Deliverable D4

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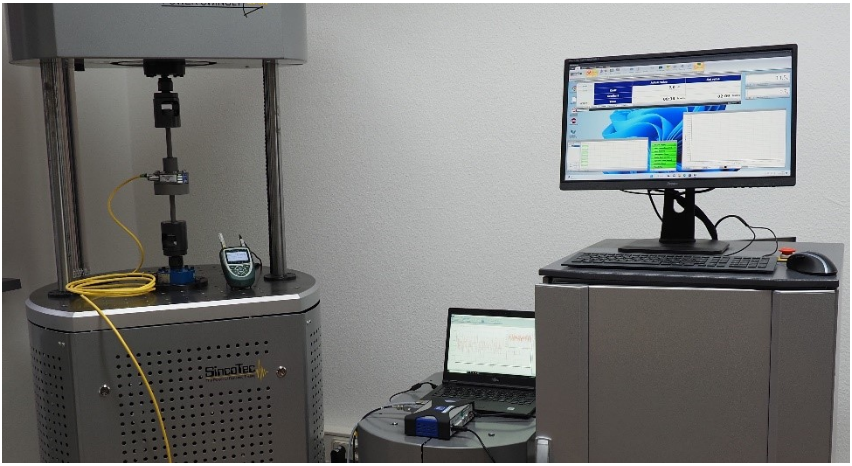
Calibration procedure for testing machines to extend the traceability chain from static to continuous forces which can be used for forces in the range of 1 N to 1 MN

Calibration - Procedure



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Comprising the results from our research and the fruitful and intensive discussions with all our other project partners worldwide.

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Section 1

Continuous calibration of the force-measuring system of uniaxial testing machines

Initial requirements

Machine

The machine shall be capable of providing a post-run time v force record in digital format for subsequent data analysis – it is likely that this record will come from a load cell (either strain gauge or piezoelectric) but other measurement systems, such as strain gauge-based pressure gauges, are not precluded.

The signal conditioning (e.g. filter type, filter frequency) associated with the force data acquisition channel shall be known and, ideally, settable.

The machine shall be capable of generating ramp force profiles over a range of different loading rates. There shall be minimal overshoot at the maximum calibration force F_{max} and the shape of the profile from 0,02F_{max} to 0,98F_{max} shall be virtually linear.

Force-proving instrument

The force-proving instrument shall be calibrated in accordance with the static calibration procedure detailed in ISO 376.

The force-proving instrument shall also be either continuously calibrated as detailed in section 2 or meet the requirements of a continuous calibration reference standard as detailed in section 3.

The force-proving instrument shall be capable of providing a post-run time v force record in digital format for subsequent data analysis.

The force-proving instrument's signal conditioning settings (e.g. filter type, filter frequency) shall be known and, ideally, settable.

Procedure

Set the testing machine and proving instrument filters to the same type and frequency – if this is not possible, the machine cannot be calibrated continuously.

Immediately prior to the calibration procedure, the proving instrument, in position in the machine, shall be preloaded at least three times between zero and the maximum force to be measured, followed by a dwell time of at least 30 s at zero force.

Prior to each test, when no force is applied to the proving instrument, zero the force reading from the testing machine's force indicator.

Start logging data from both the testing machine and proving instrument.

Apply a small force of approximately $0{,}01F_{\mathrm{max}}$ to the proving instrument.

For each force rate of interest, apply an incremental ramp followed by a dwell of between 5 s and 30 s at maximum force and then a decremental ramp at the same rate, waiting 30 s after the force is removed then taking a final machine indicator zero reading. Re-zero the machine indicator then repeat this test to obtain two sets of data at each nominal force application rate. Where it is necessary to perform the calibration with the proving instrument at different orientations this need be done for only a single loading rate, as the effects of orientation and loading rate are likely to be independent. Where decremental performance is to be determined, perform an additional third test at each force rate with no dwell time at maximum force.

NOTE To give traceability to the forces recorded during the initial periods of materials tests, it is likely that, for the fastest rate verified, the maximum force will need to be applied within no more than 5 s.

In a final test, while still continuously logging data, apply a set of at least five incremental and then decremental step force changes, pausing long enough for the readings to stabilize at each level, and waiting at F_{max} for at least 30 s – the results of this test are used to determine the relative clock speeds of the data-logging instrumentation of the testing machine and of the proving instrument.

Data analysis

For all proving instrument traces, determine the deflections by subtracting the initial zero output then convert these deflections to force values, using the incremental and, if applicable, decremental coefficients determined during its continuous calibration at the loading rate closest to that used in each specific test (note that, for the decremental coefficient values to be valid, the same maximum calibration force needs to be applied). When the force-proving instrument was calibrated as described in section 3 the statically estimated coefficients can also be used.

NOTE 1 If the machine is being calibrated only for incremental forces using a proving instrument continuously calibrated only with incremental forces, the decremental force values should still be calculated, using the incremental coefficients, to enable synchronisation of the machine and proving instrument data records.

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Determine any difference in the clock speed between the testing machine and the proving instrument data acquisition hardware – this is best done by aligning the machine and proving instrument force traces for the first incremental step in the final test, then scaling one time series until the final decremental step is also aligned.

NOTE 2 This step could be avoided by logging the proving instrument's analogue output as an external input to the testing machine's instrumentation. However, it needs to be borne in mind that:

- not all proving instruments provide suitable analogue output channels
- not all testing machines provide suitable external input channels
- if both channels are available, each would need an accurate DC voltage calibration
- there will still be a time delay associated with this input that will need correcting for
- it would need to be ensured that the signal was being correctly filtered

Correct all test results for any time-scaling differences.

For each ramp test result, roughly synchronize the machine and proving instrument force traces then calculate and plot the machine force error as a function of force. Adjust synchronization of the two traces by, for example, minimizing the standard deviation of the errors after stabilization at maximum force over a 5 s range or setting the incremental and decremental errors to be equal close to the maximum force but at a value unaffected by inertial effects.

NOTE 3 It is also possible to combine the time-base check with each force rate test by adding small force steps at the beginning and end and the force rate time profile, then analysing the resulting profiles to determine both time-base differences and trace synchronization.

To determine an estimate of the error at specific force values, the following procedure is recommended:

- determine the time at which this force was recorded by the machine by interpolating between the {time, force} data pairs either side of the required force
- determine the generated force at this time by interpolating between the proving instrument's {time, force} data pairs either side of this time
- compare this value of generated force with the specified value to determine the error
- if there are significant noise or resolution effects, and also in order to determine a value of uncertainty associated with this estimation of error, these interpolations should be carried out using least-squares linear fits over a larger number of data pairs equally spaced around the force or time of interest.

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Section 2

Continuous calibration of the force-proving instrument

Initial requirements

The force-proving instrument shall be mechanically coupled to the reference standard and located on the central axis of a machine capable of generating the required force magnitudes and application rates.

NOTE 1 This work may be better performed in a normal testing machine than in a force standard machine, as loading rates and force-time profiles may be more easily set and controlled.

The force-proving instrument and reference standard shall employ nominally-identical instrumentation and associated settings. Both instruments shall be capable of providing a post-run time v output record in digital format for subsequent data analysis. It is recommended that the data logging frequency for both instruments is fast enough to take at least one reading for every 1 % of F_{max} and that the filter settings are those that will subsequently be used by the force-proving instrument when calibrating testing machines.

The reference standard shall meet the performance requirements specified in section 3.

Procedure

Apply incremental ramps followed by dwells of 30 s at maximum force then decremental ramps over the range of force rates of interest. Perform at least two tests at each of a minimum of four force rates, approximately evenly logarithmically spaced (e.g. 1 kN/s, 3 kN/s, 10 kN/s, and 30 kN/s). Where decremental performance is to be determined, perform an additional test at each force rate with no dwell time at maximum force.

Data analysis

For both sets of traces, determine the deflections by subtracting the initial zero output.

Determine synchronisation between the two outputs, for example by switching the transducers and their instrumentation modules and repeating the tests, then comparing the incremental deflection ratios as a function of force for the fastest force application rate. Correct all data by the out-of-synchronisation value determined by minimising the difference between these deflection ratio plots. An alternative synchronisation determination method might be to apply the same low frequency sinusoidal input signal to both instrumentation modules then measure the phase difference between the two recorded signals.

Convert the reference standard deflections to force values, using the incremental and decremental coefficients determined during its static calibration.

For each ramp test set of data, calculate the sensitivity of the force-proving instrument at each force by dividing its deflection by the applied force, as measured by the reference standard.

Fit separate incremental and, where required, decremental curves to these sensitivity values.

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Section 3

Traceability requirements for the continuous calibration reference standard

General

This section details the performance requirements for an instrument to be used as a reference standard against which a force-proving instrument is able to be continuously calibrated.

Initial requirements

The reference standard shall be calibrated as a force-proving instrument in accordance with the ISO 376 static calibration procedure, with the results assessed for interpolation and incremental/decremental loading (Case D), with the results (excluding reversibility, as a separate equation shall be derived for decremental forces) leading to a classification of Class 00 and an expanded uncertainty of not more than 0,01 % at all calibration forces.

The instrumentation used with the transducer to form the reference standard shall be capable of providing a post-run time v output record in digital format for subsequent data analysis.

Additional requirements

The additional requirements relate to the short-term creep characteristics of the reference standard. These characteristics are determined by an unloading creep test as detailed in the following section.

NOTE 1 The assumption being made is that, for a reference standard with very low creep characteristics, the force application rate will not significantly affect its output at a given calibration force. Tests performed loading two low-creep transducers in series have helped confirm this insensitivity to force application rate.

NOTE 2 Ideally, the reference standard’s short-term creep characteristics would be determined by a loading creep test, but this is made impractical by the combination of the time required to smoothly apply the calibration force and the subsequent stability of this force value. Studies have shown that the loading and unloading creep characteristics of force transducers are of similar magnitudes, so a test in which the calibration force is rapidly removed offers a valid method to estimate the transducer’s short-term creep performance.

When, for the reference standard’s subsequent use, partial incremental and decremental calibrations are required, additional partial static incremental / decremental runs need to be performed.

Unloading creep test

Procedure

The reference standard shall be loaded within a force machine to the maximum calibration force applied during its ISO 376 static calibration. The expanded uncertainty of this applied force shall be no greater than 1 % and the filter frequency of the reference standard’s instrumentation shall be no lower than 2 Hz.

Maintain the maximum calibration force for at least as long as the duration of the incremental run in the ISO 376 static calibration (300 s to 600 s) and then, while logging the reference standard’s output at a sampling rate of at least 10 Hz, rapidly remove the applied force (the force shall reduce from $0{,}98F_{\mathrm{max}}$ to zero in no more than 2 s).

Continue to record the reference standard’s output for at least twice as long as the loading duration (600 s to 1200 s)

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(after 10 s, the logging rate may be reduced to a minimum of 1 Hz).

Analysis

From the recorded data, identify the time at which the force was fully removed from the transducer and then ignore the data from the following second (as some of this will be affected by the instrumentation's filter settings and possibly transducer vibration).

From the data recorded after this time, identify the maximum and minimum output values, then express the magnitude of their difference as a percentage of the deflection at F_{max}. For certification as a continuous calibration reference standard, this difference shall not exceed 0,02 %.

Partial reversibility test

Procedure

This test shall be performed in the last installation position of the static ISO 376 calibration with a waiting pause of at least 10 minutes after its last measurement sequence. Partial static incremental / decremental runs covering the range from 10 % up to 30 % and 10 % up to 60 % of the maximum force with at least four evenly-distributed force steps for the incremental and decremental run with at least 30 s dwell time at each force step are to be performed.

Analysis

For each partial run the reversibility related to its own maximum deflection is to be estimated as $v_{\mathrm{FSO}} = \frac{x_{i,\mathrm{inc}} - x_{i,\mathrm{dec}}}{x_{\mathrm{max}}} \times 100\ \%$. This shall also be done for the mean reversibility of the ISO 376 calibration. Then all reversibility values related to their own maximum deflections are to be plotted against deflection in % of the maximum deflection of each run. If there is a curve which envelopes all other curves this can be fitted with a 6^{th} degree polynomial with a constant part using the least squares method.

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