UNCERTAINTY IN TORQUE CALIBRATION USING VERTICAL TORQUE AXIS ARRANGEMENT AND SYMMETRICAL TWO FORCE MEASUREMENT

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Abstract

Calibration machines up to a torque range of 20 kN·m need extensive design if the force is performed by dead weights. A machine based on two force reference standards and a vertical torque axis may serve to avoid these specific problems. The precision force transducers work at a lever arm of precision length. The test piece is mounted in vertical arrangement between a hydraulically operating rotary-actuator and the torque measuring system.
Such a calibration machine allows additionally performing easily continuous calibration.
Regarding an overall relative uncertainty not greater than $2 \cdot 10^{-4}$ there are some significant problems. The estimation of the uncertainty has been proved by comparative tests with the national torque standard by the PTB according to the guidelines EA-10/14 and EA-2/03.

Boundary conditions

The best measuring capability is given by a system with a lever-arm (beam) with direct effect of mass and the influence of gravity and earth-acceleration (Figure 1). To compare this type of calibration machine with the introduced type we will discuss the most important points:

SCHATZ Torque Primary Standard

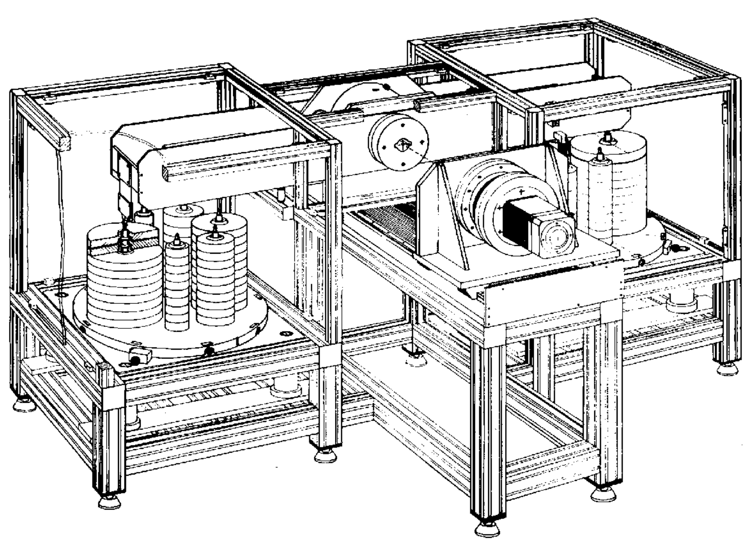

Figure 1: Principially Torque Primary Standard

- The turning point for the lever-arm (beam) is realized with an air-bearing to reduce the friction to a minimum value. The test measuring results carried out in the past 10 years gives a friction value of < $1 \cdot 10^{-7}$ (0.00001%). This type of calibration machine is called "supported beam". The measuring axis is horizontal.
- Every of the six measuring ranges are divided into ten disk-weights manipulated step by step like a chain. The uncertainty of the disk-weights is given by the German Gauge Office (Eichamt) within a tolerance of $\pm$ 0.0005 %.
- The point of coupling according to the length is corrected by the factor of gravity and earth-centrifugal force, the lift component of air and an ambient temperature of 21 $\pm$ 0.5 °C with a length of 1019.384 mm of both sides and an uncertainty of < 5 μm. For the force application to the lever a thin metal belt (foil) with a thickness of 20 μm is used.
- The gravity with the influence of the earth-centrifugal force is measured traceable to the German gravity network with a value of 9.8112401 $m \cdot s^{-2}$ with a tolerance of < $5 \cdot 10^{-8}$ $m \cdot s^{-2}$. The time-variation of the gravity as a result of influence of the gravity of sun and moon is about $3 \cdot 10^{-7}$ $m \cdot s^{-2}$.
- In the measuring range between 1 N·m and 1000 N·m, all significant torque values can be realized with the torque values being constantly increased or decreased. This is achieved by selecting different mass echelons for clockwise torque and counterclockwise torque. When both loading systems are used at the same time, the respective actual torque results from the difference between clockwise and counterclockwise torque.

To build such a type of calibration device up to a torque of 20 kN·m need an extensive and very expensive design concerning the air-bearing and the dead weights.
The other idea is to build a machine based on two force reference standards and a vertical torque axis may serve to avoid these specific problems (Figure 2).

1 Precision tension force transducers
2 Lever-arm of precision length
3 Test piece (for instance torque reference transducer)
4 Adaptation
5 Hydraulically operated rotary-actuator
6 Oil-hydraulic pump
7 Directional setting valve

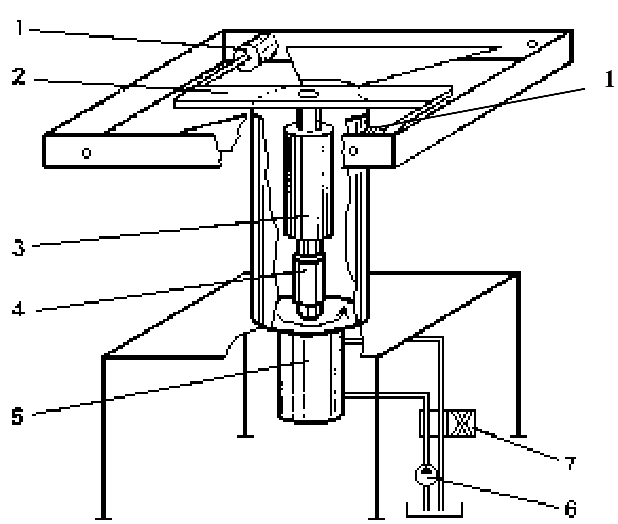

Figure 2: Simplified function-diagram of the 20 kN·m-calibration device

A pair of precision force transducers is fixed to the frame and work at both ends of a lever-arm of precision length. For the force application to the lever a thin metal belt is used. The test piece is

mounted in vertical arrangement between a hydraulically operating rotary-actuator and the lever-arm. This rotary-actuator generates torque up to 20 kN·m with an oil pressure up to 21 MPa and a rotating angle up to ±45°. The transducer under test with the lever-arm and the coupled force transducer give a virtual point of torque axis. That causes no bearing is necessary. This system is called “unsupported beam”.
Such a calibration machine allows additionally performing easily continuous calibration for shorter and simplified testing times.

Possibilities and influence analysis of errors

- The most important detail is the stability of the frame to minimize twist or torsion. To reduce bending moments and side forces an exactly adjustment of the pair of force is required for a symmetrical load to the frame and to produce a precise virtually axis of torque.
- Misalignment by concrete behaviour of the transducer is connected with missing gradation of freedom.
- Geometrical uncertainty in the setting of structural precision e.g. the introduction of the force is not parallel and not vertical to the torque axis.
- The thin metal belt for the introduction of force is not close fitting to the end of the lever. That causes an uncertain tangential introduction of force to the lever.
- The axial introduction of force to the force standard transducers may be not ideal.
- An additional uncertainty contribution arises from axially moving the actuator. With increasing torque the results can be influenced by the superposed bending.
- Reading errors caused by polling problems of the measuring amplifier, in the case of a 2-channel measuring system, for example DMP40, the measuring of the third channel is possible only by multiplexing the channels. This causes errors in case of fast pass through of measurement, especially by using continuous calibration.

Results of comparison measurements

In the last 2 years there have been measurements within international comparison. The results have been compared with the measurements performed in the calibration laboratory of SCHATZ.
Especially within the test measurements the possible faults mentioned in the section “possibilities and influence analysis of errors” have been erased consciously to determine their influence on the measuring results.
The results showed relatively high fault shares especially in the lower sections of the corresponding measuring ranges. Especially high non-systematic faults appeared during fast changing of measuring values as common at the continuous calibration.

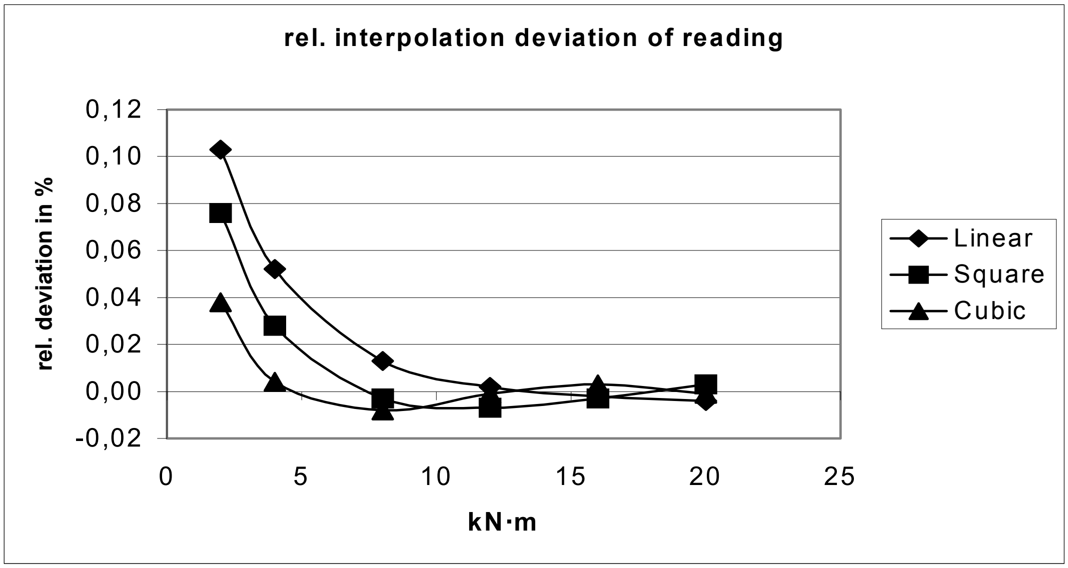

Figure 3: Typically calibration result of a 20 kN·m torque transfer standard transducer with an expanded uncertainty of about 0.01%. The calibration procedure is according to the guideline EA-10/14.

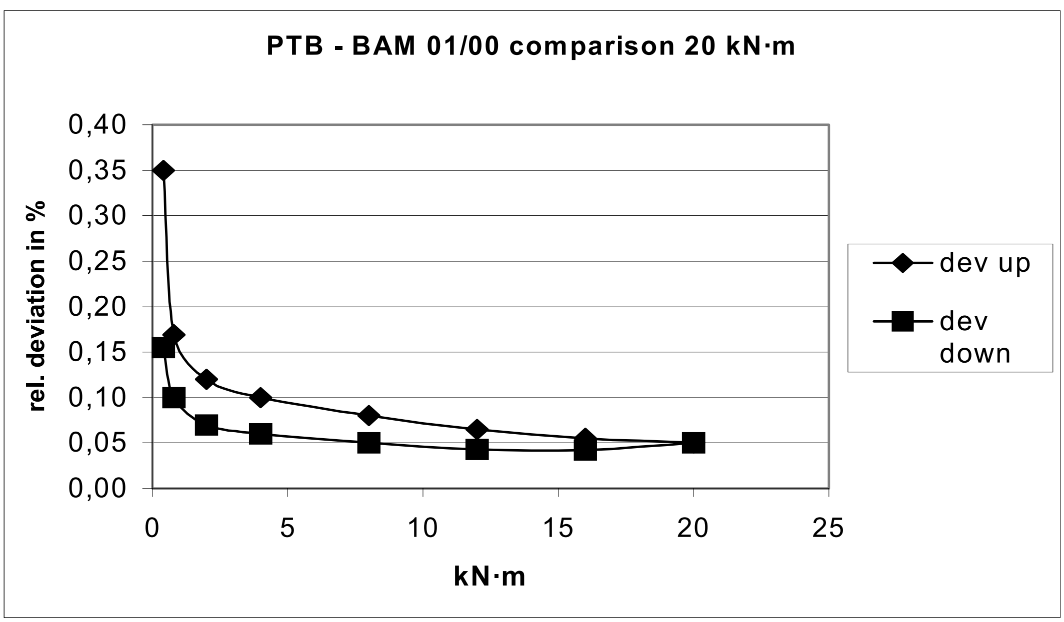

Figure 4: Result of the comparison to the national torque standard at the PTB.

The mathematical formulas to the calculation of compares the uncertainty are according to the paper “Uncertainty Scope of the Force Calibration Machines”, A. Sawla [4]:

$$M_{TCM} = M_{RefTra} * (1 - \Delta_{Drift\_RefTra}) * (1 - c_{\vartheta}) * (1 - \Delta_{Connect}) \quad (1)$$

$$= M_{RefTra} * (1 - \Delta_{Drift\_RefTra}) * (1 - c_{\vartheta}) * (2 - [M_{mid,TCM} * (1 - \Delta_{RelDev}) * (1 - \Delta_{HysTCM}) / M_{mid,TCM}] - \Delta_{Drift\_TranTra} - \Delta_{Realization} \quad (2)$$

Reduction of parasitic influences for lower uncertainty

As before reported the estimated uncertainty in calibration of torque sensors is given. The sources of the uncertainty shall be discussed with regard to the method of reduction and to improve the design to reduce bending and bending moments and the reading errors.

The reduction of bending moments is possible by using coupling elements which are highly flexible for bending but very stiff for torsion e.g. flexible coupling in exchange for the adaptation (Fig. 2 index 4). This solution is comprehensive discussed in [3].
To supervise the centre of the torque axis a measuring system shall be used.
Additional the forces must be applied in such a way that the high precision of the lever length is preserved during the complete test. The close fitting of the thin metal belt shall be guarantee by using a pair of clamping springs.
To reduce the reading errors caused by polling problems of the measuring amplifier DMP40 an exchange to a system with three measuring channels with absolute synchronically data acquisition e.g. MGCplus with three ML38 is necessary. This system allows in combination with qualified software a continuous data acquisition including online-interpolation.

On the other hand the design of the calibration machine makes it possible to investigate the effect of superposed bending on the torque sensor using a dead weight on the lever-arm. The test results can be used for correcting the calibration results.

General estimation

Experiments with the introduced calibration device have shown, that in case of using appropriate force transducers, flexible coupling with hydraulic clampings and a three-channel synchronically working electronic precision data acquisition system, a calibration device with a measuring range from 500 N·m up to 20 kN·m only has to be equipped with 6 pairs of force reference transducers to reach an expanded relative uncertainty of $U < 5 \cdot 10^{-4}$.

If you compare prices for calibration devices you will see that prices for calibration systems working with the "continuous comparison method" are much lower than for systems working with "absolute calibration".

If this calibration method is chosen one should consider, that it is much more appropriate for most torque measuring instruments as the step-by-step method regarding the practical application.

Supported by special software - including interfaces for suitable data recording systems - it is also possible to include calibrations of measuring chains.
In some special cases it might be impossible to embed the transducer to be tested into the automated data determination process. Then it is also possible to do a step-by-step calibration if the control of the drive system is prepared correspondingly.

Conclusions

The consideration to do a calibration following the comparison method at this machine makes possible an optimized procedure regarding time together with a most favorable load procedure concerning the application. This procedure also offers a load process which can be varied in wide scopes. Thus even exotic measuring ranges of transducers can be calibrated without problems because discrete steps are not necessary for the calibration. The ranges of steps can be edited easily via software.

The described procedure should be used and offers not only high cost savings but also precise measuring results together with a fully automated procedure.

References

[1] Kenzler, D.: "Application of the Continuous Calibration Procedure for Industrial Standard Calibration of Torque- and Force-Transducers"; IMEKO TC3 1998, Taejon, Korea
[2] Oblasser, J.: "BAM entwickelt Drehmoment-Kalibrierstand ", Materialprüfung 32 (1990) 3,47
[3] Brüge, A., Peschel, D., Röske, D.: „The influence of misalignment on torque transducers"; IMEKO 2001, Vol. 3, Paper 25
[4] Sawla, A.: "Uncertainty Scope of the Force Calibration Machines", IMEKO 2000

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