INVESTIGATIONS ON TRANSDUCERS FOR TRANSFER OR REFERENCE IN CONTINUOUS TORQUE CALIBRATION

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ABSTRACT

The highest level of torque calibration is achieved by direct loading and, due to the use of mass stacks, is associated with the step-by-step method.
In order to fit the demand of applications especially in industry, calibration devices with the ability of performing continuous loading were developed which are working as reference machines.

A benefit of continuous methods is that the time for a loading-unloading cycle can be ten times or more shorter than using the step method. This fast change in torque leads to conditions of use that cannot be represented in the national torque standards. Therefore the appointed reference- and transfer-transducers should have negligible sensitivity to fast loading effects. With such transducers the results of slow absolute calibrations in the national torque standards are valid also in the fast continuous-working machines.

In Germany a guideline treating this problems of continuous calibration is in preparation at a working group of the German Calibration Service (DKD). In this guideline special qualification-tests are proposed which can be performed in existing direct loading machines and which can deliver information about the suitability of transducers as reference or transfer for continuous working machines.

In this paper we describe these qualification-tests, discuss the results of the tests in comparison to the behaviour of the tested transducers in continuous measurements and recommendations for the selection of transducers for continuous use are given.

1 INTRODUCTION

The DKD guideline DKD-R 3-9 was created to support the endeavours of laboratories, which are developing continuous calibration facilities for force and torque in the uncertainty range of 0.1%. Because continuous methods are quite new in the field of force and torque, only few experiences exist. Therefore the guideline includes recommendations for the selection of transducers intended for transfer or reference. The proposed qualification test ST3-9 (Step Test 3-9) was designed as a qualifying examination for the transducers concerned. In this function it also should provide traceablility for continuously used reference transducers, since continuous loading sequences are not possible with the existing standard calibration machines.
For the field of torque we examined, if the test is possible and sensible with our 1-kN·m standard calibration machine, if the results are significant and if there are alternatives to the ST3-9 and we tested in how far the results of the direct loading machine relate to the behaviour of the transducers in a continuously working machine.

2 TRANSDUCERS

Five transducers of three manufacturers were used in the measurements. Four of them with a nominal value of 50 N·m and one (R43) with 100 N·m, used in the 50 N·m sub-range. The transducers R34 and R35 are of the same type.

Former investigations showed, that the creep coefficients of the transducers have high influence to their behaviour during continuous loading [1]. In Table 1 the results of unloading creep measurements are given, calculated with (1) and (2), were S is the signal of the transducer as a function of time, S_{100} the signal with 100% load, t the time after removing completely the load, $S(0)$ the signal at t=0, b_1 and b_2 are the creep coefficients, c_1 and c_2 the relative creep coefficients and τ_1 and τ_2 the time constants of two exponential functions.

$$S(t) = S(0) + b_1\left(1 - e^{-\frac{t}{\tau_1}}\right) + b_2\left(1 - e^{-\frac{t}{\tau_2}}\right) \qquad (1)$$

$$c_n = \frac{b_n}{S_{100}}, \quad n = 1, 2 \qquad (2)$$

Tab. 1: Creep coefficients

transducer	S_{100} in mV/V	c_1	τ_1 in s	c_2	τ_2 in s
R35	1.313752	7.3E-6	36	-3.6E-5	499
R34	1.340315	-5.9E-5	37	-3.7E-5	499
R43	0.668078	-1.0E-4	30	-9.7E-5	500
G12	2.200887	4.6E-5	36	3.8E-5	499
H03	1.563658	-8.4E-5	45	-1.3E-4	598

Each transducer creeping is a combination of a fast component with a time constant of about 40 seconds and a slow component of about 500 seconds. A remarkable fact is, that transducer R35 has not only both component with small amplitudes, but also different signs. The short term creep and the long term creep are compensating in the first seconds. This yields a very flat beginning of the creep curve for this transducer.

3 QUALIFICATION TEST ST3-9

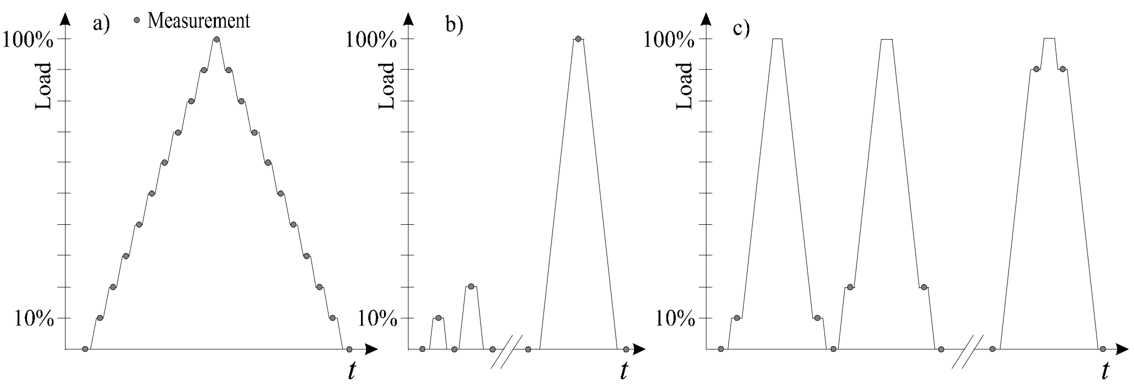

Fig. 1: Qualification test ST3-9. a: step calibration as reference, b: step-test for sensitivity, c: step-test for hysteresis.

In order to determine the influence of loading time to the sensitivity, a series of increasing steps of the standard calibration machine was proposed, each beginning and ending with 0% load (Fig. 1b). The sequence for testing the dependence of the hysteresis on the loading time is a series like in Fig. 1b, but each with an interstation at 100% load (Fig. 1c).

Sensitivity and hysteresis results of the step-tests are compared with the results of a stepwise calibration according to DIN 51309 [2] (Fig. 1a). Initial preloads are not illustrated in the figures.
To obtain great effects, the step-test should be performed as fast as possible. In the calibration machine used the time for loading the masses t_R ranges from 7 s for a 10%-step to 25 s for 100%. After loading the masses, the time t_W = 5 s is needed to readjust the lever and for settling vibrations. For the step calibration the time need is $t_R + t_W$=25 s per step.

Because of the low difference between the time regimes of step-tests and the stepwise calibration, the results show no significant influence of creeping parameters on sensitivity and hysteresis. Another difficulty are the ST3-9 sequences performing different loads in one series. With this, the start point of every step is influenced by the unloading creep of the previous step, which is not only a function of waiting time after unloading $t_{W,unload}$, but also of the amount of load in the last step. To avoid this effect, $t_{W,unload}$ should be in the range of c_2 of the transducer. That means a time interval between two steps of about 10 minutes and a time need for the three parts of ST3-9 of about 4 hours per transducer.

4 QUALIFICATION TEST ST-PTB

Because of these difficulties we designed a test – called ST-PTB - that fits the conditions and possibilities of our standard calibration machine in a better way (Fig. 2).

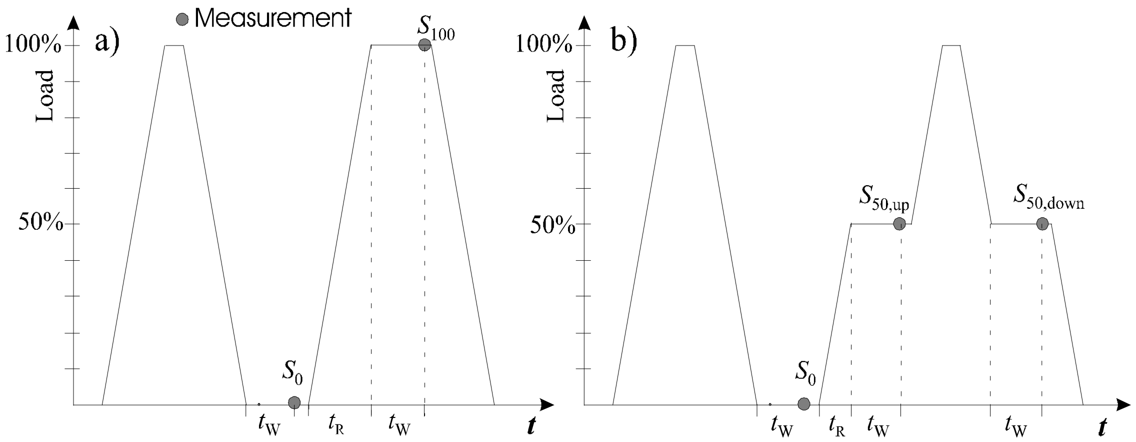

Fig. 2: Qualification test ST-PTB. a: step-test for sensitivity, b: step-test for hysteresis.

The test consists of steps from 0% up to 100% and, after a waiting time t_W, back to 0%. Before each step there is a 100%-preloading with subsequent waiting time $t_{W,unload}$= t_W. Analogically the test for hysteresis consists of 100%-preloadings and steps up to 50% with interstation at 100% and waiting time before and after the interstation. Varying t_W from 300 s to 5 s, we obtain relative deviations in sensitivity ΔS_{rel} at 100% load and hysteresis ΔH_{rel} at 50% load as follows:

$$\Delta S_{100,\mathrm{rel}}(t) = \frac{(S_{100}(t) - S_0(t)) - (S_{100}(325s) - S_0(325s))}{S_{100}(325s) - S_0(325s)} \quad (3)$$

$$\Delta H_{50,\mathrm{rel}}(t) = \frac{(S_{50,\mathrm{down}}(t) - S_{50,\mathrm{up}}(t)) - (S_{50,\mathrm{down}}(325s) - S_{50,\mathrm{up}}(325s))}{S_{100}(325s) - S_0(325s)} \quad , t=t_R+t_W \quad (4).$$

As shown in Fig. 3, this test procedure leads to relative deviations of sensitivity, which are increasing with decreasing loading time and which are increasing with increasing creep coefficients (Tab. 1). The results for ΔS_{rel} at 50% are within the uncertainty of the calibration standard machine identical to the results at 100%. The relative deviations of hysteresis (Fig. 4) are also dependent on the loading time, but the influence of creep coefficients is not very clear. The deviations due to different load velocities are for both sensitivity and hysteresis within the amount of summarised creep coefficients (Tab. 2). The dependence of sensitivity and hysteresis on the loading time follows the theoretical expectance that was discussed in [1].

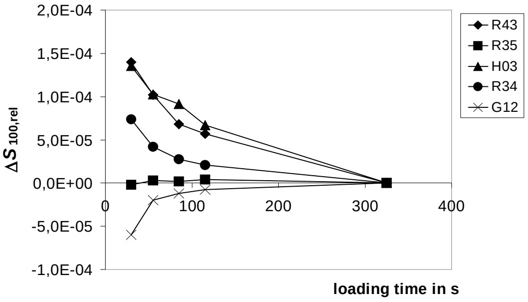

Fig. 3: Deviations of sensitivity due to different loading times during test ST-PTB

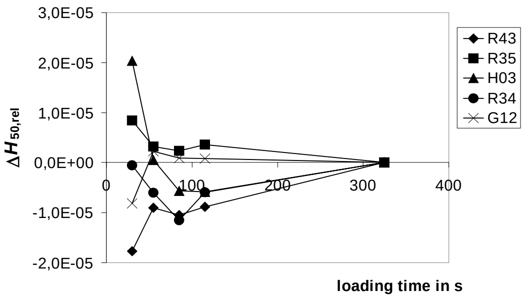

Fig. 4: Deviations of hysteresis due to different loading times during test ST-PTB

5 CONTINUOUS MEASUREMENTS

The continuous measurements were performed with a reference calibration machine driven by motor and gear box. The best qualified transducer among the tested is R35 with deviations of sensitivity and hysteresis at the resolution limit of the PTB's torque standard machine. Therefore we selected this as reference during the continuous calibrations. All continuous measurements at the reference calibration machine are relative to this transducer. Corresponding to the test ST-PTB, continuous measurements were taken with different loading times and the response curves of the tested transducer were calculated as described in a former paper [3]. From this curves, sensitivity and hysteresis were taken analogically to the direct loading.

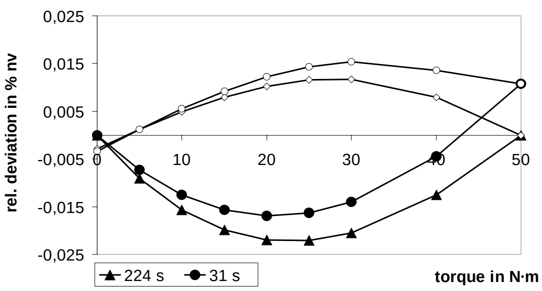

Fig. 5: Continuous calibration of transducer G12. Relative deviation of signals from a linear interpolation, regular characteristic curves.

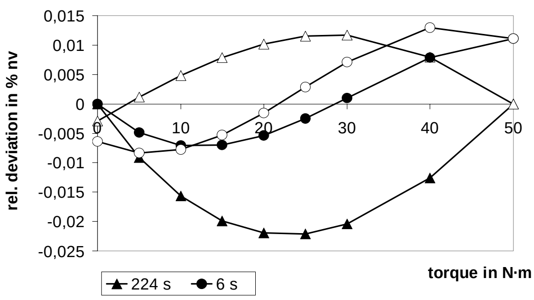

Fig. 6: Continuous calibration of transducer G12. Relative deviation of signals from a linear interpolation, deformed characteristic curve for t=6 s.

The differences between the continuous and the stepwise derived results are within $5 \cdot 10^{-5}$ if the loading time is higher than 50 seconds. Faster loadings lead not only to higher deviations due to the creep effect, but also to dynamical deformations of the calculated response curves (Fig. 5 and Fig. 6). These deformations are not caused by interpolation errors, because interpolations with higher degrees than the commonly used cubic ones deliver no decrease of the residual sum. Moreover the deformations were mainly observed at transducers with higher creep coefficients.

Even if mistakes in the calculation seem to be excluded, the effect is not understood and needs more investigations. Nevertheless for transducers with a creep smaller than $1\cdot10^{-4}$ the relative deviations in sensitivity an hysteresis between direct loading and continuous loading are smaller than $5\cdot10^{-5}$ in the treated range of loading time (Fig. 7 to Fig. 10).
All deviations discussed so far are relative to a slow measurement at the same calibration machine. But also the direct comparison between torque standard machine and continuously working reference machine gives very good consistence (Tab. 2). The differences between the two machines are within $1\cdot10^{-4}$ for t>50 s. This is within the best measurement capability of the reference machine for stepwise calibration of $2\cdot10^{-4}$.

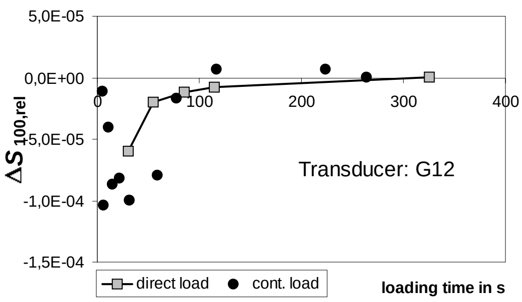

Fig. 7: Rel. deviations of sensitivity in dependence on loading time of the transducer G12. Direct loading compared with contiuous loading.

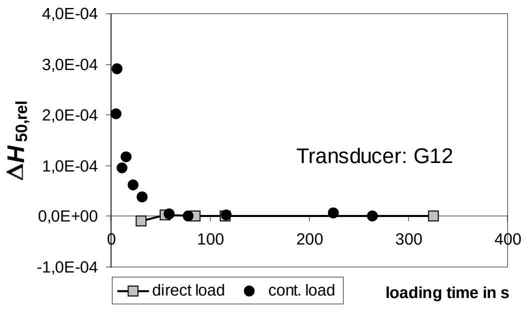

Fig. 8: Rel. deviations of hysteresis in dependence on loading time of the transducer G12. Direct loading compared with contiuous loading

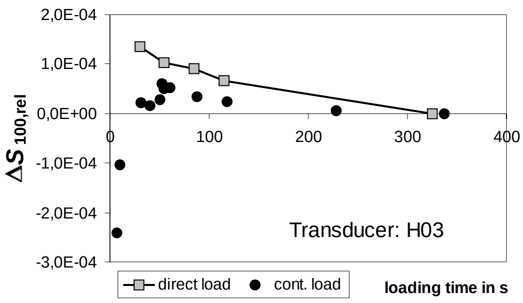

Fig. 9: Rel. deviations of sensitivity in dependence on loading time of the transducer H03. Direct loading compared with contiuous loading.

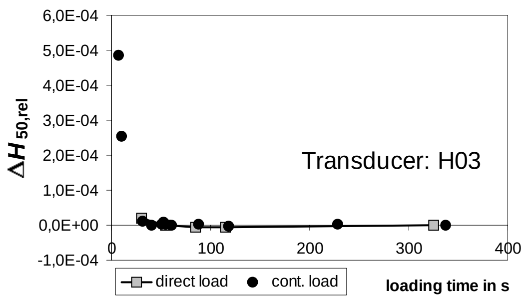

Fig. 10: Rel. deviations of hysteresis in dependence on loading time of the transducer H03. Direct loading compared with contiuous loading

Tab.2: Measurement results

transducer	c_1+c_2	c(3 min)	c(20 min)	$\Delta S_{100,rel}$(30 s), direct load	$\Delta H_{50,rel}$, direct load	rel. dev. S_{cont}-S_{abs}(300 s)
R35	-2.9E-5	-3.4E-6	-2.9E-5	-2.1E-6	2.4E-6	no data
R34	-9.6E-5	-6.9E-5	-9.3E-5	7.4E-5	-1.2E-5	1.6E-5
R43	-2.0E-4	-1.4E-4	-1.9E-4	1.4E-4	-1.8E-5	-5.6E-5
G12	8.4E-5	5.8E-5	7.9E-5	-6.0E-5	-8.1E-6	-3.9E-5
H03	-2.1E-4	-1.2E-4	-1.9E-4	1.4E-4	2.0E-5	1.0E-5

The table 2 gives an overview to the results. For each transducer the creep sum (c_1+c_2), the creep value after 3 minutes (c(3 min)), the creep value after 20 minutes (c(20 min)), the relative deviation of sensitivity at 100% load for a loading time of 30 s at the standard calibration machine ($\Delta S_{100,rel}$(30 s)), the maximum of relative deviation of hysteresis at 50% load at the standard calibration machine ($\Delta H_{50,rel}$) and the relative deviation of the sensitivity at a loading time of 300 s at the continuous calibration machine referred to the same calibration at the standard calibration machine (S_{cont}-S_{abs}(300 s)) is given. Because the transducer R35 was used as reference in the continuous measurement, there is no data in the last column for this transducer.

6 CONCLUSIONS

The qualification test ST3-9 is not adequate for the use in the PTB's torque standard calibration machine, because this machine yields test sequences, which are not fast enough in comparison to a normal step calibration and because the succession of steps of increasing load gives rise to creep effects on the 0%-start-value of the steps.

A step test ST-PTB, proposed by the authors, avoids the problems of ST3-9 and provides dependencies of sensitivity and hysteresis on creep parameters of the transducers. In contrast to ST-3-9, ST-PTB delivers the effects in dependence on the loading time in a wide range. The effect of different load levels, which is an aim of ST3-9, was found to be negligible. Therefore a test on only one load level is sufficient. Choosing the 50%-Level, sensitivity and hysteresis can be tested in one series (Fig. 2b) in a time of about 30 minutes per transducer in comparison to several hours per transducer with ST3-9. The test ST-PTB is suitable for delivering traceability and as a method to select torque transducers for reference and transfer in continuous calibration facilities.

Transducers with a creeping sum (c_1+c_2 in Tab. 2) smaller than $1{\cdot}10^{-4}$ are suitable for continuous calibrations in the uncertainty range of 0.1%. A good estimation for this creeping sum is the creeping value after 3 minutes (*c*(3 min) in Tab. 2). With such transducers direct loading and continuous reference calibration are identical within $5{\cdot}10^{-5}$ in the loading time range from 25 s to 325 s.

Measurements using continuous method in a reference calibration machine are comparable with the results using direct loading in the range of loading times of more than 30 seconds. Faster loading than in 30 seconds shows deformations of continuous response curve which could not be explained with creeping effects only. This should be investigated in subsequent work.

REFERENCES

[1] Andreas Brüge, "Fast Torque Calibrations Using Continuous Procedures", *Proceedings of the Joint International Conference IMEKO TC3/TC5/TC20, Celle, Germany, 2002*, **VDI-Berichte 1685**, VDI-Verlag GmbH, Düsseldorf, 2002, pp. 343-348

[2] DIN 51309, "Kalibrierung von Drehmomentmeßgeräten für statische Drehmomente", Beuth-Verlag GmbH, Berlin, 1998

[3] Diedert Peschel, Andreas Brüge, "Calibration of Torque Measuring Devices – Step-by-step or Continuous Procedure", *Proceedings of the IMEKO TC3 / APMF '98 Congress*, Taejon, Republic of Korea, 1998, pp. 275-279

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