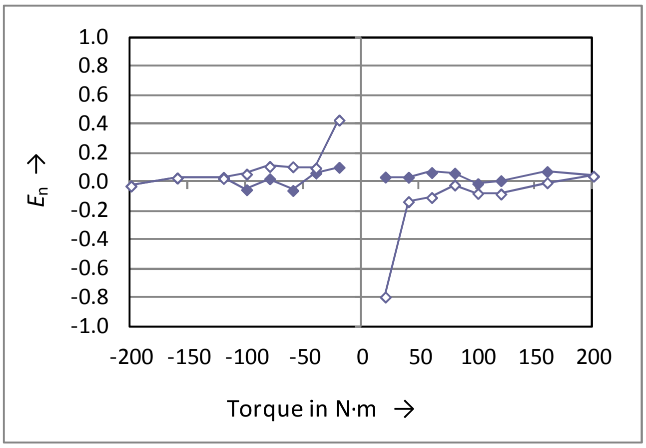

Figure 82: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

TÜV AT

Type of measuring device: reference (with square drives)
Measurement axis: vertical
Best measurement capability (k = 2): $1 \cdot 10^{-3}$

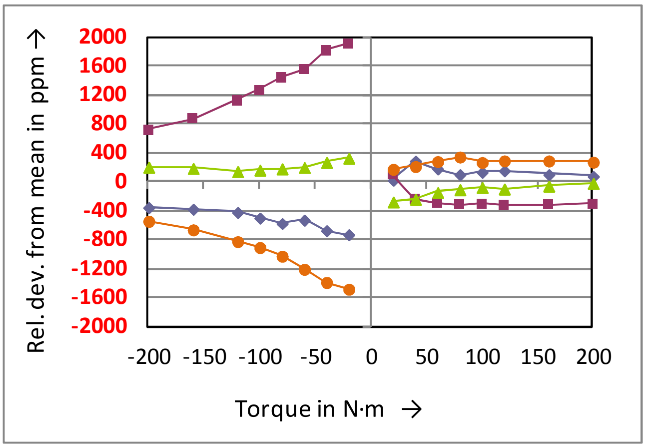

Figure 83: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

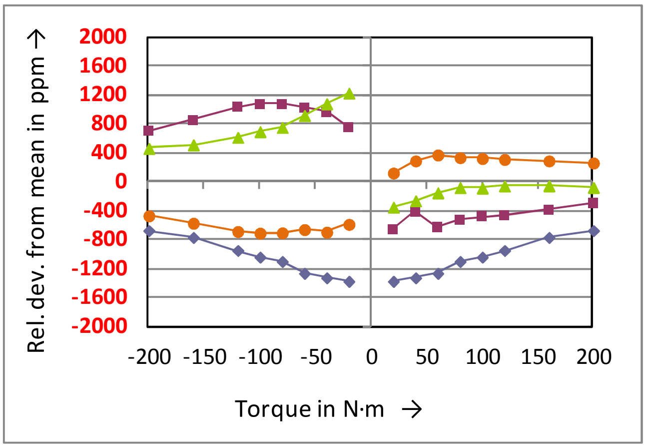

Figure 84: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

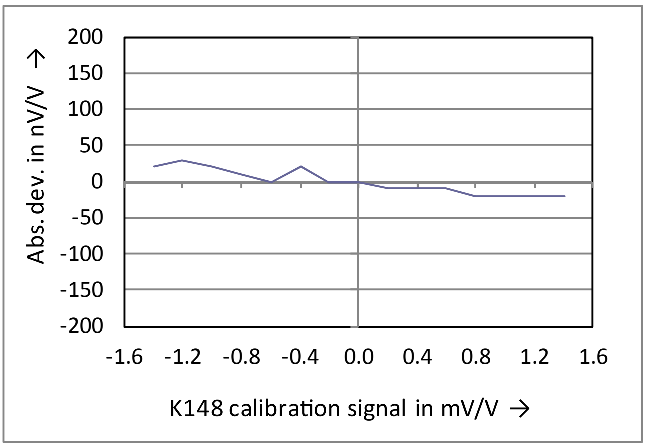

Figure 85: Absolute deviations of the signals of the amplifier used (MGCplus with ML38) from the calibration signals of the bridge standard K148, only one measurement

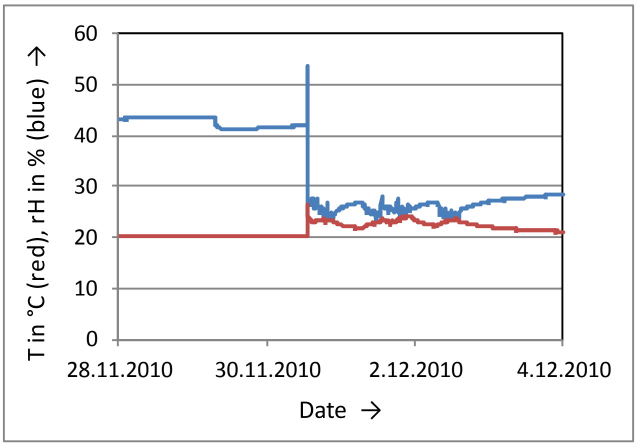

Figure 86: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

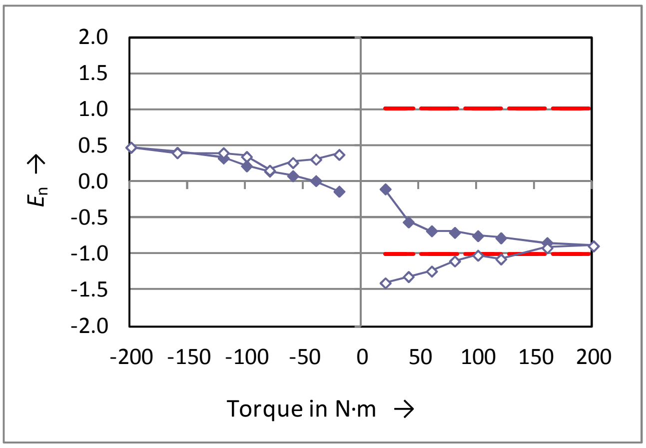

Figure 87: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

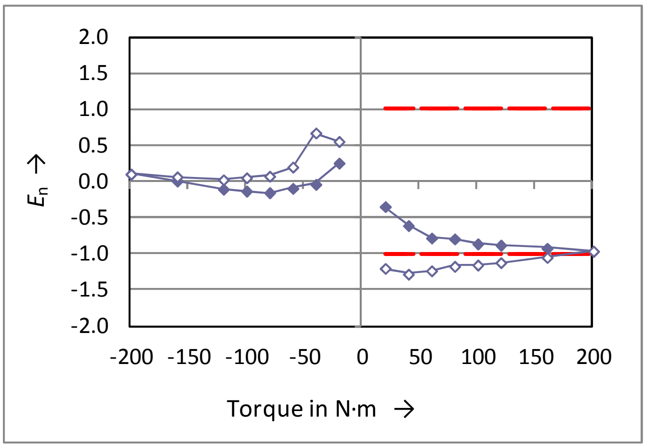

Figure 88: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

24801 – KDK (DAkkS No.: D-K-15180-01-00)

Type of measuring device: reference
Measurement axis: horizontal
Best measurement capability (k = 2): $2 \cdot 10^{-3}$

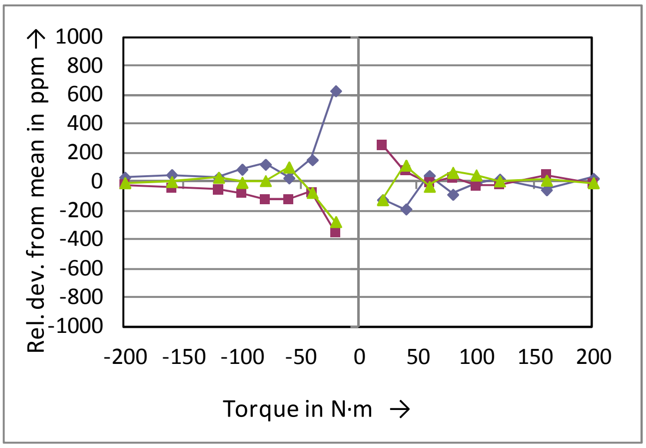

Figure 89: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

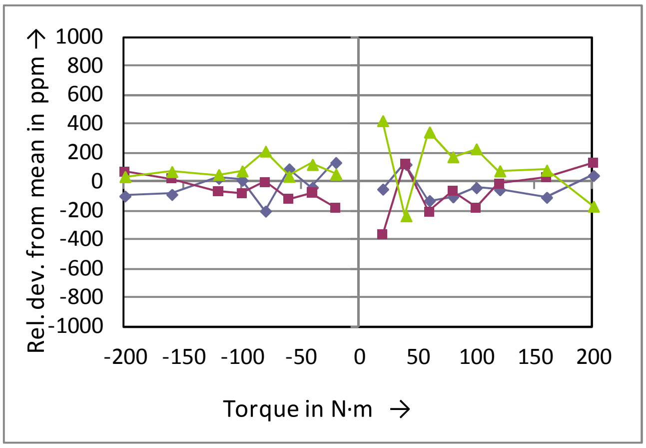

Figure 90: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

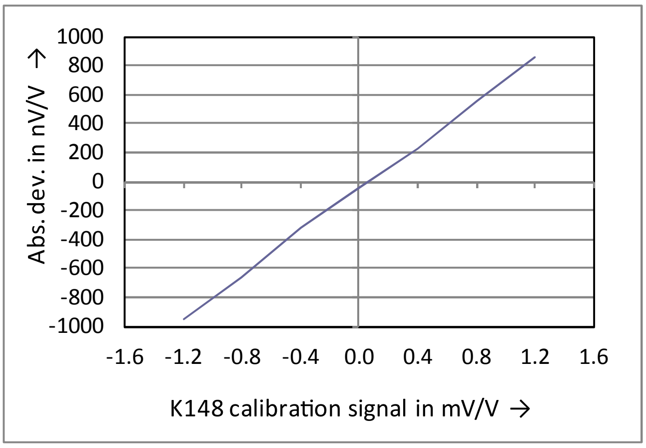

Figure 91: Absolute deviations of the signals of the amplifier used (NI 9237) from the calibration signals of the bridge standard K148, only one measurement

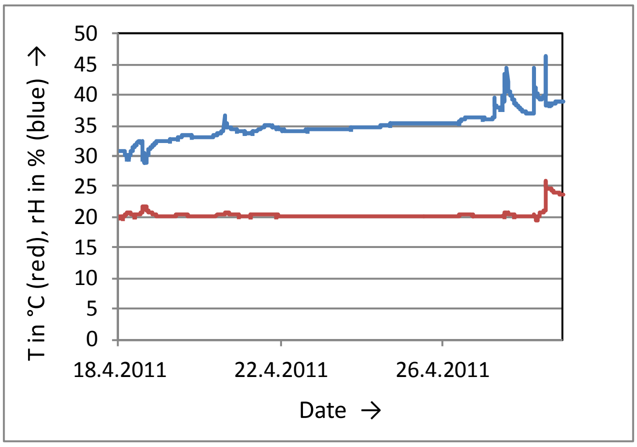

Figure 92: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

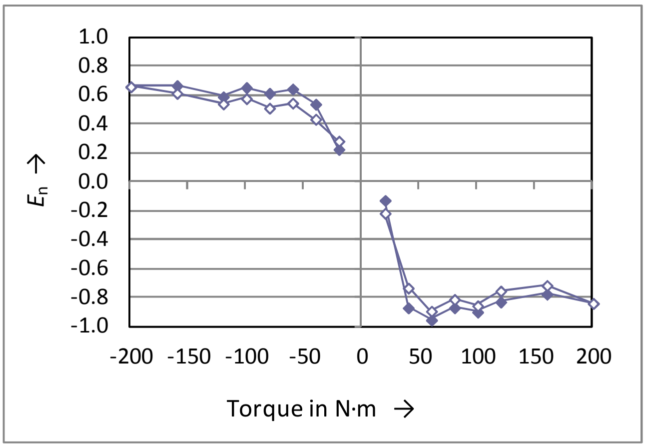

Figure 93: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

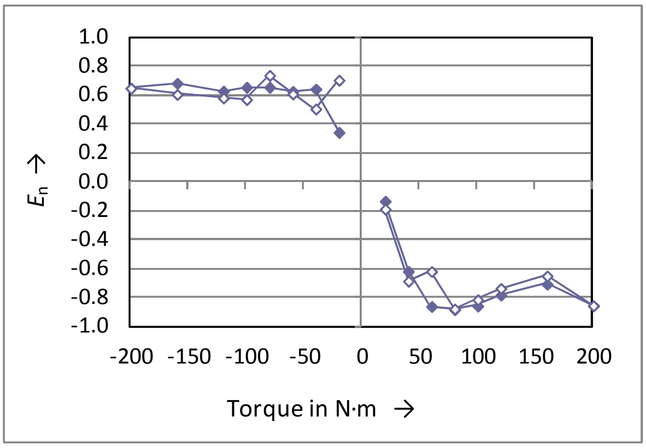

Figure 94: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

50601 – Q-direct (DAkkS No.: D-K-15001-01-00)

Type of measuring device: reference
Measurement axis: vertical
Best measurement capability (k = 2): $2 \cdot 10^{-3}$

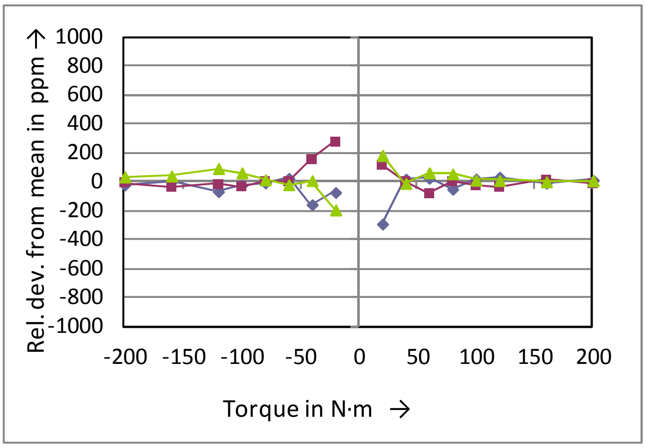

Figure 95: Relative deviations of the results of the three series of measurements of the TT1 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle)

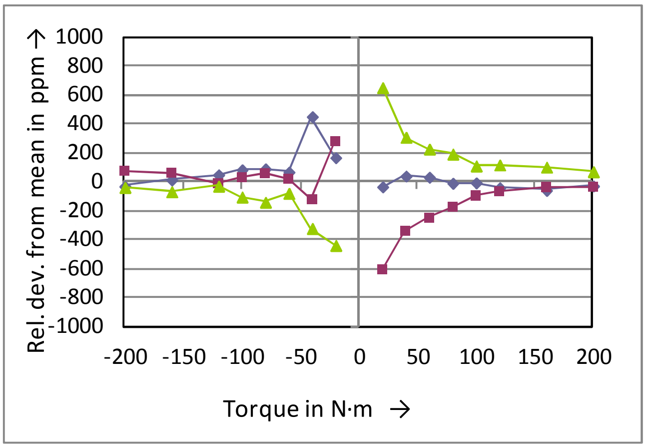

Figure 96: Relative deviations of the results of the three series of measurements of the TB2 transducer (only quantitatively increasing torque) related to their mean value (mounting positions: 1 – diamond, 2 – square, 3 – triangle

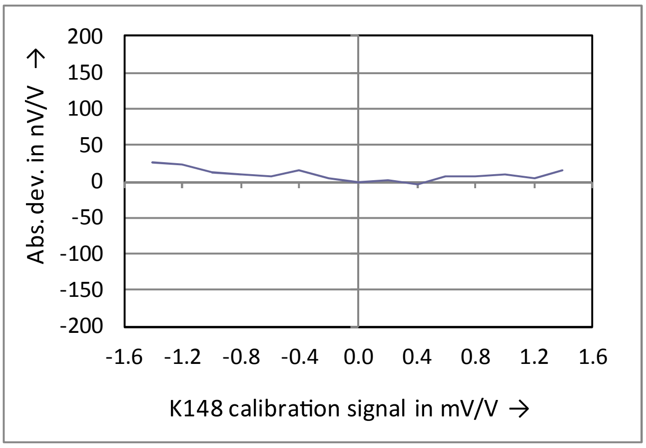

Figure 97: Absolute deviations of the signals of the amplifier used (MGCplus with ML38) from the calibration signals of the bridge standard K148, only one measurement

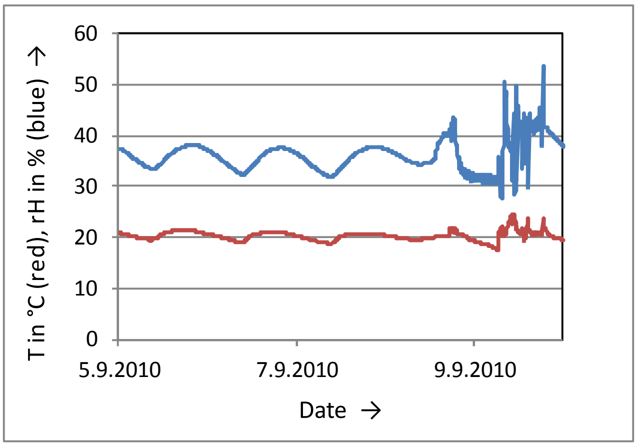

Figure 98: Temperature (red curve) and relative humidity (blue curve) before, during and after the measurements

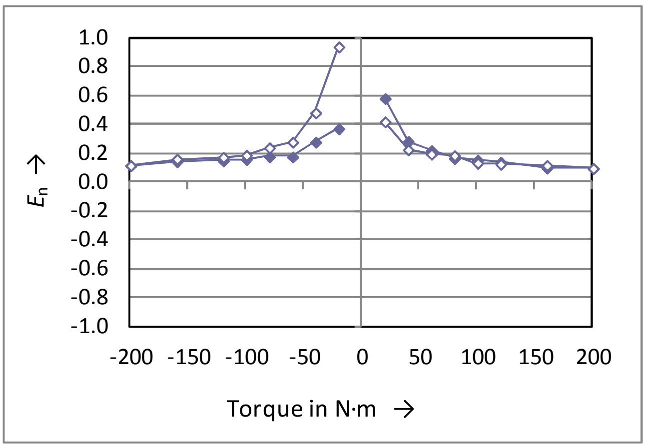

Figure 99: Calculated E_n factors for the measurement result of the TT1 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

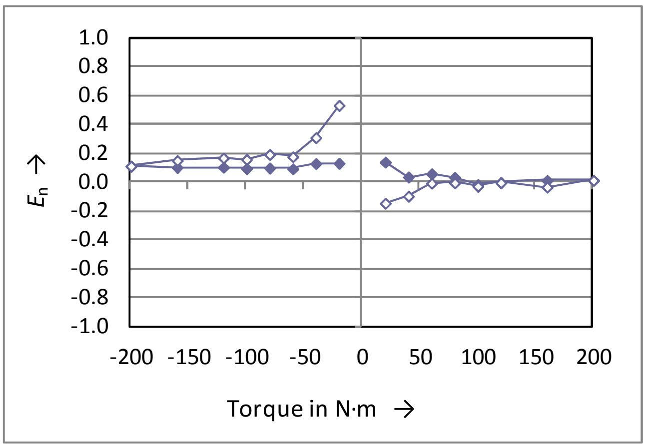

Figure 100: Calculated E_n factors for the measurement result of the TB2 transducer (filled symbol – increasing torque, blank symbol – decreasing torque)

Influence of bending moments and side forces on the transfer standards

Some of the participant's results suggest that, in one case or another, the alignment of the calibration device was not optimal. This seems to be particularly true for cases where the sensitivities strongly depend on the mounting positions as, for example, for the curves determined by means of the TB2 transducer in laboratory 09301. In order to be able to evaluate this influence, the combined bending moment-cross force dependence of the output signal of the transfer standards was measured in the laboratory *DrehmomentService Dr. Peschel*.

In a first measurement, both transducers were clamped horizontally and, while being unloaded, were rotated around the likewise horizontal axis. In doing so, the dead weight, which is different for both transducers, and which acts as cross force and additionally causes a bending moment, produces a measurement signal. The magnitude of the measurement signal depends, inter alia, on how well the torque measuring bridge is balanced against this influence. Ideally, there should be no signal change. However, Figures 101 and 102 show that such a signal variation occurs: the nominal signal-related relative changes from the mean value are represented, respectively. As can be seen, the effect is stronger in case of the TB2 transducer; here, it should be noted that the mass of the TB2 transducer with adapters is about four times as large as that of the TT1 transducer. The observed changes, however, are negligible in both cases.

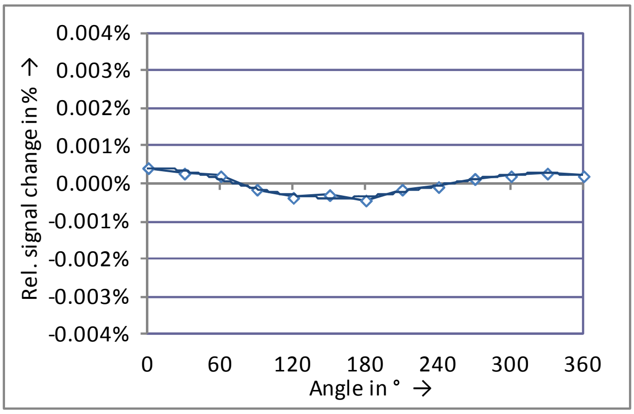

Figure 101: Relative change in the signal of the torque measuring bridge of the unloaded TT1 transducer, related to the nominal signal and during rotation around the horizontal measurement axis (symbols – measurement points, bold line – regression function)

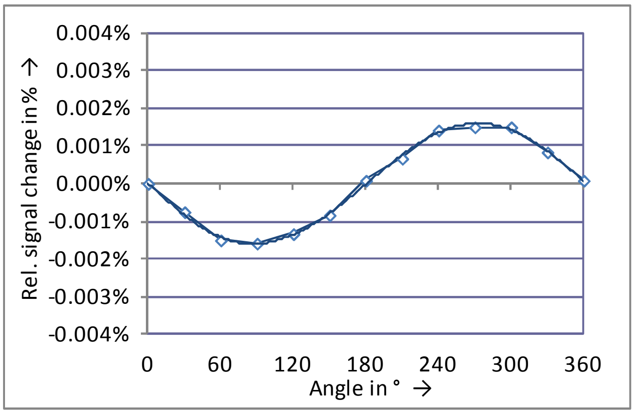

Figure 102: Relative change in the signal of the torque measuring bridge of the unloaded TB2 transducer, related to the nominal signal, during rotation around the horizontal measurement axis (symbols – measurement points, bold line – regression function)

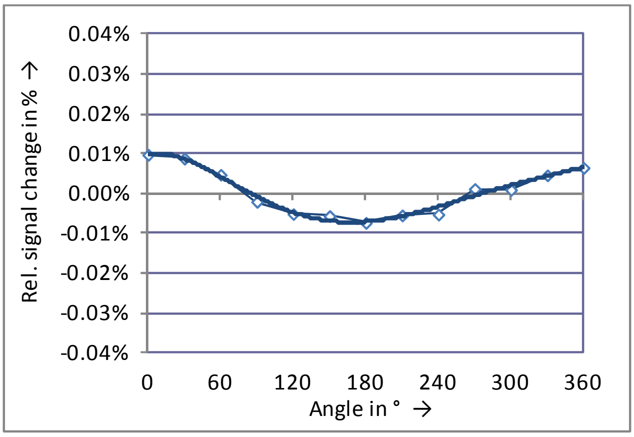

Figure 103: Relative change in the signal of the torque measuring bridge of the TT1 transducer with a transverse load of 102 N (corresponding to a bending moment of 11.2 N • m), related to the nominal signal and during rotation around the horizontal measurement axis (symbols – measurement points, bold line – regression function)

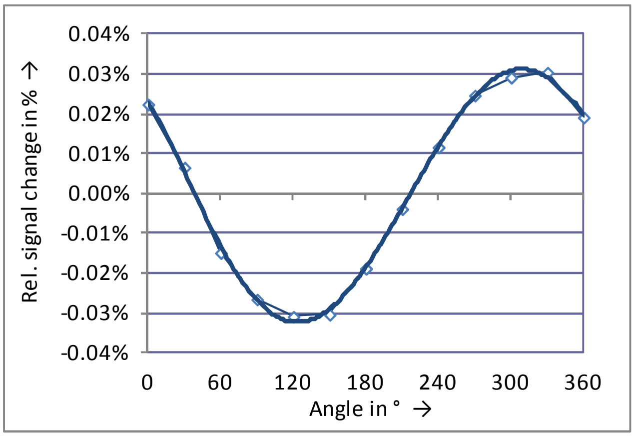

Figure 104: Relative change in the signal of the torque measuring bridge of the TB2 transducer with a transverse load of 158 N (corresponding to a bending moment of 18.2 N • m), related to the nominal signal and during rotation around the horizontal measurement axis (symbols – measurement points, bold line – regression function)

In a further measurement (Figures 103 and 104), a constant weight force of 102 N and 158 N was applied perpendicular to the measurement axis at a distance of 110 mm to 115 mm from the measuring bridge, and the output signal for different angular positions of the transducers in the range from 0° to 360° was recorded. In doing so, the very small effect of the dead weight shown in Figures 101 and 102 was corrected. The now different scaling of the ordinate axes is to be observed.

For the TT1 transducer, the distance between the force and the measuring point was about 110 mm. With a force of 102 N, a bending moment of 11.2 N·m was produced. In case of the TB2 transducer, the distance was approximately 115 mm, so that the application of a force of 158 N resulted in a bending moment of 18.2 N·m. The diagrams show that the influence on the TB2 transducer is visibly larger and cannot solely be explained by the greater cross force or the greater bending moment.

Unfortunately, these results cannot directly be used to explain the deviations detected in individual measurements. If the cross forces and bending moments (also axial forces are possible), which are generated by clamping the transducer in the calibration device, are kept constant during the measurement, it is not to be expected that they will change the sensitivity of the torque measuring bridge with respect to the torque. Such an effect of a change in the sensitivity of the measuring bridges by constant additional components has not yet been demonstrated (but cannot be ruled out either). Rather, it is likely that the additional components themselves were changed by the application of torque, thus causing cross-talk which, in turn, suggests a change in sensitivity. Here, further information can only be provided by a direct multicomponent measurement or a measurement of the deformation state during loading. Ideally, however, and by means of a good alignment and the use of flexible couplings, the auxiliary components acting on the calibrator should be sufficiently small.

Calibration certificates

Basically, the calibration certificates provided by the laboratories comply with the requirements. Until the end of the comparison, two of the participants had not submitted the duly completed calibration certificates.

In the **general structure** of the calibration certificates, there were minor differences regarding the

- complete denomination of the adaptations (7)
- designation of the calibration device (1)
- specifications concerning the measuring cables (3)
- specifications concerning the calibration conditions (3)
- specifications concerning the measuring amplifiers (1)
- specifications concerning the calibration item (1).

In two cases, the graphic representation of the results was missing; in another case, it did not make sense.
The distribution of the deviations among the participants was as follows: 00101: 1, 09301: not evaluated, 37801: 0, 37701: 1, 10401: 1, 41401: 1, 47801: 1, 49301: 2, 08001: 1, 19801: 3, 51101: 1, Porsche: 2, TÜV-AT: not evaluated, 50601: 1, 24801: 4.

All in all, it can be said that these are only minor deviations which can be avoided if appropriate care is taken. They do not call into question the validity of the calibration.

The reported **results** contained the following factual and formal deviations:

- result at 0 N·m in case II equal to 0 mV/V (1)
- partly, the indicated measurement uncertainties are smaller than the bmc value (2)
- minor variations in the calculated results and measurement uncertainties in the last decimal place (2)
- too many decimal places of the coefficients of the regression functions (3)

- minor deviations in the calculated characteristic values, inter alia sign errors (3)
- characteristic quantities: h = 0 mV/V at 100%, but was not measured (1)
- characteristic quantities: r with a wrong number of digits, a false value or missing unit (5)
- formal errors: unit in „[ ]“, variables are italicized, improper resolution of results
- diagrams: relative deviations cannot be determined at 0 N·m, the functions have no value at 0 N, and the curves do not pass through the origin of coordinates (1)
- diagrams: the complete third series of measurements is missing (1)
- diagrams: the measuring points should not be connected by a interpolation function of any sort (1)
- the certificates of four participants did not contain any charts.

The distribution of the deviations among the participants was as follows: 08001: 3, 10401: 3, 24801: 5, 37701: 4, 37801: 1, 49301: 8, 50601: 2, Porsche: 7, TÜVAT: 4.

It has to be taken into account that in calibration certificates which result from measurements in reference facilities, the reported raw values are usually fitted and tared values. A note to the reader concerning this fact would be helpful. Bilingual certificates should include a statement indicating which language is legally binding – for DAkkS certificates, it is the German language. It is sufficient, if the required statement is given in the second language. If the charts show linearity deviations, the linear reference value must be specified to ensure that the representations are comparable.

Many of these deviations have already been eliminated in the context of audits or assessments. However, the list shows that there are a number of possible errors, and it is only by systematic monitoring that the avoidance of errors can be ensured.

8. Evaluation of the interlaboratory comparison

In this interlaboratory comparison, the metrological performances of 13 laboratories accredited by the DKD or DAkkS, and two other laboratories not accredited in Germany, were compared to the torque laboratory of PTB. In general, it can be stated that the calculated E_n values range from -1 to 1. In the case of one participant (37801), a single value lies outside this range; for two laboratories (37701 and 10401) a total of three values are outside this range. Only two laboratories have several values that fall outside this interval (09301: only TB2; TÜV AT: TT1 and TB2). The last-mentioned laboratory used square drives, and thus the conditions did not quite meet the requirements of the interlaboratory comparison. Nevertheless, the measurement uncertainty was increased to $2 \cdot 10^{-3}$. It could not be clarified why the TB2 transducer in laboratory 09301 showed relatively large constant deviations while the TT1 transducer did not. It can be assumed that in this measurement the TB2 transducer reacted more sensitively to the slightly higher temperature or lower relative humidity. At a later point in time, a repeated measurement with the same TB2 transducer during an assessment of the laboratory, and under much better ambient conditions, showed a significantly better agreement with the measurement in the PTB.

As a result, it can be stated that this DKD interlaboratory comparison showed an excellent agreement of the measurement results of the 15 participants and can thus be considered a very good confirmation of compliance with the measurement uncertainties the laboratories are designated or accredited for. The notes regarding the result reports (calibration certificates) may help to detect possible causes of error in the creation of these certificates and to take the appropriate steps to avoid these errors.

References

[1] Röske, D.
Final report on the torque key comparison CCM.T-K1. Measurand torque: 0 N·m, 500 N·m, 1000 N·m, Metrologia: 46 (2009), Tech. Suppl., 07002 [Online only], 32 pages.
Link: http://dx.doi.org/10.1088/0026-1394/46/1A/07002