

IMEKO 2010: TC3, TC5 and TC22 Conferences
 Metrology in Modern Context
 November 22–25, 2010, Pattaya, Chonburi, Thailand

CREEP MEASUREMENT IN REFERENCE TORQUE CALIBRATION MACHINES

*Andreas Brügge*¹

¹Physikalisch-Technische Bundesanstalt, FB 1.2, Braunschweig, Germany, andreas.bruege@ptb.de

Abstract – Creep measurements in reference torque calibration machines cannot be performed like those in direct load calibration machines. Comparisons between creep measurements in both situations lead to recommendations for reference methods yielding results which are equivalent to results based on direct load methods. Furthermore, some effects are discussed which might affect the comparability of creep measurements.

Keywords: torque transducer, creep, reference calibration machine

1 INTRODUCTION

Creep is an important parameter in characterising torque transducers. It affects their amount of hysteresis and their suitability for dynamic applications. Detailed instructions are, thus, given in DIN 51309 [1] for measuring creep in direct loading torque calibration machines. The recommendations in this standard are conclusions of research about creep behaviour in direct loading machines [2]. Because in reference torque calibration machines these methods are not practicable, alternative methods for measuring creep are in use in accredited torque laboratories. In this paper, some commonly used methods are examined and compared to the method used in direct loading calibration facilities. Thereby, the limits of creep measurement and the influencing factors are discussed as well as practical implications in continuation of a previous paper [3] in which a possible mathematical characterisation of creep was proposed.

2 CREEP VALUE DEFINITION BY MEANS OF MEASUREMENTS IN DIRECT LOADING MACHINES

Creep measurements need the possibility of constant, fast loading and unloading, which is given in direct loading machines in an optimal way. Corresponding to typical time constants of the creep effect [2] of several hundreds of seconds, a classical creep measurement is the 20-minute-load or rather the 20-minute-unload sequence in which the response of a torque transducer to a fast load step is monitored over a significant part of its exponential relaxation (long-term creep). Then the relative creep value $c_{rel,1200s}$ is the difference between the relaxed signal $S(t'=1200\text{ s})$ at the end of the monitoring and the first

undisturbed signal $S(t'=0\text{ s})$ after the load step relative to the tared signal of a full load $S_{tar}(100\%)$.

$$c_{rel,1200s} = \frac{(S(t'=1200\text{ s}) - S(t'=0\text{ s}))}{S_{tar}(100\%)} \quad (1)$$

In this calculation $t'=0\text{ s}$ is the time of the first signal which is not affected by the change of load starting at t_{ch} and lasting until t_{rd} .

$$t' = t - t_{rd} \quad (2)$$

Although loading mass movement inhibits its measurement, creep begins with the first change of load and proceeds proportionally to the advance of the change. Thus, the choice of the starting point of creep calculation at t' is given by the load speed capability of the calibration machine.

In Fig. 1 a typical creep response of a reference torque transducer to a load step and a fit to the measurements are shown.

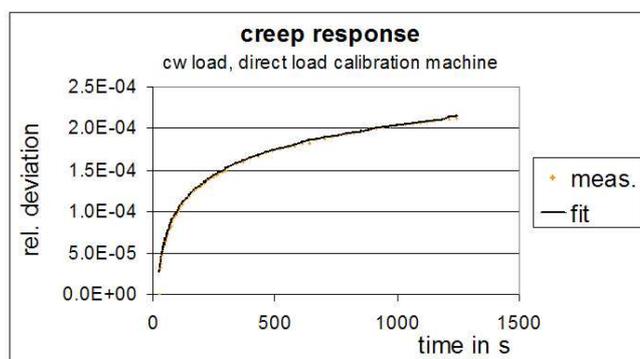


Fig. 1: Example of a load creep response of a torque transducer gained at a direct load torque calibration machine. Time starts with the change of the load t_{ch} .

With the PTB-1-kN·m calibration machine, the duration of load change is $t_{rd} - t_{ch} = 30\text{ s}$. The fit allows an extrapolation to the hypothetical start of the load change, provided this change would be ideally rectangular. However, for $t = 30\text{ s}$ measurement and fit are close together, the creep calculated according to the difference method (1) depends highly on the definition of the starting point. As shown in Fig. 2, a variation of this point by more than one reading time interval of 2 seconds causes a deviation of the calculated creep by more than 5% relative to the value at the 30 s-point. Because of mechanical or

electrical instabilities at the very time of this 30 s-point, a shift of the starting point can become necessary, if there is no possibility to spend another 40 minutes in a repetition of the creep measurement.

To avoid these problems, the creep measurement data $S(t)$ can be represented by a function consisting of a sum of exponential terms and a drift term [3].

$$S(t) = S_0 + \sum_i A_i e^{-\frac{t}{\tau_i}} + d \cdot t \quad (3)$$

Usually the number of $i=2$ provides very good agreement between the measuring data and the representation.

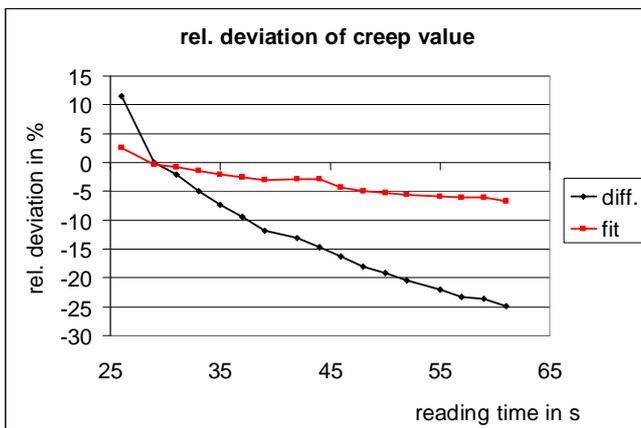


Fig. 2: Comparison of the deviations of the relative creep calculated with the difference method (1) and with the fit method (3) using measured data starting with a reading time indicated in the abscissa. The deviations are relative to a calculation using data beginning 30 seconds after the start of the load change.

The mathematical representation allows the calculation of the creep value at the 30s-point even if the data do not cover this time – by extrapolation. The relative deviation of these extrapolations is smaller than 5% for data missing up to 8 reading time intervals in the example given in Fig. 2. Moreover, the mathematical representation affects an averaging of signals with a high noise level (Fig. 3).

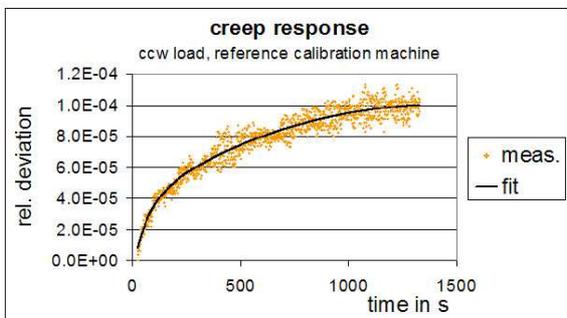


Fig. 3: Load creep response of a torque transducer gained at a reference torque calibration machine performing manual loading. A fit according to (3) can reduce the influence of signal noise.

Calculating the creep value by the representation method is, therefore, less dependent on the quality of the creep measurement data.

While the fit follows the measurements very well, an analysis of the fit convergence indicates that the fitted parameters do not show a sharp minimum (Fig. 4).

Thus, the identification of the fit parameters with a physical model is not advisable. Altogether the uncertainty of the fitted creep value can be estimated as less than $1 \cdot 10^{-5}$, which is the uncertainty for the long-term creep method at the direct load machine too.

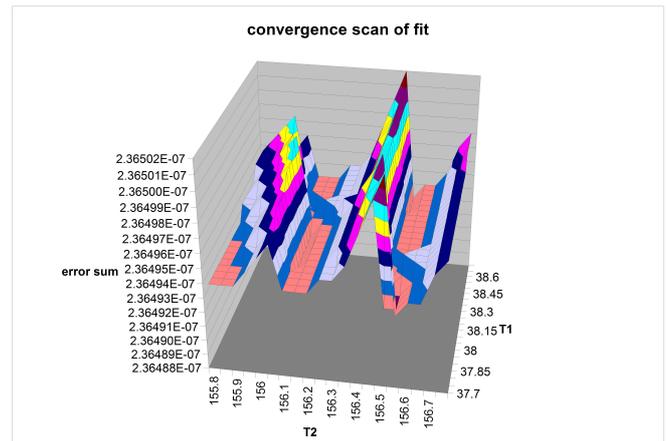


Fig. 4: The convergence scan of the mathematical representation of a creep curve shows no sharp minimum in the error sum arguing for unique parameters. T_1 and T_2 are time constants of exponential terms.

In order to reduce the time required for a creep measurement, a method for short-term creep determination was proposed [2] and became part of DIN 51309 [1] (short-term creep). According to [1], data obtained during the 3-minute waiting time after a preload sequence with a load persistence of 30 s can deliver a good estimation of the unload creep value.

$$C_{rel,short} = 4 \frac{(S(t' = 180 \text{ s}) - S(t' = 0))}{S_{tar}(100\%)} \quad (4)$$

3 CREEP MEASUREMENTS IN REFERENCE TORQUE CALIBRATION MACHINES

In reference torque calibration machines, no zero point is defined. It is possible to drive the machine to the zero point of the reference transducer, but the mechanical creep of the machine and the signal creep of the reference transducer account for uncertainties in the creep measurement of the transducer under test of the same order as the wanted value. Some laboratories therefore propose performing unload creep by quickly mechanically disconnecting the loaded machine, so that the measuring side of the transducer is free while the creep measurement is executing (drive load).

Another possibility is to carry out loading and unloading with the help of masses attached to a lever arm (manual load).

These loading methods can be implemented both for long-term creep and for short-term creep. One aim of this

work is to test whether such creep measurements in reference torque calibration machines are equivalent to those conducted in direct loading machines. An example of a comparison between relative creep values measured with the different methods is given in Tab. 1.

Table 1: Overview of creep value results obtained with different methods using a 100 N·m torque transducer.

method	rel. creep value in 10^{-4}			
	cw, load	cw, unload	ccw, load	ccw, unload
direct load, short-term creep		-1.5		1.5
direct load, long-term creep	1.8	-1.5	-1.9	1.5
drive load, short-term creep		-3.1		1.7
drive load, long-term creep		-1.3		1.5
hand load, short-term creep	2.6	-3.0	-3.2	3.0
hand load, long-term creep	1.2	-1.4	-1.4	1.4

The results of direct load methods are consistent and symmetrical for the loading direction, but unsymmetrical for load/unload sequences. Though it is possible to find examples with these unbalances, usually the creep was found to be symmetrical.

Using reference torque calibration machines, the short-term creep method proves to be unsuitable to reproduce the results of the direct load measurements, unlike the direct load method, where the short-term creep works very well. The best results are possible with the long-term creep method and unload sequence, where the maximum deviation was found to be $0.2 \cdot 10^{-4}$.

Without automated mass handling, it was found to be very difficult to obtain useful load creep measurements. Manually placed masses can cause oscillations both of bending and of torsion, which give rise to higher fitting deviations in the representation of the creep curve. Besides this, the use of a lever and a mass requires an air bearing, which is not to be expected at every reference calibration machine. With the drive load method, of course, it is not possible to perform load creep sequences.

More than the creep values in Tab. 1, a comparison of fitted creep curves can illustrate the differences between the three loading methods (Fig. 5). Compared to the methods at the reference machine, the direct load method produces shorter time constants. This causes higher creep values if the start time for creep calculation is placed into the area with high inclination. To identify the physical reasons for this observation, more measurements at different transducers, torque ranges and time schedules are necessary.

For the needs of transducer characterisation, the compliance between the creep values of the direct load machine and the reference calibration machine is good enough and the estimated uncertainty is also appropriate to it.

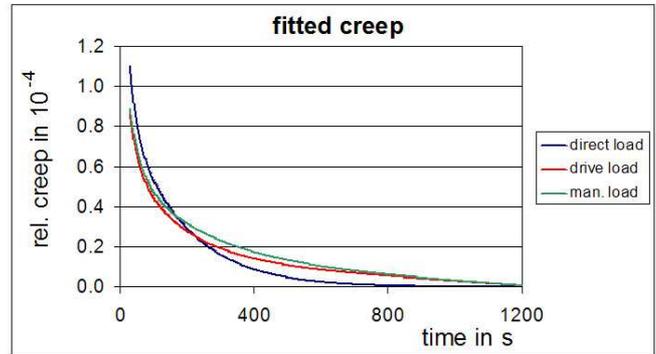


Fig. 5: Comparison of fitted creep curves of the same transducer measured with different loading methods.

4 SECONDARY CREEP EFFECTS

Some effects which can cause differences between the creep curves at diverse methods are associated with the sequence timing. Though they are not as obvious as the creep itself, they should be taken into account, if more than a rough estimate of the creep is wanted.

In the first order, creep is considered to be proportional to the load, i.e. a load up to or an unload from 50% of full load should produce a creep amount of about half of that observed at full load creep. In this case the relative creep value is expected to be constant for different partial load situations. In fact, as shown in the example in Fig. 6, there can be a dependency of the relative creep value on the level of load.

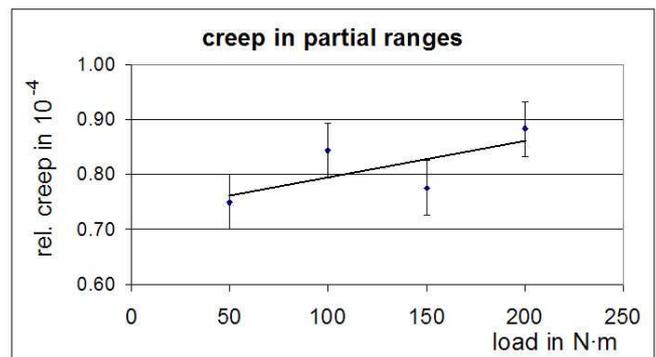


Fig. 6: Relative creep value of a 200 N·m torque transducer unloaded from partial load.

In Fig. 6 this effect is about 10^{-5} and, therefore, just within the range of uncertainty of the creep measurement, but the result is significant because the sensibility of creep measurements in direct comparison is considerably better.

Furthermore, creep depends on the previous history of the transducer. In Fig. 7 the results of similar creep measurements are shown, whose load situation just before the load change was of a different persistence. A duration of

the previous load of 30 seconds leads to a relative creep value of about half of the creep value resulting after a previous load of more than an hour. Whatever the creep dominating element within the transducer may be, it seems to show a memory of its previous history. According to this idea, the persistence effect appears to obey an exponential law as the creep does itself.

- [3] Brüge, A., *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

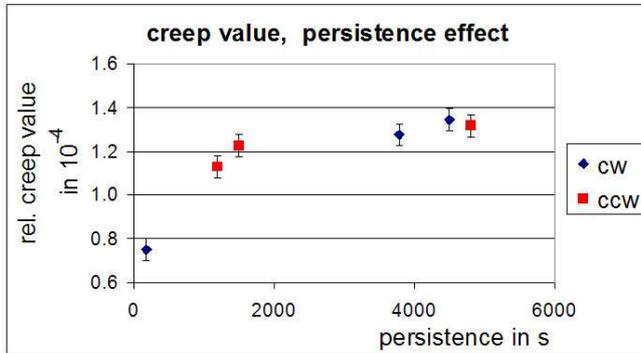


Fig. 7: Relative creep values of a torque transducer obtained after different durations of previous load.

The time schedule of creep measurements for direct comparison should, therefore, be defined very strictly, not only concerning the progress of the load change but also relating to the previous history of loads. In the example of Fig. 8, the transducer needs at least half an hour to erase the memory of a previous load, so this should be the minimum interval between two independent creep measurements.

5 CONCLUSIONS

For the best comparability with direct load methods, creep measurements in reference torque calibration machines should be performed as an unload sequence, opening the loaded calibration machine quickly.

To reduce the influence of the persistence effect and of the partial range effect, the time schedule should be appointed strictly and should include recovering intervals of at least 30 minutes.

Because of mechanical oscillations and inappropriate noise levels, the creep data should be processed by a mathematical representation consisting of several exponential terms and a drift term.

Altogether, creep measurements in reference torque calibration machines can achieve a relative uncertainty of 5%, i.e. about $1 \cdot 10^{-5}$ for the usual amount of a relative creep value of $2 \cdot 10^{-4}$.

REFERENCES

- [1] DIN 51309:2005-12, *Calibration of static torque measuring devices*, DIN Deutsches Institut für Normung e.V., Beutz-Verlag GmbH, Berlin, Issue 2005-12
- [2] Peschel, D.; Röske, D., *Determination of Creep Value Using Short-Term Creep*, Proceedings of the XVth IMEKO World Congress, June 13-18, 1999, Osaka, Japan, vol. III, pp. 245-249