Measurement: Sensors 18 (2021) 100132

Contents lists available at ScienceDirect

Measurement: Sensors

journal homepage: www.sciencedirect.com/journal/measurement-sensors

Compensation of synchronization error effect in testing machine calibration

ARTICLE INFO

Keywords
Force calibration
Data synchronization
Continuous loading
Material testing machines

ABSTRACT

The paper presents an evaluation of synchronization issues when performing material testing machine calibration using continuous loading. A procedure for the compensation of a rangewide error in calibrated force values is proposed based on a correction factor determined from static and transient errors difference at a chosen force step. The procedure was applied for a calibration of a testing machine with a 20 kN force transducer and 200 N/s to 2000 N/s loading rates. The results show good performance of the compensation technique, reducing calibration errors to below 1% in non-synchronized signals even under unknown filter and delay setting.

1. Introduction

A procedure for the calibration of a uniaxial material testing machine's force measuring system is defined in the international standard ISO 7500–1 [1]. The standard defines a static (quasi-static) calibration procedure at discrete force steps but also explicitly allows a slowly increasing or decreasing force during calibration. For testing machine calibration, a procedure with continuous loading would be of benefit as it mimics actual test procedures during the application of testing machine, where some tests are already finished within 30 s, which is the shortest allowed step time when calibrating force transducers according to the international standard ISO 376 [2] (calibration of force transducers used for the calibration of testing machines).

Ideally, the data acquisition between machine's force measuring system and the external force measuring reference system should be synchronized and both should be using the same signal filtering settings. In practice, there are two main obstacles in achieving these requirements. First, the external force reference system is typically a separate system logging the measured values to a separate computer, and secondly, the filter settings of the machine's force measuring signal are not known, so that there is generally a mismatch between the filter settings to be expected.

The first issue can be partially overcome by integrating the external reference system data acquisition into the machine control software, but also in this case there is a possible acquisition delay due to the data communication protocol in case of asynchronous data transfer. Another possibility is to try to synchronize the data obtained from separate systems at data post processing, by trying to time align both data sources. However, in both cases the unmatched filter setting issue due to unknown signal filtering remains.

In a separate investigation [3] we analysed the effect of changing the step time from values typical for a static force transducer calibration to shorter time steps intervals including continuous loading. The investigation included changing the step time from 120 s to 2 s and also to removing the steps altogether and loading in continuous manner (120 s, 60 s, 30 s, 15 s, 10 s, 5 s, 2 s, and continuous loading with a 200 N/s load rate). The results showed large possible errors mainly due to the non synchronized data acquisition, Fig. 1.

In this figure it can be seen, that inappropriate filter settings caused an error from several percent to above 30%. It was observed, that the signal delay can prevent correct signal values pairs to be determined, resulting in a time-delay caused force value error, Fig. 2.

The aim of this paper is to investigate the possibility of a correction of time delay caused errors in post processing of material testing machine calibration data based on data presented in Fig. 2, allowing a calibration to be performed with unknown testing machine signal filter settings.

2. Equipment

2.1. Material testing machine

The measurements were performed on a material testing machine of a nominal capacity 600 kN of type Z600E manufactured by Zwick/Roell, Germany, built in 2012, Fig. 3. 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. The machine is using a single load cell for the whole force range up to 600 kN. To acquire the signal from an external strain-gauge bridge amplifier, the testing machine control software was set-up to simultaneously record values from its force measuring system and from the external amplifier and save the measured values in its software database.

https://doi.org/10.1016/j.measen.2021.100132

Available online 17 September 2021

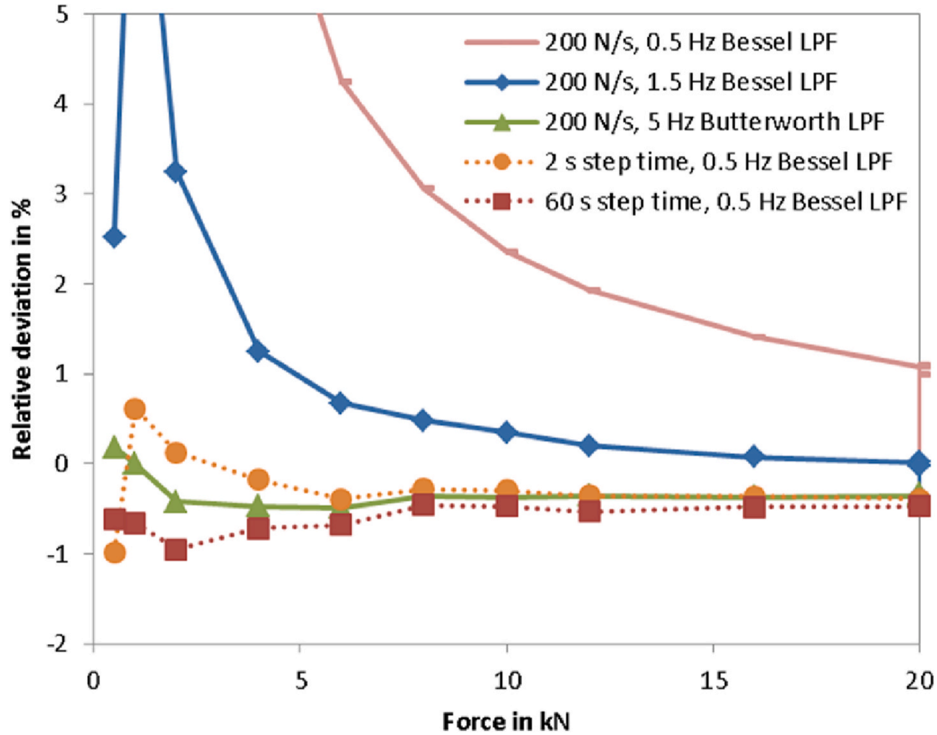

Fig. 1. The error effect due to data acquisition delay for various loading profiles: static calibration with 30 s step interval and 2 s step interval (both 0.5 Hz Bessel filter), and continuous calibration with 200 N/s loading rate for 0.5 Hz Bessel filter, 1.5 Hz Bessel filter and 5 Hz Butterworth filter.

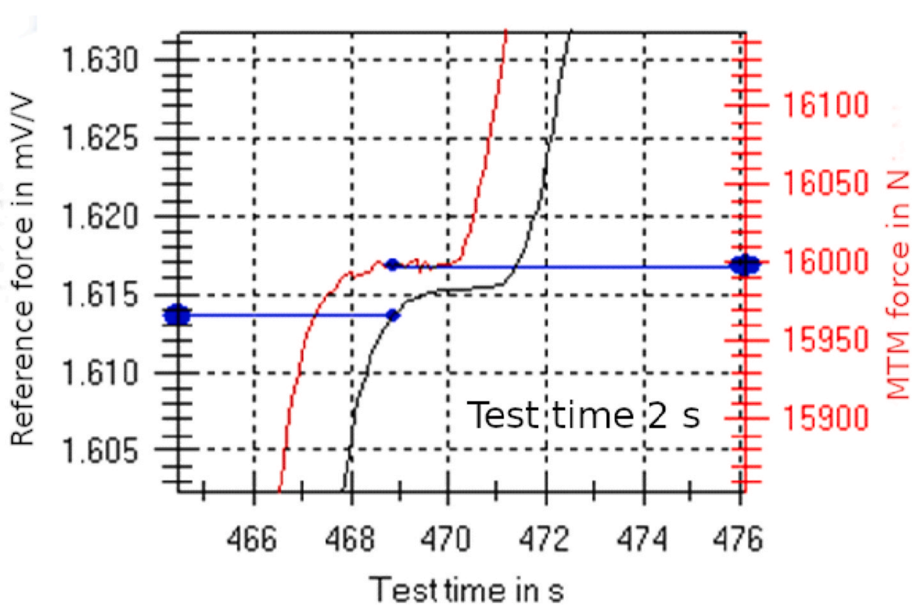

Fig. 2. Mismatched force value pair due to time shift of measured signals – reference value not stabilized.

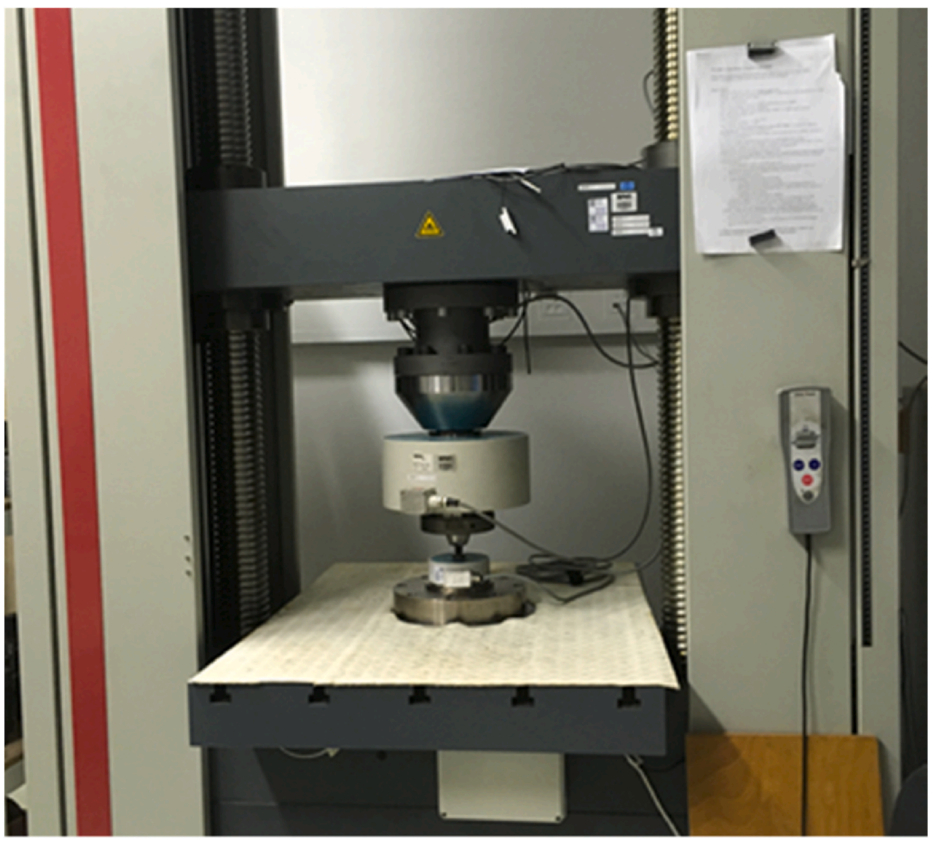

Fig. 3. Material testing machine Zwick/Roell Z600E.

Fig. 4. HBM 20 kN Z4A force strain-gauge bridge force transducer and HBM MGCplus system with HBM ML38B strain-gauge bridge amplifier module.

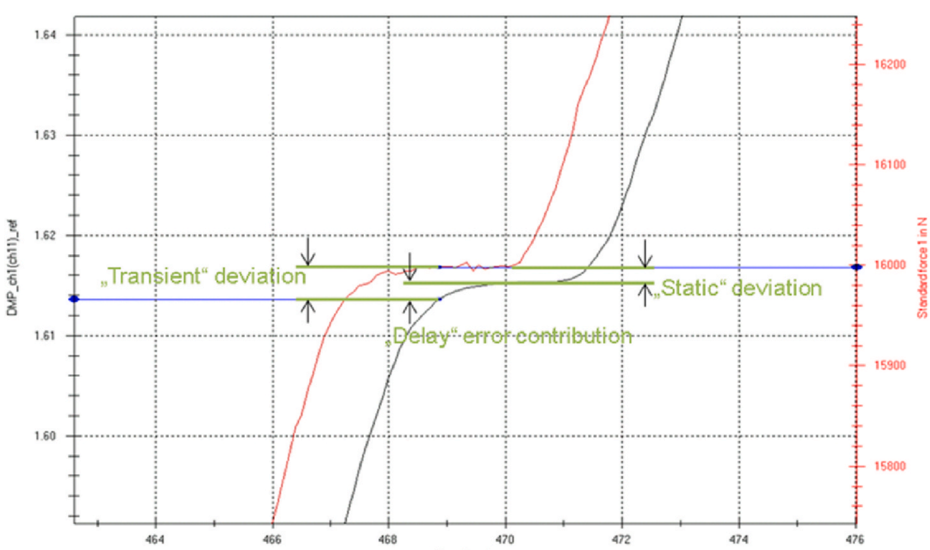

Fig. 5. Influence of signal delay on calibration error calculation.

2.2. Transfer standard

Reference equipment for investigation was selected as typical equipment for 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 regarded as one single measuring system. The transducer-amplifier measuring chain was calibrated on a 20 kN deadweight force calibration machine at ZAG to establish the static force reference values (with 60 s step time). Transducer and amplifier are shown in Fig. 4.

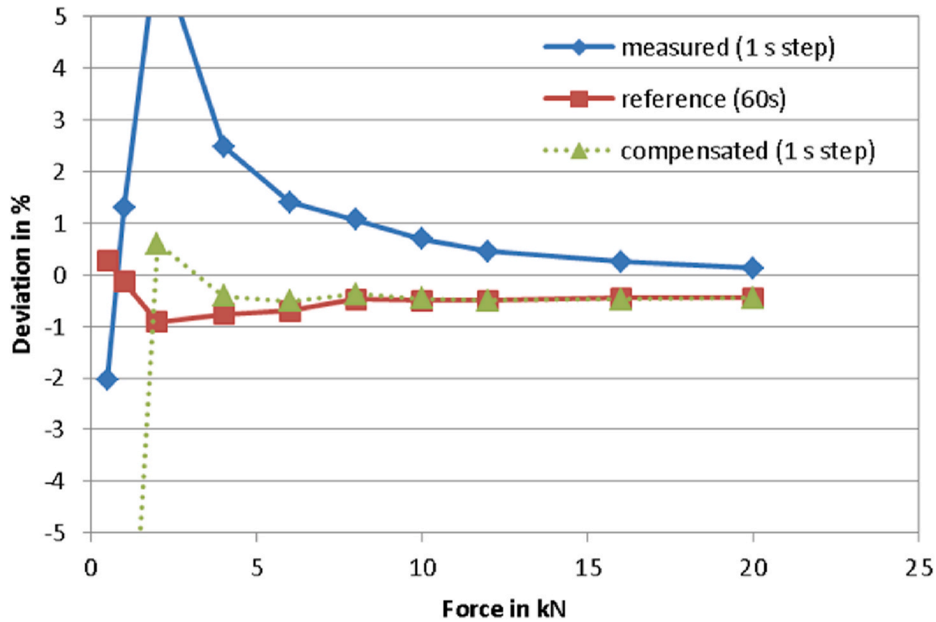

Fig. 6. Error of 1 s step calibration measurement and same measurement after compensation of "delay" error. Static calibration result with 60 s step time shown for comparison.

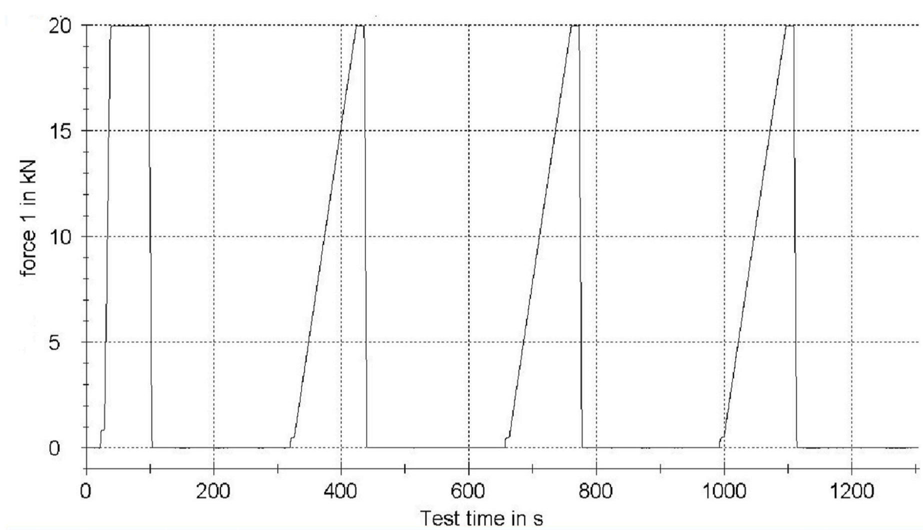

Fig. 7. Loading profile for continuous loading with a rate of 200 N/s (one preload and three increasing series).

The amplifier was connected to the testing machine control software via a serial connection using RS-232 communication protocol to transfer measured values directly to the machine software and take advantage of using a single software for data logging and unified timebase for data acquisition.

3. Procedure

As shown in Fig. 2, time delay in measured signal causes a wrong pair of force values to be selected for calibration error calculation. This causes the established error to deviate from the correct static error as shown in Fig. 5. The "transient" error differs from "static" error due to the influence of the "delay error". If there were no time delay, "transient" error would be the same as "static error". If the time delay is the same throughout the loading profile and loading rate is the same, the same "delay" error contribution could be used to correct all measurement points.

The "transient" deviation value pair can be extended to be acquired in the linear load rate part of the signals and compared to static force value pair to establish the correction necessary to compensate the

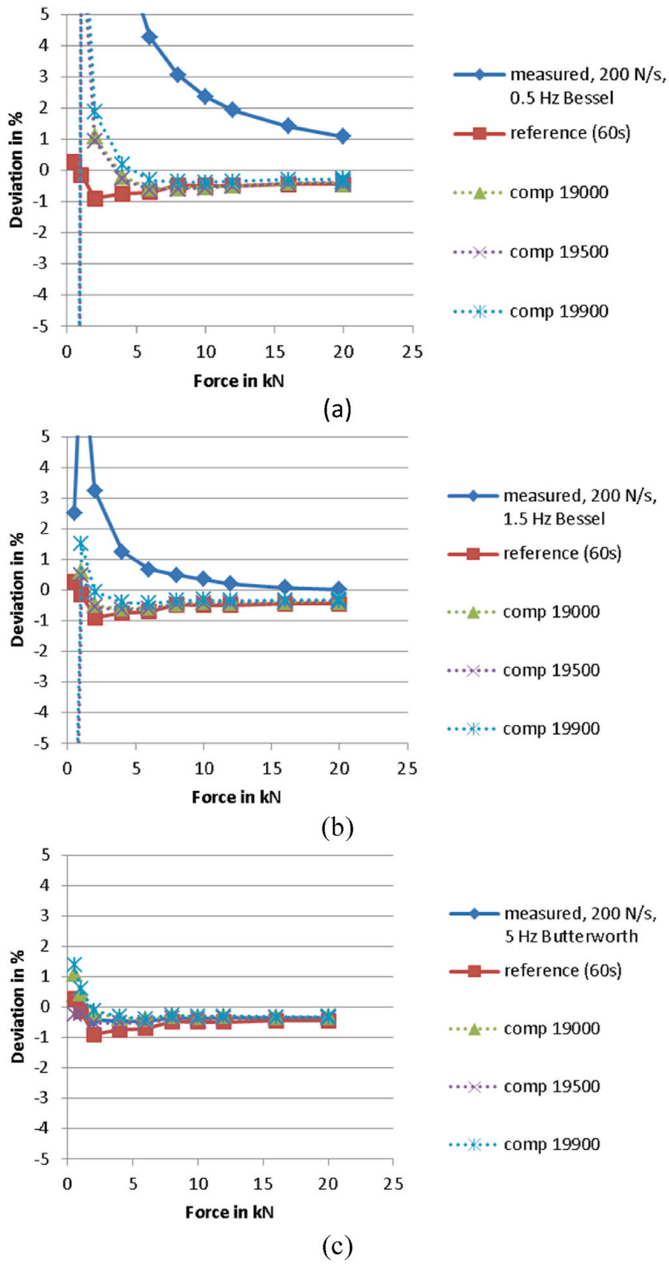

Fig. 8. Error for continuous loading with a rate of 200 N/s, for 0.5 Hz Bessel filter (a), 1.5 Hz Bessel filter (b) and 5 Hz Butterworth filter (c). Compensated curve for each calibration is shown with reference curve for comparison.

continuous loading delay error. For this procedure to work, there should be a static part of the loading profile to determine "static" error and the "transient" error should be determined at a force value close to the "static" error point. A holding time at the maximum force value of the loading profile that is long enough for both signals to stabilize and all filtering and signal acquisition delay effects to subside, with "transient" error determined in the linear load rate range just before the top of the profile, seem appropriate.

The procedure for the evaluation of the synchronization effect was based on comparing the testing machine measured signal with the signal from the external reference calibration system and estimating the "delay" error contribution. The transfer standard was positioned in the testing machine before the tests and its position was not changed during tests to exclude any mechanical influences arising from loading the transducer, leaving mostly data acquisition synchronization errors to influence the results.

After the determination of the "delay" error contribution, the measured signals were corrected to compensate for the non-synchronization of the signals.

4. Results

The principle presented in section 3 was first applied to a calibration measurement series with 1 s step time, 200 N/s loading rate between force step, and 0.5 Hz Bessel low pass filter setting. The results are shown in Fig. 6. There was a significant error exceeding 5% compared to a 60 s step time reference curve, caused by non-synchronized data. After the determination of "delay" error contribution, the measured signals were corrected to compensate for the non-synchronization of the signals.

An absolute force error of 116 N was determined as the "delay" error contribution near the maximum force of 20 kN and testing machine error curve was corrected for this value at each discrete force point. The corrected curve is shown in Fig. 6 with a reference curve for static calibration with a 60 s step time. The agreement between compensated curve and reference curve is very good for the most part of the range, achieving an agreement within 0.5% of the reference curve, reducing the error by more than five times, for over 75% of the calibrated range. Measured values below 10% of the transducer range result in larger dispersion and deviations, but these forces are also in the very low end of the testing machine force range (below 0.04% of the machine force range) where the machine set-up can influence the results.

The analysis continued by extending the compensation procedure to continuous loading. The testing machine was calibrated by a 200 N/s continuous loading profile as shown in Fig. 7.

To test the delay error compensation, the calibration was repeated with the same loading profile but with different filter setting on the external amplifier: 0.5 Hz low pass Bessel filter, 1.5 Hz low pass Bessel filter and 5 Hz low pass Butterworth filter. When reaching the maximum force, the force was kept constant to establish "static deviation", and "transient deviation" was determined at the linear portion of the increasing profile points before reaching the maximum force. For comparison and analysis, the value for "transient deviation" was determined at three points: at 19.9 kN, at 19.5 kN and at 19.0 kN testing machine force value.

Fig. 8 shows the results of the calibration and the results of corrected curve based on "delay" error contribution compensation only, without any other information about the machine instrumentation filter settings, the data acquisition delay or other influences. It can be seen, that while the measured curve using the 5 Hz Butterworth filter is in good agreement with the reference curve (obtained by step loading with a 60 s step interval), there are significant deviations up to several percent for the 1.5 Hz Bessel filter setting and even more so for the 0.5 Hz Bessel filter setting, which introduces the most delay into the system, a deviation of more the 5%. But in all cases, the "delay" error contribution compensation provided results very close to the reference curve. Even for the largest delay when using the 0.5 Hz Bessel filter, the compensated curve was within 1% deviation from the reference curve for the most part of the range, improving the deviation significantly.

To further validate the procedure, the calibration of the testing machine was performed with higher loading rates. Fig. 9 shows the result of a continuous loading rate of 1000 N/s, reaching the maximum force within 20 s. Fig. 10 shows the result of a 2000 N/s loading rate. The filter setting was 5 Hz Butterworth low pass filter in both cases. The results demonstrate that a "transient" error determination point at 95%

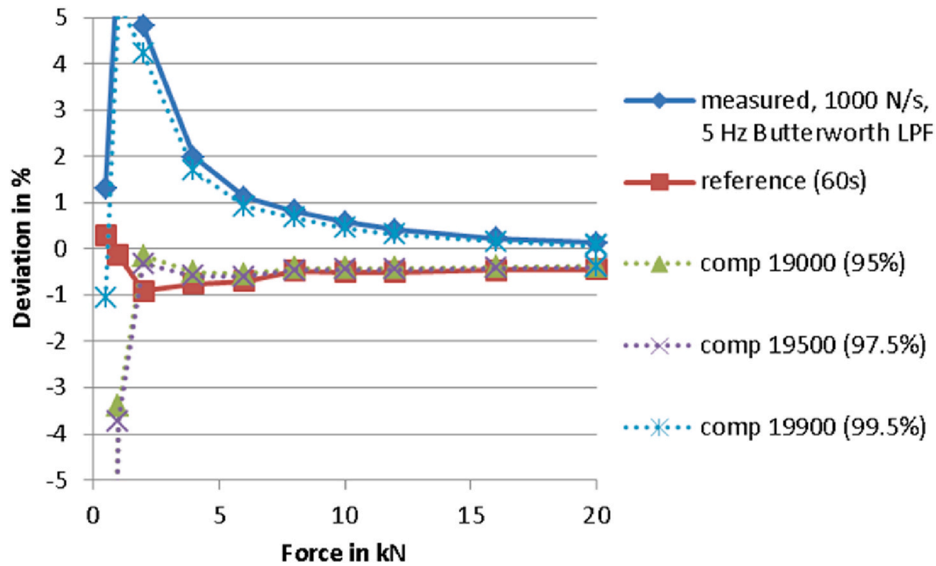

Fig. 9. Error compensation for continuous loading with a rate of 1000 N/s, 5 Hz Butterworth low pass filter.

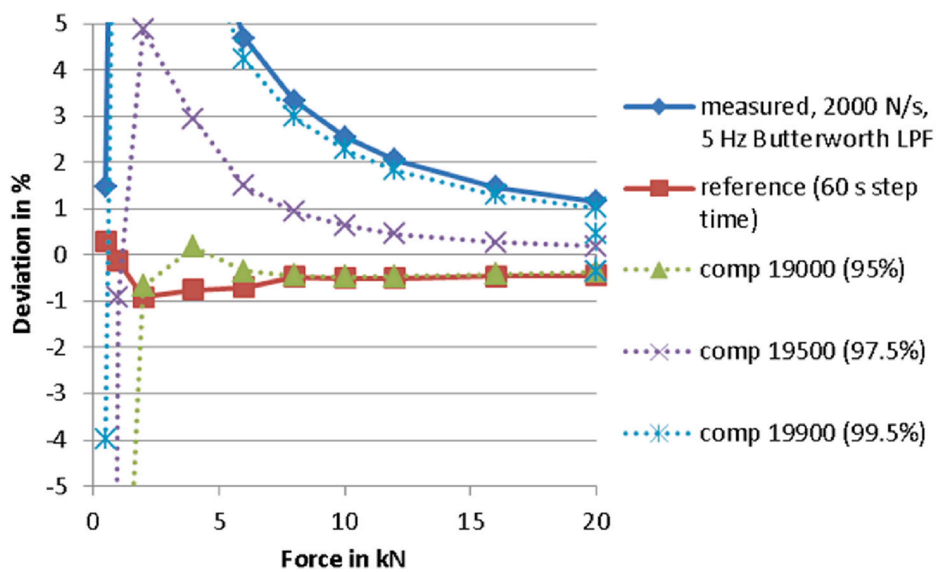

Fig. 10. Error compensation for continuous loading with a rate of 2000 N/s, 5 Hz Butterworth low pass filter.

of the maximum load provided appropriate correction factor to reduce the deviation to within 1% of the reference curve.

5. Conclusion

A possible procedure for the compensation of non-synchronization errors was presented. The results of the synchronization effects analysis suggest it is possible to correct non-synchronized calibration results based on a fixed absolute “delay” error force correction value in cases where the loading rate is constant. The compensation procedure is independent of the testing machine setting and does not require previous knowledge of the filter setting or data acquisition delays. The procedure can significantly reduce the calibration deviation error, to below 1% also for the cases where high loading rates are applied or where slow filter settings are used during the calibration. Calibration of a testing machine with a high loading rate is of benefit as it more closely follows the actual loading rates during testing applications, and furthermore allows more calibration series to be performed during the calibration of a testing machine, possibly with several loading rates.

Acknowledgments

This work is a part of the project 18SIB08 which has received funding from the EMPIR programme co-financed by the Participating States and from the European Union’s Horizon 2020 research and innovation programme.

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