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ON THE STABILITY OF MEASURING DEVICES FOR TORQUE KEY COMPARISONS

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Abstract: Key comparisons are an important approach for the national metrological institutes to ensure that the units of the different physical, chemical and other quantities are realized and disseminated according to the stated uncertainties. In May 2005, the first world-wide CIPM torque key comparison (CCM.T-K1) has been started.
The main purpose of this paper is to compare the stability of the torque standard machine, the travelling standard (torque transfer standard) and the amplifier DMP40 of the pilot laboratory with the combination of the bridge standard BN100 and the same amplifier.

Keywords: torque measurement, stability, key comparison.

1. INTRODUCTION

In spring 2004, the Working group “Force” of the CIPM’s (Comité International des Poids et Mesures) Consultative Committee for Mass and Related Quantities (CCM) decided to carry out first world-wide key comparisons in the field of torque measurement. For the CCM.T-K1 key comparison the torque steps 500 N·m and 1000 N·m were agreed to compare dead-weight torque standard machines (tsm) with specified expanded ($k = 2$) relative uncertainties of measurement in the range of $1 \dots 4 \cdot 10^{-5}$ [1].

In order to get comparable results on the different torque standard machines of the participants it is of outmost importance to have stable torque measuring devices (torque transducers) as travelling standards. For the measurements carried out by the participants and the pilot laboratory a high-precision amplifier must be used. All participating laboratories use the same type of amplifier - the DMP40 produced by the German company Hottinger Baldwin Messtechnik GmbH (HBM). Instead of sending one particular DMP40 together with the travelling torque standard to the participants it was decided that every participant uses the laboratory’s own amplifier. A check of the deviations between the different amplifiers has to be carried out with a bridge standard BN100 produced by the same company. This bridge standard belongs to the travelling equipment [2]. It is expected that the BN100 is not sensitive to the influences of the transportation to the participants and back to the pilot laboratory.

The paper deals with the long-term stability of the different components of the measuring chain, mainly the travelling standard and the BN100. Unfortunately there is no “standard for the standard”, i.e. a measuring device (transducer, amplifier, bridge standard) which is more stable compared with the device used in the inter-comparison and which could be used for these investigations. Therefore, the idea is to carry out additional measurements each time when the travelling equipment is in the pilot laboratory and to get some statistical data and evidence for the stability of each of the components.

2. INVESTIGATION OF THE STABILITIES

The CCM.T-K1 key comparison is carried out with two torque transfer standards, one of type TT1 (solid cylinder, open housing) and the second of type TB2 (hollow cylinder, enclosed housing). Due to its hermetically enclosed housing the TB2 transducer is less sensitive to influences of the ambient conditions, especially caused by changes of the air humidity. On the other hand, the TT1 transducer output signal changes relatively by several 10^{-5} for a 10% change of the relative air humidity. In some laboratories it is not easy or even impossible to control the relative humidity of the ambient air with a sufficient accuracy. Therefore only the TB2 transducer is considered in the following.

2.1. Key comparison scheme

Figure 1 shows the principle scheme of the key comparison. According to this scheme the torque transfer standard is calibrated on the torque standard machine of the pilot laboratory with the same DMP40 after the measurement at each of the participants. In addition, this DMP40 is calibrated with the BN100 which was also used in the participating laboratory to calibrate the laboratory’s own DMP40. The BN100 itself was traced back to the national standard of the voltage ratio at PTB.

2.2. BN100 and mV/V scale

In the calibration certificate the value of the expanded ($k = 2$) uncertainty of measurement is specified as $10 \cdot 10^{-6}$ mV/V, not including a contribution coming from the long-term stability. On the other hand a standard uncertainty of $5 \cdot 10^{-6}$ mV/V corresponds to a relative uncertainty of $1 \cdot 10^{-5}$ related to a deflection (= reading at torque step minus reading at zero) of 0,5 mV/V, which is the value of the TB2 transducer at 500 N·m. This uncertainty is of the same order of magnitude as the uncertainties of the best machines to be compared. Fortunately, the stability of the devices is much better than the deviation from the absolute scale. Therefore the best way would be to relate all results not to the absolute scale of mV/V with the relatively high uncertainty, but to a scale defined by a stable measuring device, whether it will be a BN100 or a DMP40 or both. In the following it will be shown that the pilot's DMP40, the TB2 transducer and the 1 kN·m torque standard machine represent a sufficiently stable measuring chain. We expect that the DMP40s of the participants and the travelling TB2 and BN100 can ensure reliable results of the intercomparison.

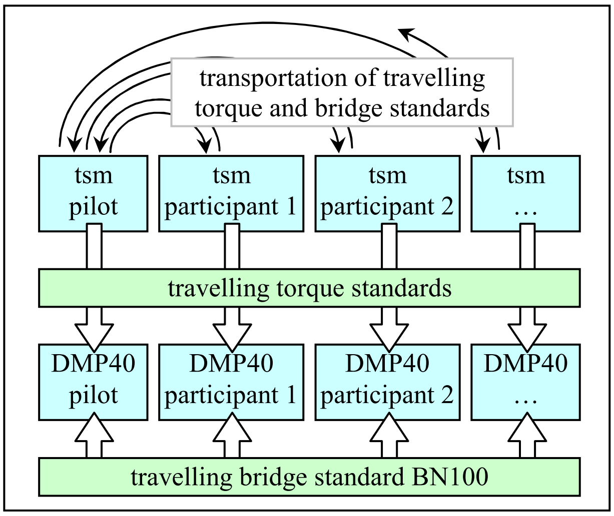

Fig. 1. Key comparison scheme (tsm = torque standard machine)

2.3. DMP40 and BN100

The pilot has made calibrations of the own DMP40 with the circulated BN100 over a time period of eleven months. Suitable calibration points were selected according to the signals of the travelling standards at the agreed torque steps. The results show, that the repeatability and, hence, the stability of the deviations over this time with transportation of the BN100 to six different countries in Asia and Europe is very good (see table 1, figures 2 and 3).

Table 1. Mean value and standard deviation of the deviations of the DMP40 calibrated with a BN100.

BN100: Nominal value in mV/V		Mean value of deviation in nV/V		Standard deviation of the deviations in nV/V	
-1,4	**1,4**	27	**21**	2	**1**
-1,3	**1,3**	25	**21**	2	**1**
-1,1	**1,1**	25	**23**	2	**1**
-1,0	**1,0**	24	**23**	2	**1**
-0,9	**0,9**	23	**24**	2	**1**
-0,7	**0,7**	25	**24**	1	**1**
-0,6	**0,6**	25	**24**	1	**1**
-0,5	**0,5**	26	**23**	1	**1**
-0,1	**0,1**	28	**21**	1	**1**
-0,0	**0,0**	25	**22**	1	**1**

Nevertheless, a difference between positive and negative voltage ratios can be seen in the figures 2 and 3. The spans for the negative ratios are larger than that for the positive. In fact, for 1 mV/V (the nominal signal of the TB2 at a torque of 1 kN·m) the span is 3 nV/V. For -1 mV/V (corresponding to a torque of -1 kN·m) this value is 7 nV/V with a maximum of 8 nV/V at -1,4 mV/V. The reason for this disagreement is unknown. It can be caused by the DMP40 or the BN100 or even both of them. A way to check this can be to include a second DMP40 (which will also be operated only in the lab and not transported to other participants) into the monitoring. An unstable BN100 should cause similar deviations on both DMPs whereas an unstable DMP40 should change only the calibration results of this single amplifier and not influence the other DMP.

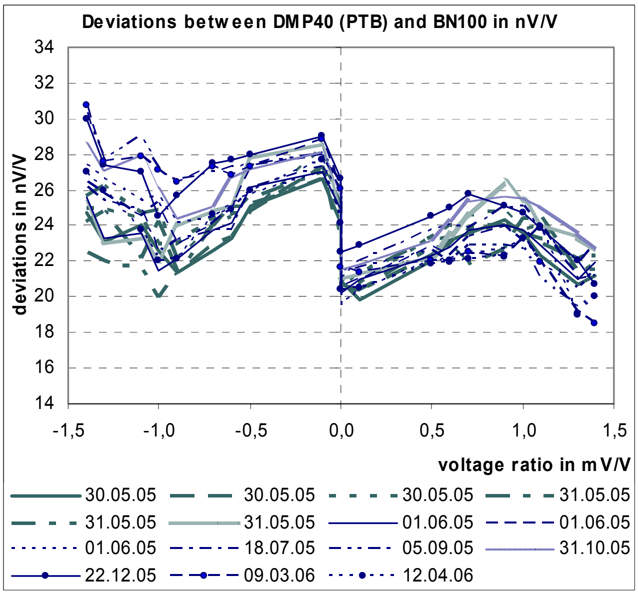

Fig. 2. Deviation in nV/V between the indication of the DMP40 and the nominal voltage ratio selected at the BN100 over eleven months (15 series)

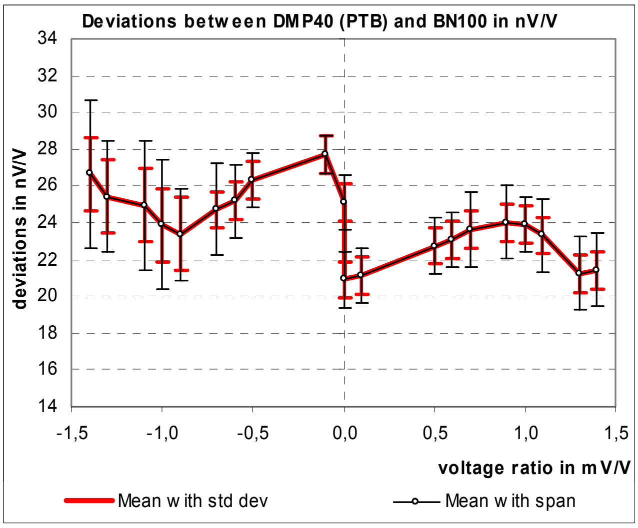

Fig. 3. Mean values of the 15 series from figure 2 with their spans and standard deviations

The figures 4 and 5 show the results for the second DMP40 (#2). It can be seen that the spans are smaller for the negative voltage ratios and are of the magnitude of that for the positive ratios. This seems to demonstrate that the BN100 is more stable than the first DMP40.

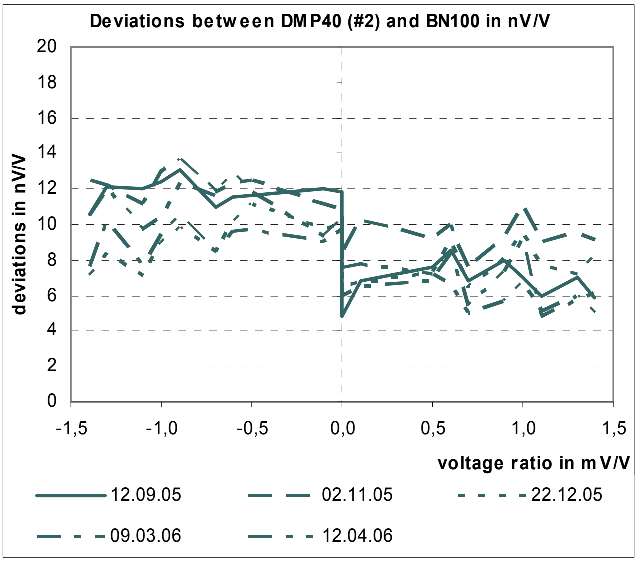

Fig. 4. Deviation in nV/V between the indication of the DMP40 (#2) and the nominal voltage ratio selected at the BN100 over seven months (5 series)

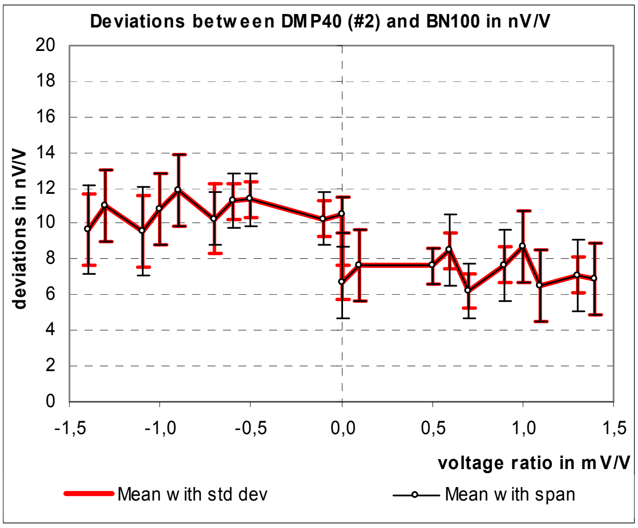

Fig. 5. Mean values of the 5 series from figure 4 with their spans and standard deviations

2.4. DMP40 and TB2 with applied torque

The repeated calibrations on the PTB's torque standard machine yielded also a very good long-term stability (see figures 6, 7, 9 and 10, deflection = zero-reduced signal, error bars show the expanded relative uncertainty mainly caused by the tsm). The maximum relative deviation from the mean of the seven deflections is $2.4 \cdot 10^{-6}$ for clockwise torque and $7 \cdot 10^{-6}$ for anticlockwise, such showing a better stability for the clockwise direction. The reason for this can be the above described slightly greater fluctuation of the indications of the DMP40 in the range of negative voltage ratios.

In figure 8 one of the results of the TT1 transducer is given for comparison. It corresponds to figure 7 for the TB2. It can be seen that the maximum relative deviations are more than four times higher compared with the TB2 even under very stable and defined conditions in the pilot laboratory.

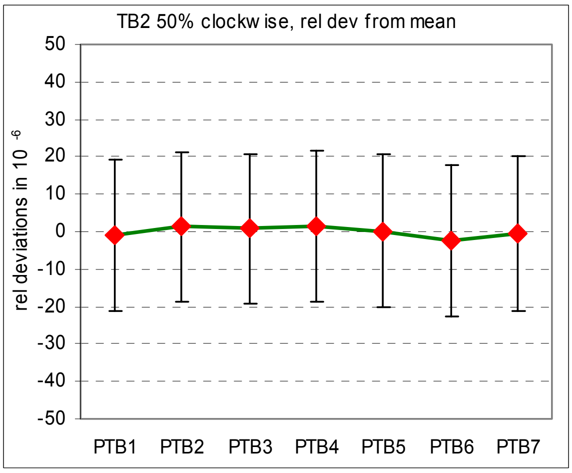

Fig. 6. Relative deviation in 10^{-6} of the deflections from their mean for the 500 N·m step (clockwise torque) in the PTB's 1 kN·m torque standard machine with the TB2 over eleven months

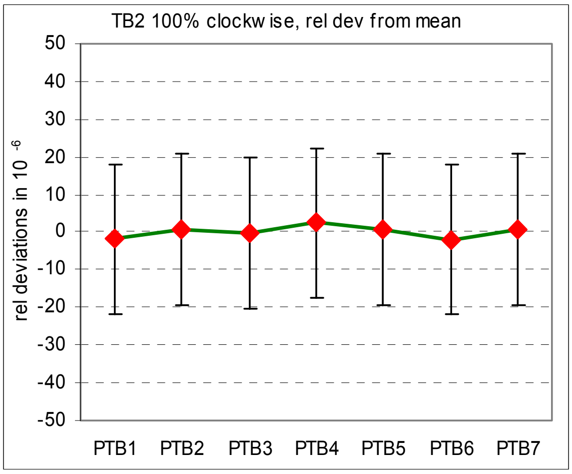

Fig. 7. Relative deviation in 10^{-6} of the deflections from their mean for the 1000 N·m step (clockwise torque) in the PTB's 1 kN·m torque standard machine with the TB2 over eleven months

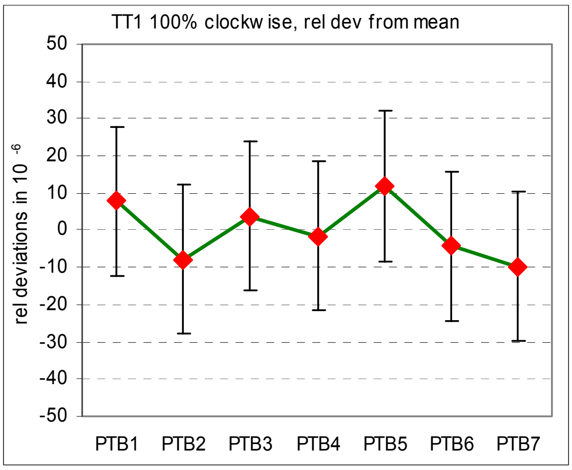

Fig. 8. Relative deviation in 10^{-6} of the deflections from their mean for the 1000 N·m step (clockwise torque) in the PTB's 1 kN·m torque standard machine with the TT1 over eleven months

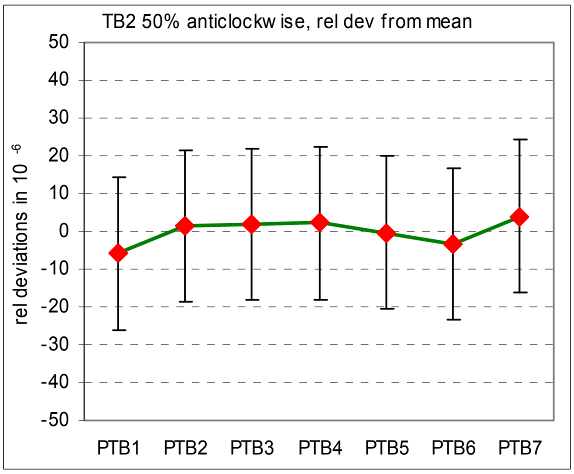

Fig. 9. Relative deviation in 10^{-6} of the deflections from their mean for the -500 N·m step (anticlockwise torque) in the PTB's 1 kN·m torque standard machine with the TB2 over eleven months

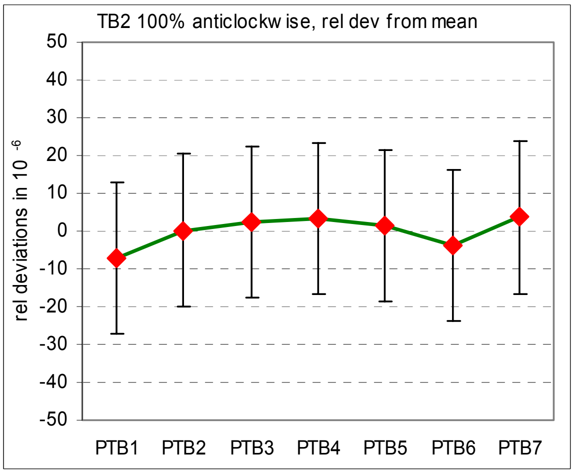

Fig. 10. Relative deviation in 10^{-6} of the deflections from their mean for the -1000 N·m step (anticlockwise torque) in the PTB's 1 kN·m torque standard machine with the TB2 over eleven months

A last diagram (see figure 11) shows the deviations of the zero-reduced signal of the TB2 in the different mounting positions in the 1 kN·m tsm of PTB from the overall mean found in the seven measuring series in the pilot laboratory over the period of eleven months. One could expect that the signals for each series show a dependency on the mounting position following a sine function. But this is not obvious from figure 11. One reason for not observing this sine function is the good alignment of the tsm and the very small parasitic components (reduced also by the flexible couplings used in the machine). Another reason is that the TB2 is very insensitive to parasitic components.

3. CONCLUSION

The results given in this paper show an excellent reproducibility of the torque generated in the 1 kN·m torque standard machine of the PTB and also an outstanding stability of the TB2 torque transfer standard used in this investigation. The absolute value of the torque was not

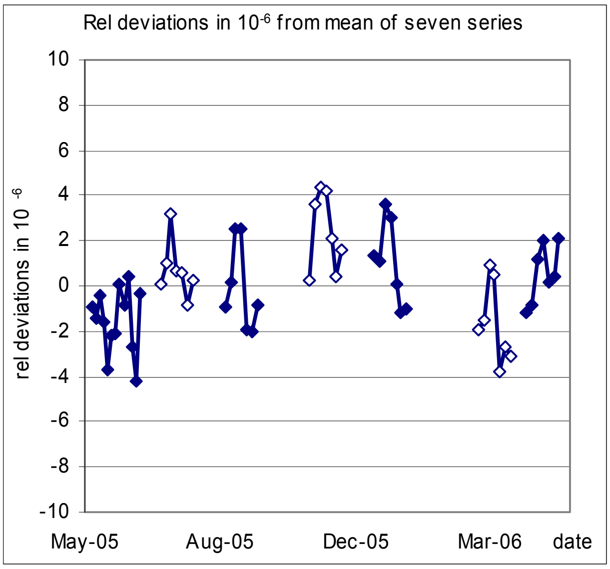

Fig. 11. Relative deviation in 10^{-6} of the deflections in the 7 x 60° mounting positions and the seven series from their mean for the 1000 N·m step (clockwise torque) in the PTB's 1 kN·m torque standard machine with the TB2 over eleven months

subject of this paper. It will be discussed in a special report on the key comparison.

Stable travelling standards are a very important prerequisite for the comparison of standard machines. The presented here investigations give reason to hope that good results of the first world-wide key comparison in the field of torque measurement can be achieved.

The results found in these investigations should also apply to key comparisons in force and pressure where the same technology and similar measuring devices are used.

ACKNOWLEDGMENTS

Our gratitude is for all colleagues in the participating laboratories for their patient work and co-operation.

We would like to dedicate this publication to our revered colleague Mr. Manfred Kreutzer, who was responsible for the development of precision amplifier technology at HBM for many years and who goes into retirement after 39 years of activity for this company. Mr. Kreutzer has contributed fundamentally to this field such ensuring that the results presented here got "measurable" at all.

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