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Analysis of loading profile effect on testing machine calibration results

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ABSTRACT

The paper presents an evaluation of the loading profile effect on the testing machine calibration. First, a 20 kN force transducer was calibrated in a force calibration machine. This transducer was then used for a number of calibration runs in a 600 kN material testing machine where the time step interval of the same loading profile was varied from 120 s to 0 s. Results show good agreement for most of the range but highlight an increasing error due to synchronization and filtering issues in measured signals when approaching very short step intervals and continuous loading.

1. Introduction

Force calibration procedures are defined in international standards such as ISO 376 standard [1] for static calibration of transfer transducers used for static calibration of uniaxial material testing machines (MTMs) according to ISO 7500–1 [2], and are based on quasi-static loading procedures.

ISO 376 standard defines basically a stepwise loading with at least 30 s between the measured force step values. While a continuous loading with force rate assuring a 30 seconds time interval between discrete values would technically also be compliant, the main reason for a stepwise loading in practical calibrations is linked to the majority of high precision force calibration machines for force transducer calibration being direct loading dead-weight force calibration machines. Only some force calibration machine types allow continuous loading, e.g. jockey weight machines [3]. Dead weight machines on the other hand offer a limited number of discrete force steps and relatively slow loading procedure, making it difficult to reliably realize short loading times [4].

When transfer standard transducers are used to calibrate a material testing machine following the ISO 7500-1 standard procedure for the testing machine calibration, there is no step time requirement, the standard allows even "slowly" increasing/decreasing force during calibration, but stepwise loading is typically performed nonetheless. The main reason for this might be the requirement in ISO 376 standard that requires transfer standard transducers to be used under loading conditions they were first calibrated under – statically. The performance of these transducers is not evaluated for short time intervals or continuous loading, and they are therefore sometimes considered as not having adequate traceability for continuous measurements (some guidelines on continuous calibration of force transducers is described in a German DKD-R 3–9 document [5]).

However, the applications of material testing machines almost never require a pure static force but measure test results in all parts of a continuous test curve. This should be taken into account during calibration of the testing machine and such machines should be evaluated for force loading profiles applied during testing.

The aim of the presented paper was to investigate the influence on different loading profiles on a calibration result of a testing machine's force-measuring system which could potentially affect subsequent results of a tensile test performed, e.g. tensile test according to ISO 6892–1 [6]. In this analysis a transfer standard, calibrated according to ISO 376 in a deadweight force calibration machine was used to calibrate a material testing machine with several different loading profiles to establish any effect of the loading profile on the calibration result of the testing machine.

2. Equipment

2.1. Material testing machine

The measurements were performed on a material testing machine of nominal capacity 600 kN of type Z600E manufactured by Zwick/Roell, Germany, built in 2012, Fig. 1. This is an electromechanical testing machine using electromotor and spindle drive to move the crosshead and generate loading forces. The machine is using standard control electronic system and standard control software and a single load cell for the whole force range up to 600 kN. To acquire the signal from the external strain-gauge bridge amplifier, the testing machine control software was set-up to simultaneously record the values from its force measuring system and from the external amplifier and save all measured values in its database.

2.2. Transfer standard

Reference equipment for investigation was selected as a typical equipment for the calibration of material testing machines. A measuring chain under investigation consisted of:

- HBM Z4A 20 kN force transducer
- HBM MGCplus system with HBM ML38B bridge amplifier module

During this evaluation, the transducer and the amplifier were

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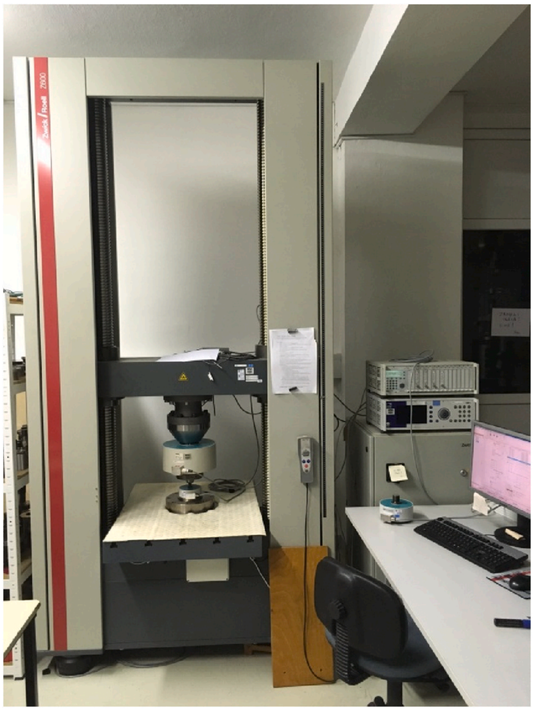

Fig. 1. Material testing machine Zwick/Roell Z600E.

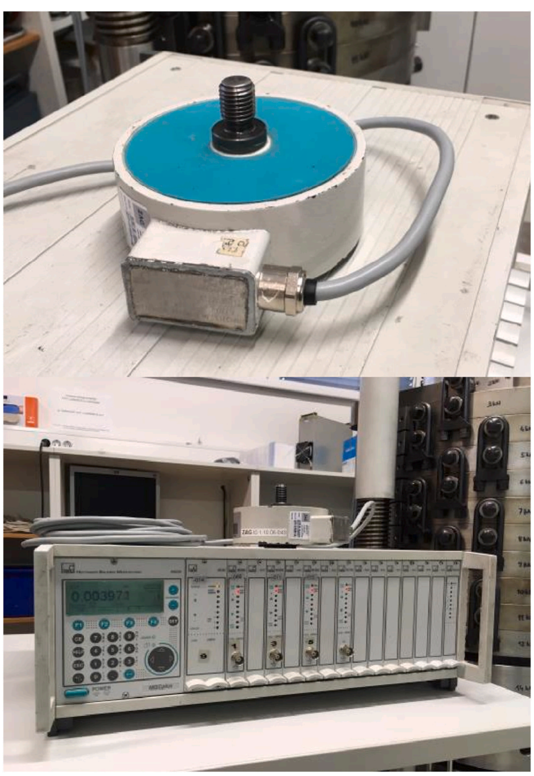

Fig. 2. HBM 20 kN Z4A force strain-gauge bridge force transducer (top) and HBM MGCplus system with HBM ML38B strain-gauge bridge amplifier module (bottom).

Fig. 3. ZAG 20 kN deadweight force calibration machine.

regarded as one single measuring system. Transducer and amplifier are shown in Fig. 2.

2.3. Force calibration machine

Calibrations of the transfer standard were performed on a 20 kN direct loading deadweight force calibration machine located at ZAG – Laboratory for metrology, Fig. 3. The accredited CMC of the machine is 0.01% with reproducibility of the generated force below 0.005%. The force calibration machine provides independent traceability to SI units via mass and gravitational acceleration.

3. Procedure

The procedure for evaluation of the loading profile effect was divided in three parts:

3.1. Part A

Calibration of the force transducer in the force calibration machine to establish the traceability to the unit of force under static conditions.

Table 1
Result of calibration of the transfer standard according to ISO 376 in a dead-weight force calibration machine.

Force in kN	Average value in mV/V	Rel. Meas. Uncertainty
0.5	0.04999	2.4E-04
1	0.09998	2.1E-04
2	0.19996	1.5E-04
4	0.39997	1.3E-04
6	0.60000	1.3E-04
8	0.80006	1.3E-04
10	1.00017	1.3E-04
12	1.20032	1.3E-04
16	1.60075	1.3E-04
20	2.00133	1.3E-04

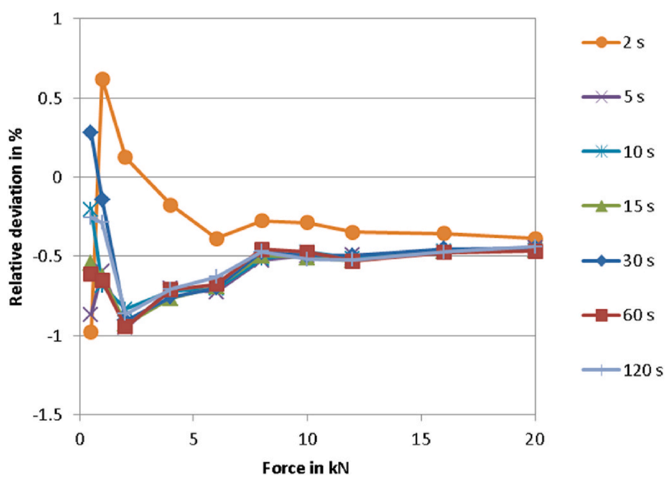

Fig. 4. The effect of the step time interval on the machine calibration error result.

The calibration procedure follows ISO 376 standard procedure.

3.2. Part B

Calibration of the material testing machine with the transfer standard using a typical time interval for the calibration and static conditions following ISO 7500–1. The transfer standard was positioned in the testing machine before the tests and its position and orientation was not changed during tests to exclude any mechanical influences arising from the loading the transducer. The calibration of the material testing machine was then repeated with different loading profiles. The step hold interval at each calibration step was changed between the measurement series.

3.3. Part C

Calibration of the material testing machine with the transfer standard under continuous loading profile conditions.

4. Results

4.1. Part A

The 20 kN transfer standard transducer was calibrated in the 20 kN dead-weight force calibration machine according to the ISO 376 procedure to establish its reference values under the static conditions and assure the metrological traceability to the unit of force. The time interval between the steps was 60 seconds. The filter setting on the amplifier was 0.5 Hz low pass Bessel filter. The calibrated range was from 0.5 kN to 20 kN for compressive loading. Results are shown in Table 1.

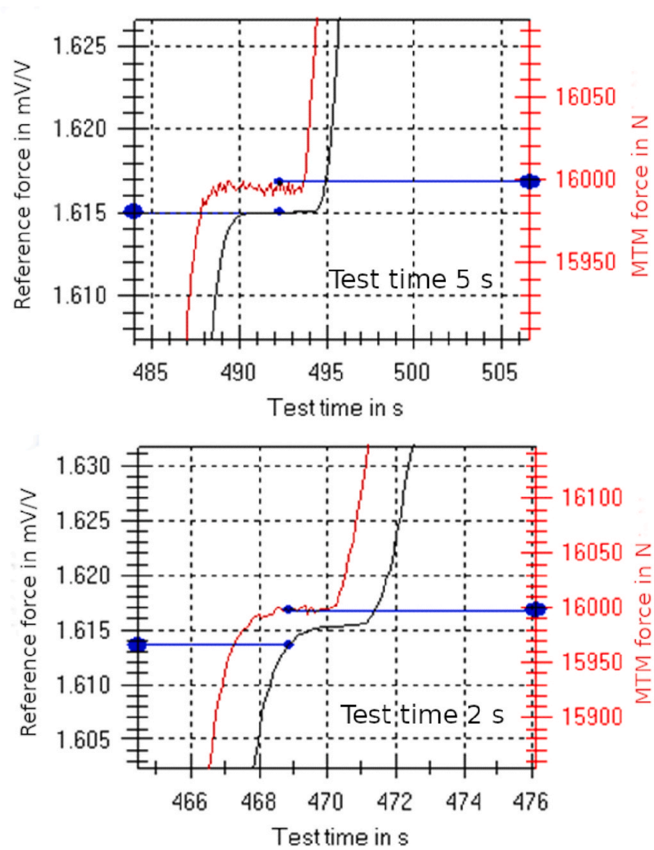

Fig. 5. Comparison of 5 second interval (top) and 2 second step interval (bottom).

4.2. Part B

The machine's force measuring system was calibrated by the 20 kN transfer standard in a single rotational position with one preload followed by three increasing force series with force steps from 1 kN to 20 kN. The loading rate between the force steps was set to 200 N/s for all tests. The step interval was changed between the tests from 120 s down to 2 s (120 s, 60 s, 30 s, 15 s, 10 s, 5 s, 2 s) with all other parameters kept constant (temperature, transfer standard position, force step values, amplifier filter settings, loading rate, etc.). The filter setting on the amplifier was set to 0.5 Hz low pass Bessel filter for all measurements.

The average value was calculated from three increasing force series for each force step for each step interval measurement to determine the deviation of the results. Fig. 4 shows the results of the calibration. The testing machine nominal range is 600 kN and the values at the bottom of the evaluated range (below 2 kN) include some larger dispersion. The standard deviation of the three series exceeded 1% in some cases at these values, and while the results are displayed on the graphs, they should be viewed as informative only. Range from 2 kN to 20 kN is to be regarded as representative.

The results of the calibration were very similar and within the measurement uncertainty (expected 0.1% or more) for force step intervals from 120 s down to 5 s, but there was a clear deviation in the resulting error observed for the 2 s step interval. Investigation of the recorded signals from the machine and the external calibration system showed a phase shift of the signals, Fig. 5.

It can be seen that the phase shift (delay) affected both cases (all cases), but the 5 second step waiting time was sufficiently greater than the phase shift and the values from both signal were acquired under stable conditions. This was not the case anymore for the 2 s time step, where the delay combined with transient response of the signals caused

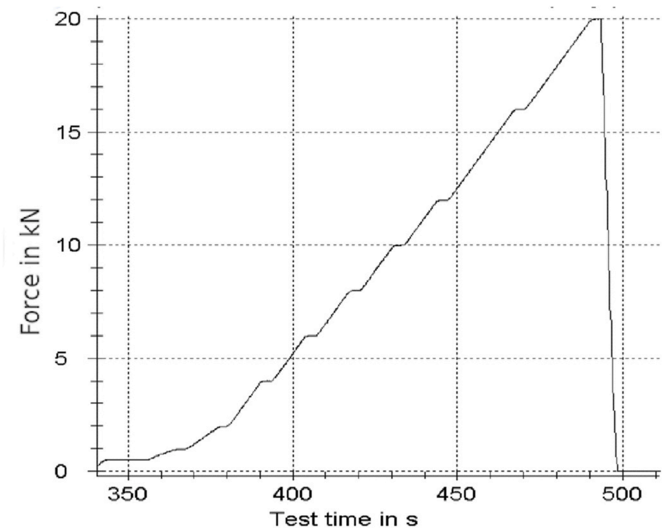

Fig. 6. Loading profile with 2 second step interval.

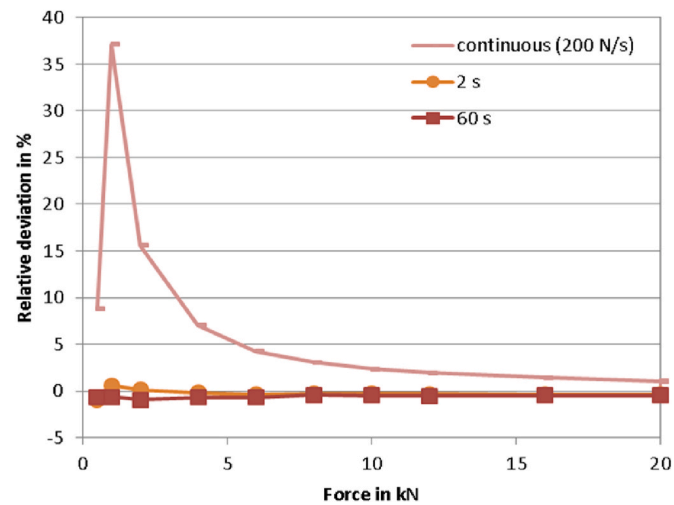

Fig. 8. Continuous calibration with 200 N/s (0.5 Hz Bessel filter), and static calibration with 2 s and 60 s step intervals.

the external signal value to be acquired before it reached the stable step value. The phase shift of the signals is caused by the filtering effects of the external amplifier (0.5 Hz Bessel filter), acquisition delay due to the asynchronous data acquisition over serial communication from the amplifier and also other possible effects. The 2 s step loading profile is shown in Fig. 6.

4.3. Part C

The transfer standard was then used to calibrate the machine with a continuously increasing force, with a constant loading rate of 200 N/s (zero to maximum loading in about 100 seconds), without any calibration steps between zero and maximum value during the increasing series, Fig. 7.

The filter setting remained set to 0.5 Hz Bessel low pass filter, same as for the stepwise loading. The results of the continuous calibration are compared to the 2 s and 30 s step loading results in Fig. 8. Due to the inappropriate filter setting for continuous loading, the results of the continuous calibration show large errors from 2% to above 30%.

As the filter setting introduces a delay into the data acquisition, it significantly affects the error result and the reference signal is not synchronized (it is delayed) with the testing machine load cell signal.

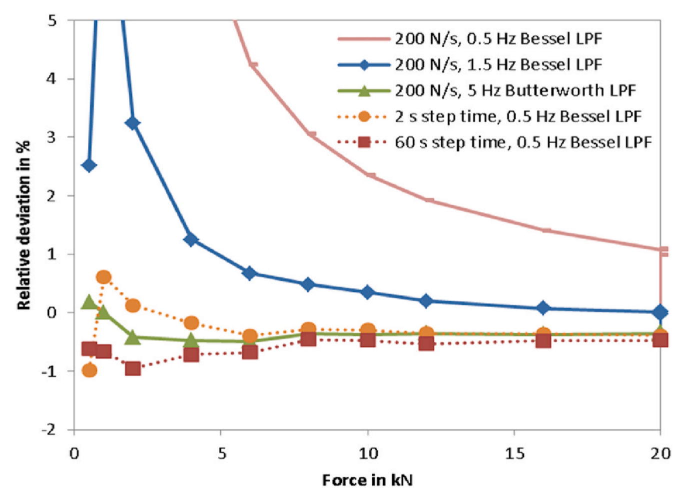

Fig. 9. Static calibration with 30 s step interval, 2 s step interval (both 0.5 Hz Bessel filter) and continuous calibration with 200 N/s loading rate for 0.5 Hz Bessel filter, 1.5 Hz Bessel filter and 5 Hz Butterworth filter.

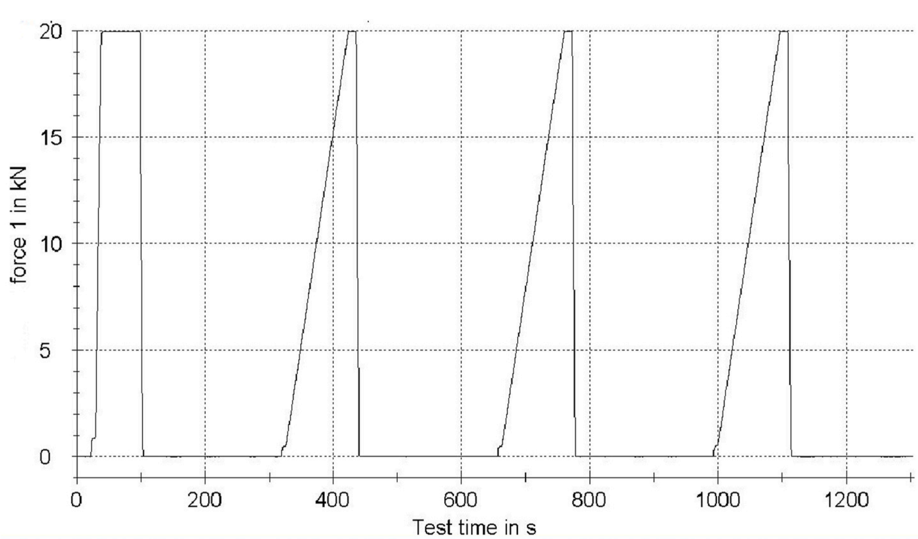

Fig. 7. Loading profile for continuous loading with a rate of 200 N/s (one preload and three increasing series).

Changing the filter setting to 1.5 Hz Bessel low pass filter and further to the 5 Hz Butterworth filter setting resulted in a reduced delay and improved results. When the same measurement was repeated with the 5 Hz Butterworth filter setting, the results improved significantly, Fig. 9, and agreed well with the reference static curve, to within 0.5% above 2 kN.

As the creep of the 600 kN testing machine's load cell is low in the bottom range, the results suggest that the transfer standard transducer produces comparable results from static to continuous loading [7] and the results could give an approximation of necessary additional measurement uncertainty contribution, validating the transfer transducer at the same time.

5. Conclusion

The presented results of the loading profile analysis suggest, that a transducer statically calibrated in a force calibration machine according to ISO 376 procedure, can provide comparable testing machine calibration results for various loading profiles. The results are comparable even for a continuous loading profile, but an additional uncertainty is necessary to accommodate the loading profile effect. With such additional contribution, the calibration of testing machines would provide traceability and appropriate calibration uncertainty for static and continuous loading. The testing machine itself could serve as a comparator to evaluate loading profile effect (when the testing machine load cell exhibits low creep), even if the transfer standard is not previously calibrated with continuous forces. Care needs to be taken to ensure appropriate amplifier filter settings and synchronize the data acquisition when using short step intervals or continuous profiles.

Acknowledgments

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References

[1] ISO 376:2011, Metallic Materials — Calibration Offorce-Proving Instruments Used for the Verification of Uniaxial Testing Machines.

[2] ISO 7500-1:2018, Metallic Materials — Calibration and Verification of Static Uniaxial Testing Machines — Part 1: Tension/compression Testing Machines — Calibration and Verification of the Force-Measuring System.

[3] T. Allgeier, U. Kolwinski, D. Schwind, Jockey-Weight lever machine for force and torque, in: 18th IMEKO TC3 Conference on Force, Mass and Torque, Celle, Germany, 2002.

[4] G. Haucke, D. Schwind, R. Kumme, Investigation of force transducers with different loading procedures on jockey –weight and deadweight machines, in: XVIII IMEKO World Congress, September, 17 – 22, 2006. Rio de Janeiro, Brazil.

[5] Richtlinie DKD-R 3-9 Kontinuierliche Kalibrierung von Kraftaufnehmern nach dem Vergleichs-verfahren, Ausgabe 09/2018, Revision 0, Physikalisch-Technische Bundesanstalt, Braun-schweig und Berlin. DOI: https://doi.org/10.7795/550.20180823J.

[6] ISO 6892-1:2019, Metallic Materials — Tensile Testing — Part 1: Method of Test at Room Temperature.

[7] L. Brice, A. Knott, A. Wilson, Continuous calibration of force transducers, in: IMEKO 20th TC3, 3rd TC16 and 1st TC22 International Conference, Merida Mexico, 2007.

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