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Development of a methodology to deliver continuous force traceability for materials testing

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ComTraForce Public Stakeholder Workshop
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    - Short-term unloading creep test
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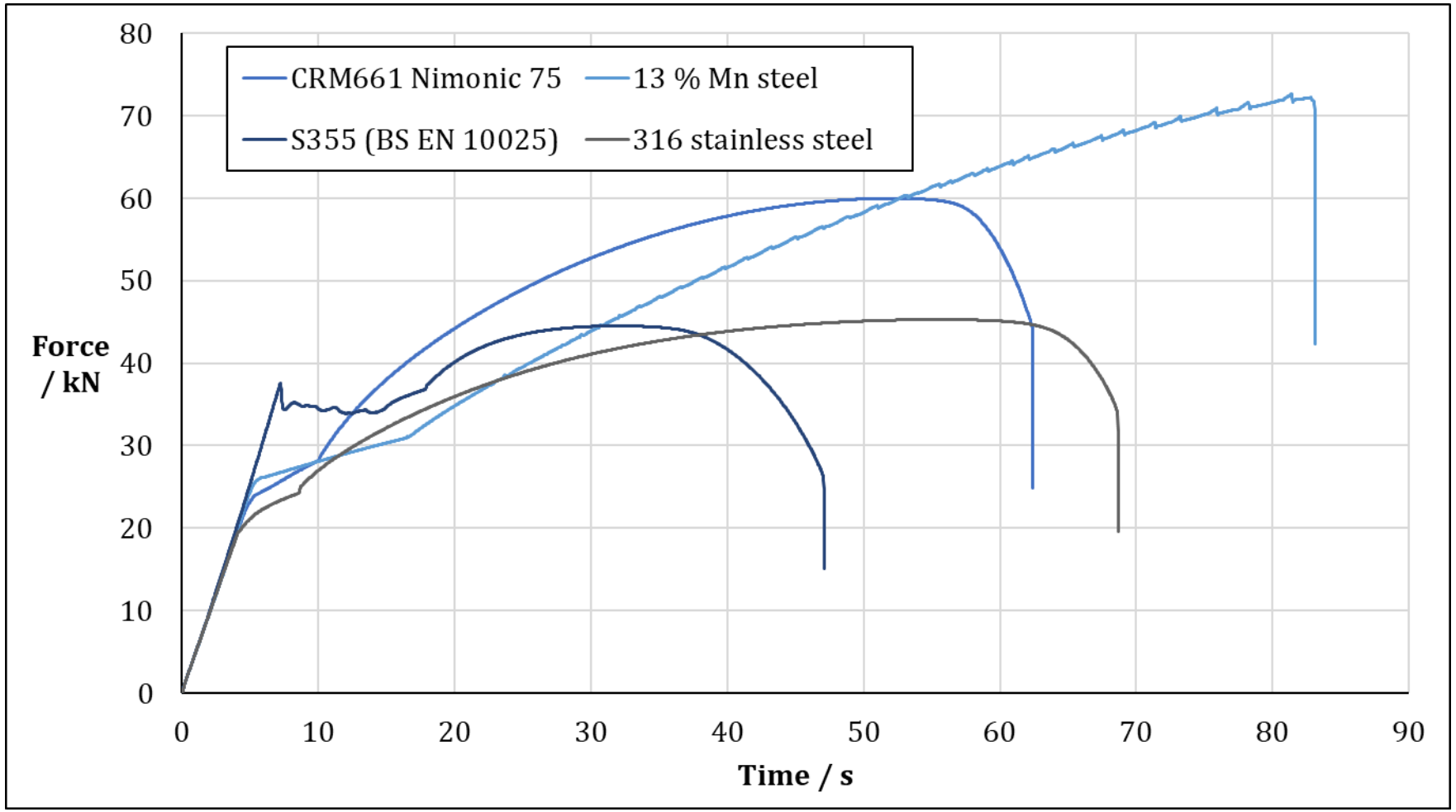
- Conclusions

Background on materials testing

- ISO 6892-1: Metallic materials – Tensile testing
  Part 1: Method of test at room temperature
- Tensile test parameters include:
  - Elastic modulus
  - Yield strength
  - Proof strength
  - Tensile strength
- All calculated values depend on force indicated by testing machine

Typical Force v Time Plots for ISO 6892-1



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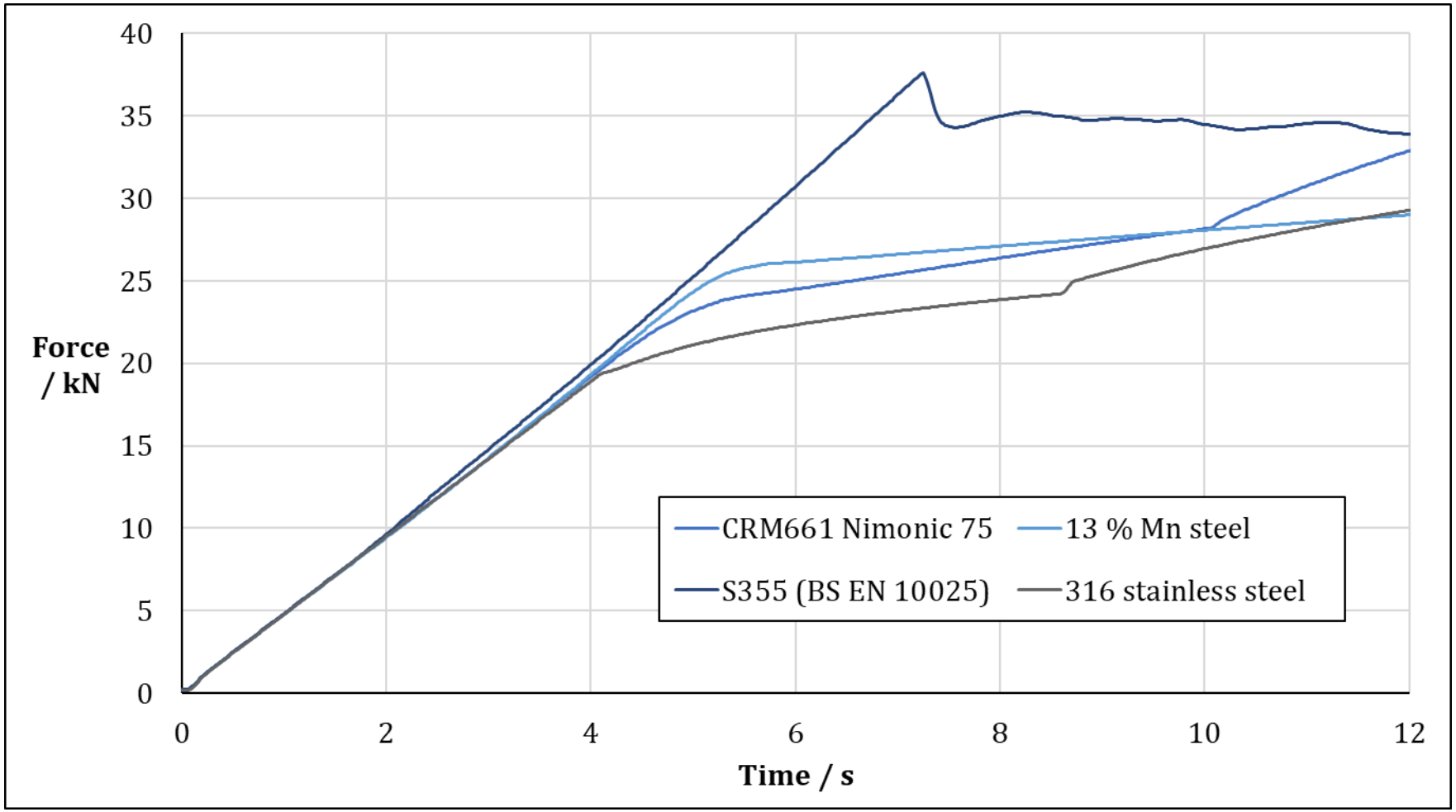
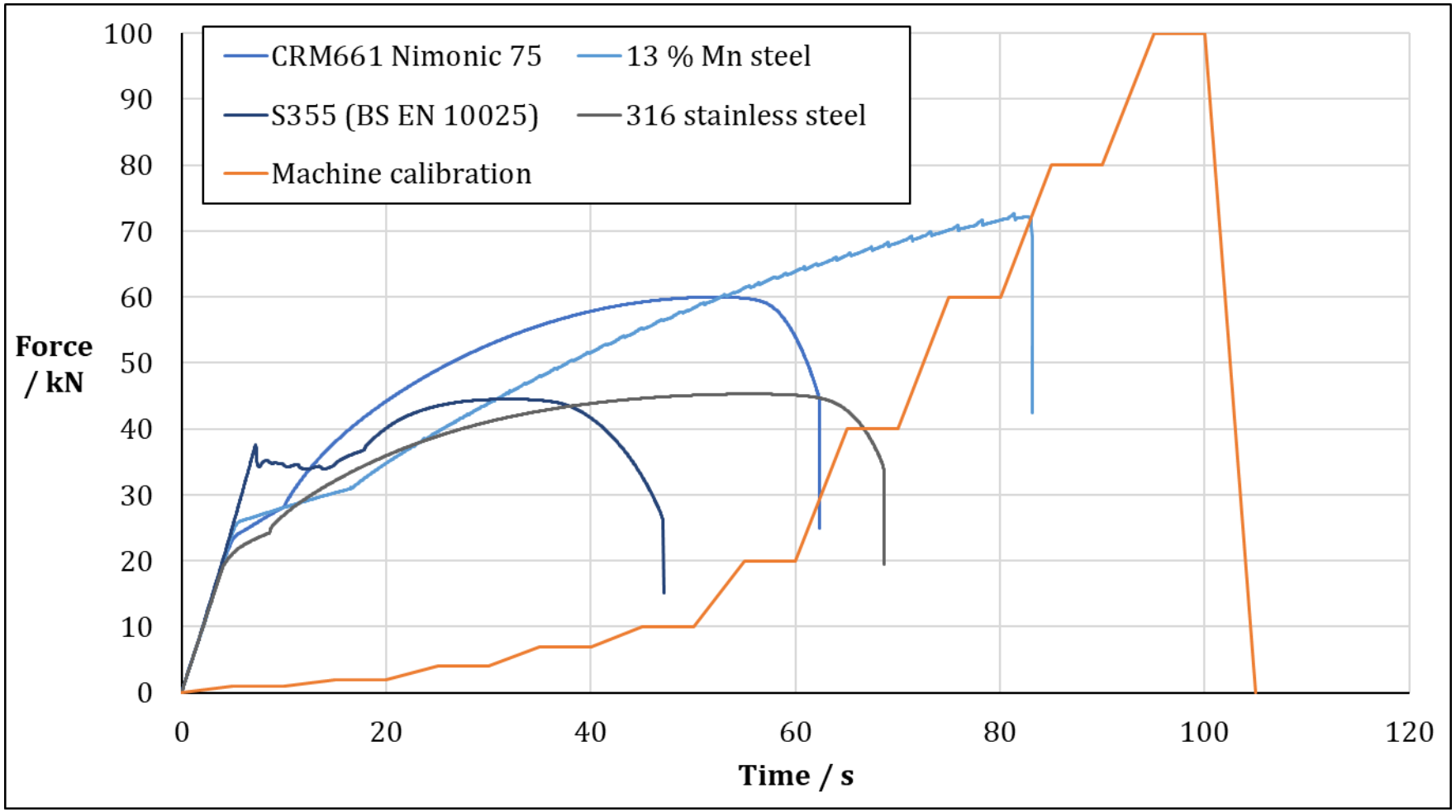
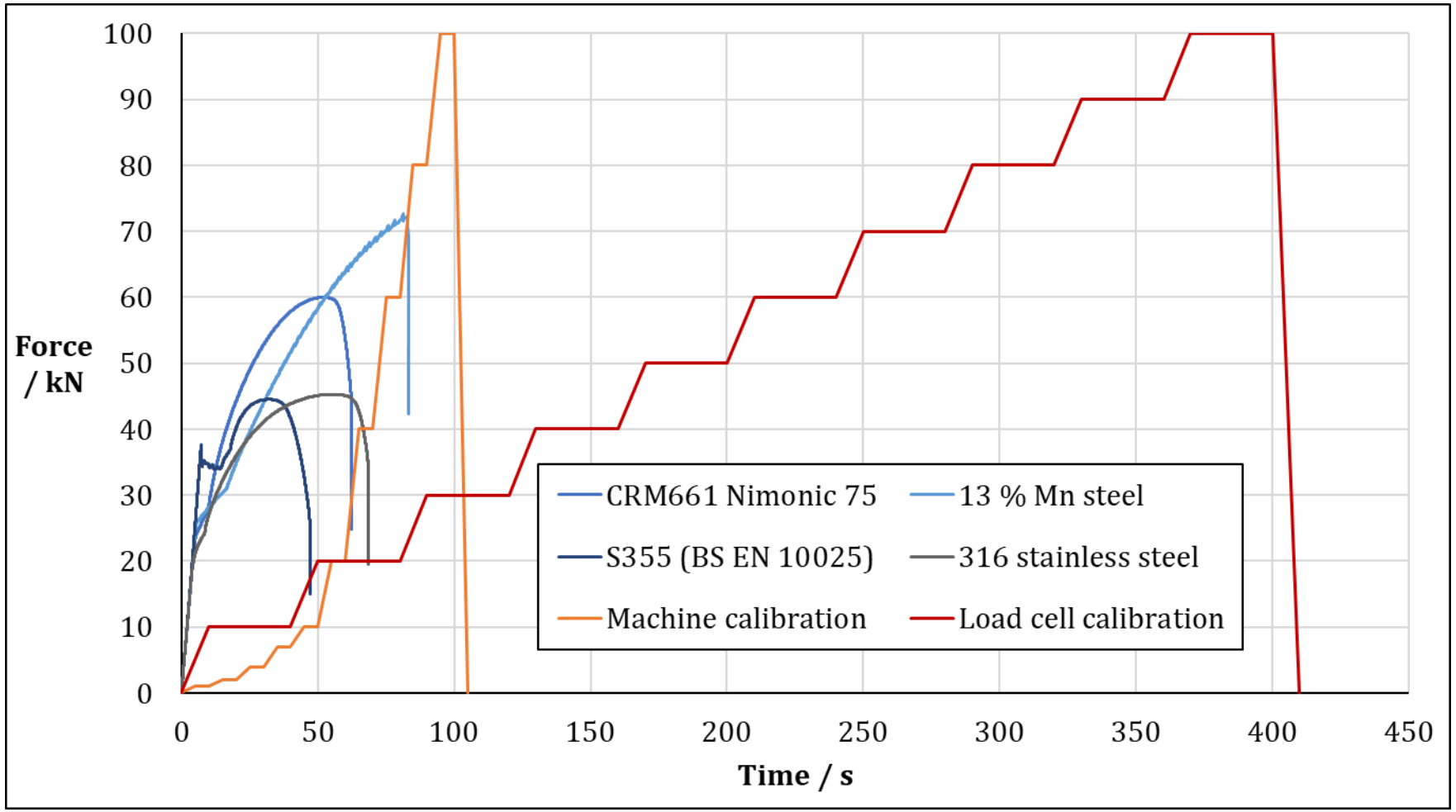


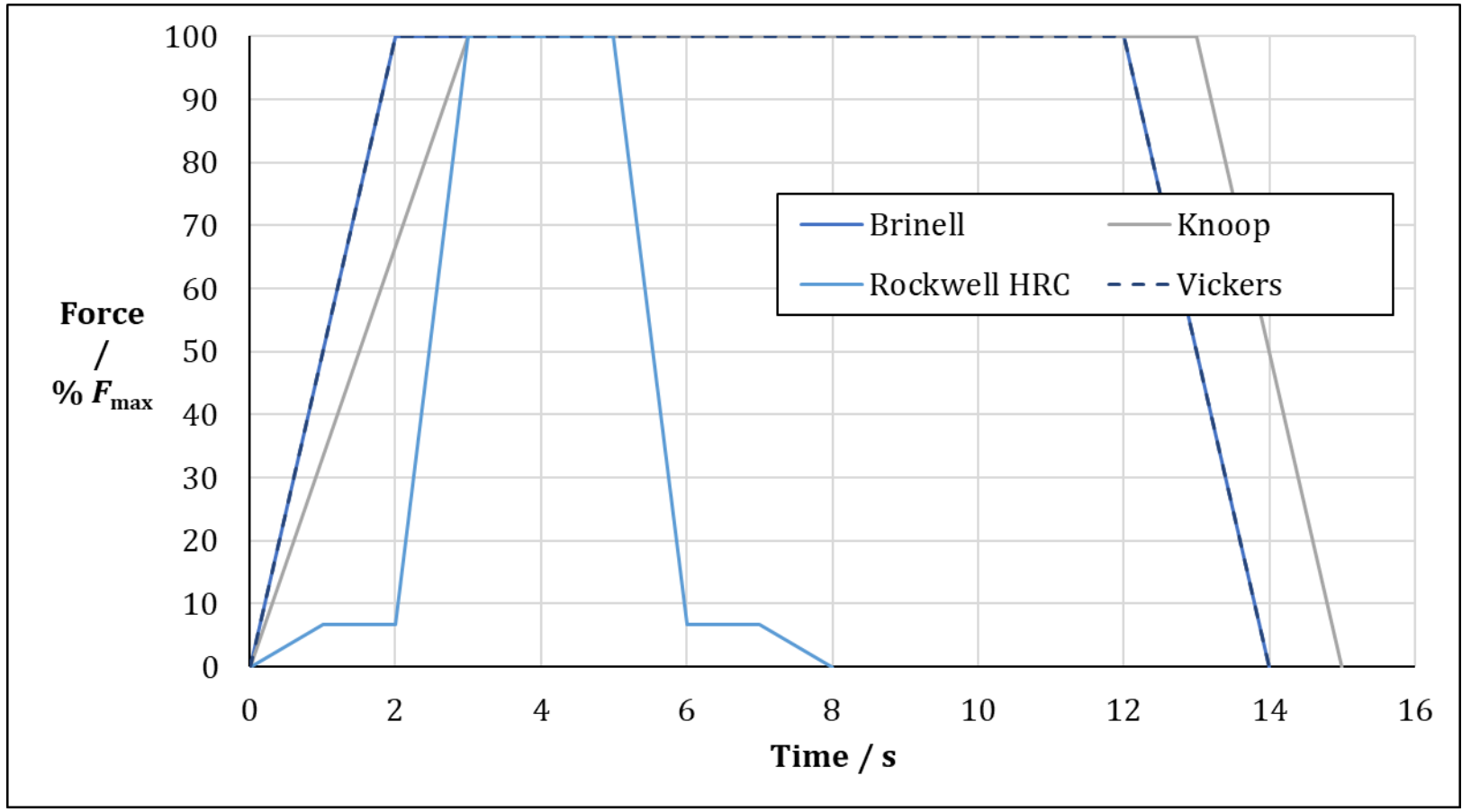
Machine Calibration to ISO 7500-1



Proving Instrument Calibration to ISO 376



Similar for Hardness Testing



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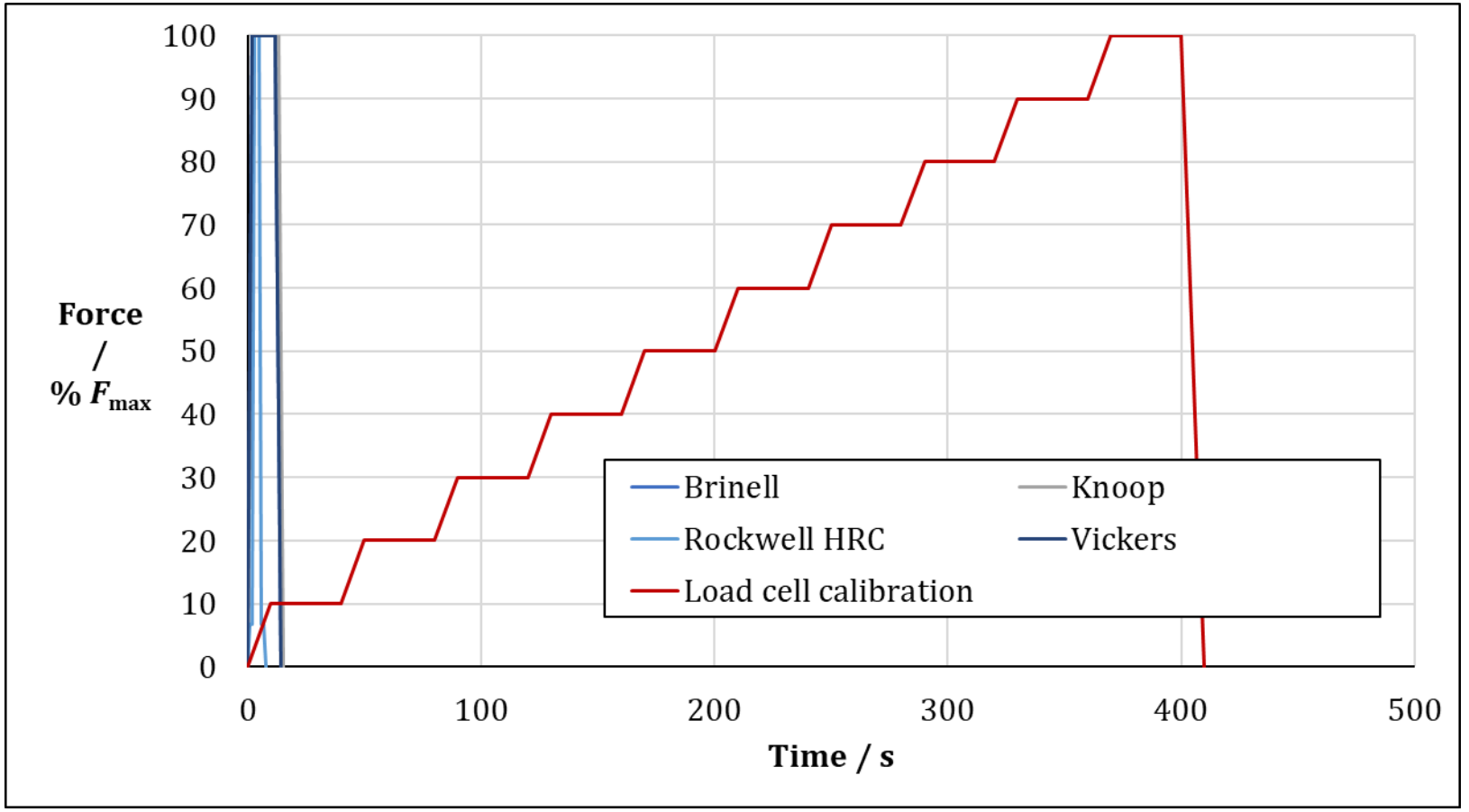

Proposed force traceability method

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Step 1

- Develop continuous force calibration reference standard
  - Top class force transfer standard, based on static calibration results
  - Additional short-term creep test and associated performance criteria

Step 2

- Calibrate proving instrument against reference standard
  - Range of force application rates, determine sensitivity differences
  - Proving instrument also to be calibrated statically

Step 3

- Use proving instrument to calibrate testing machine force display
  - Range of force application rates, determine machine errors
  - Care needed in data synchronisation

Step 1 – Reference standard

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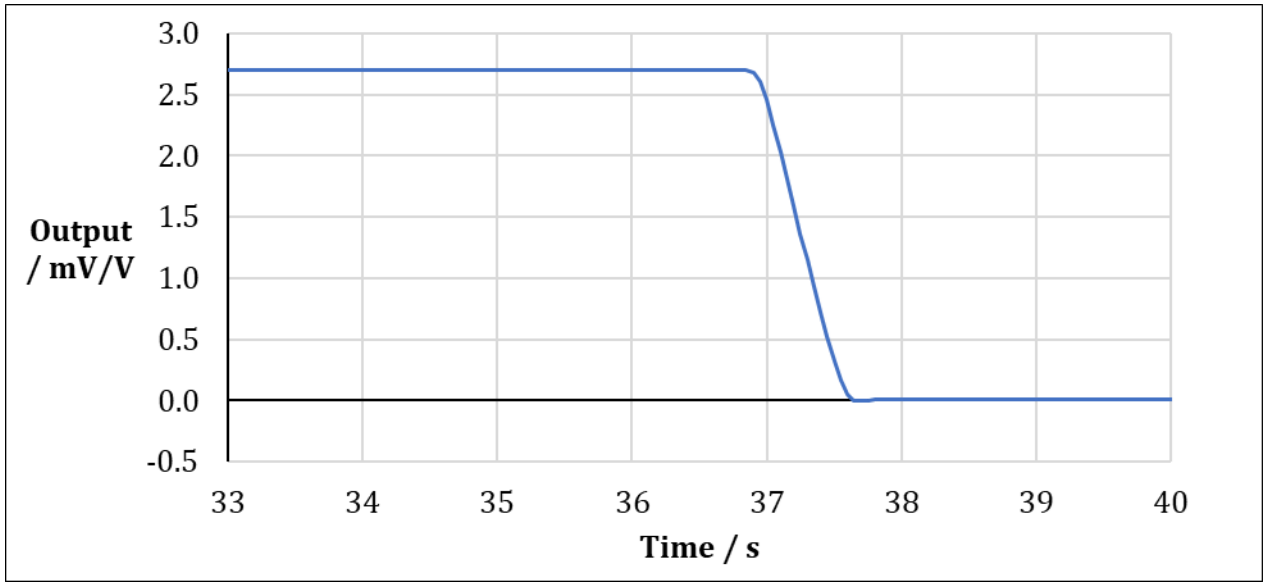
Initial requirements

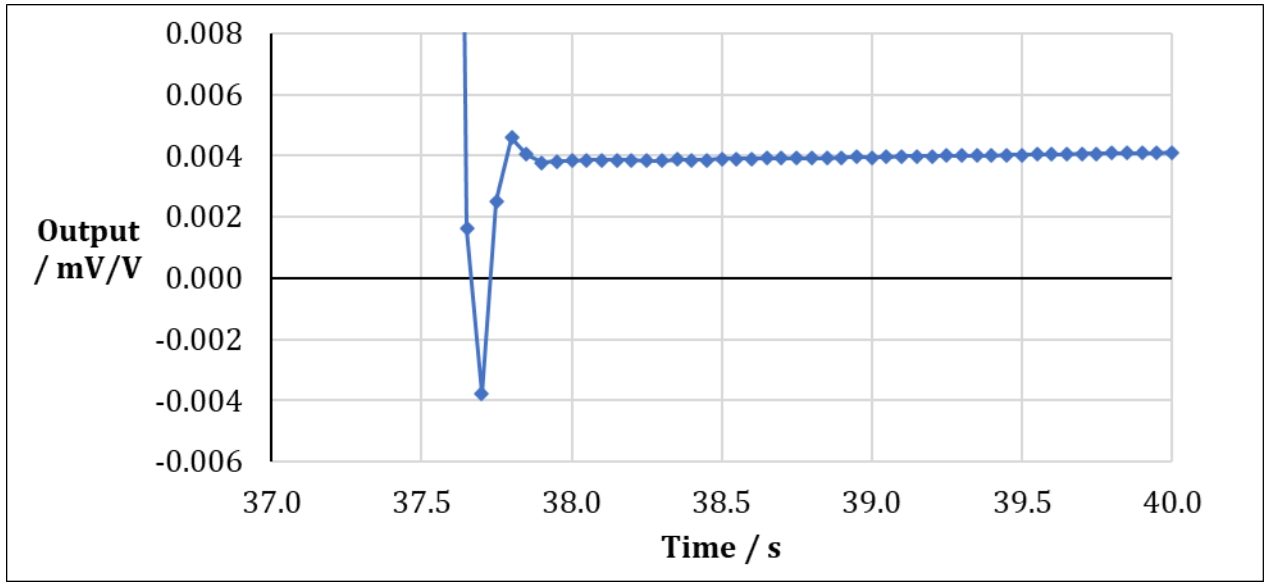
- Statically calibrated to ISO 376 for interpolation and incremental/decremental loading
  - Must meet Class 00 for all performance criteria excluding reversibility (as a separate decremental interpolation equation is to be determined, with same maximum force always applied)
  - Expanded calibration uncertainty at each force not to exceed 0,1 %
- Instrumentation to be capable of providing a post-run time v output record in digital format for subsequent data analysis

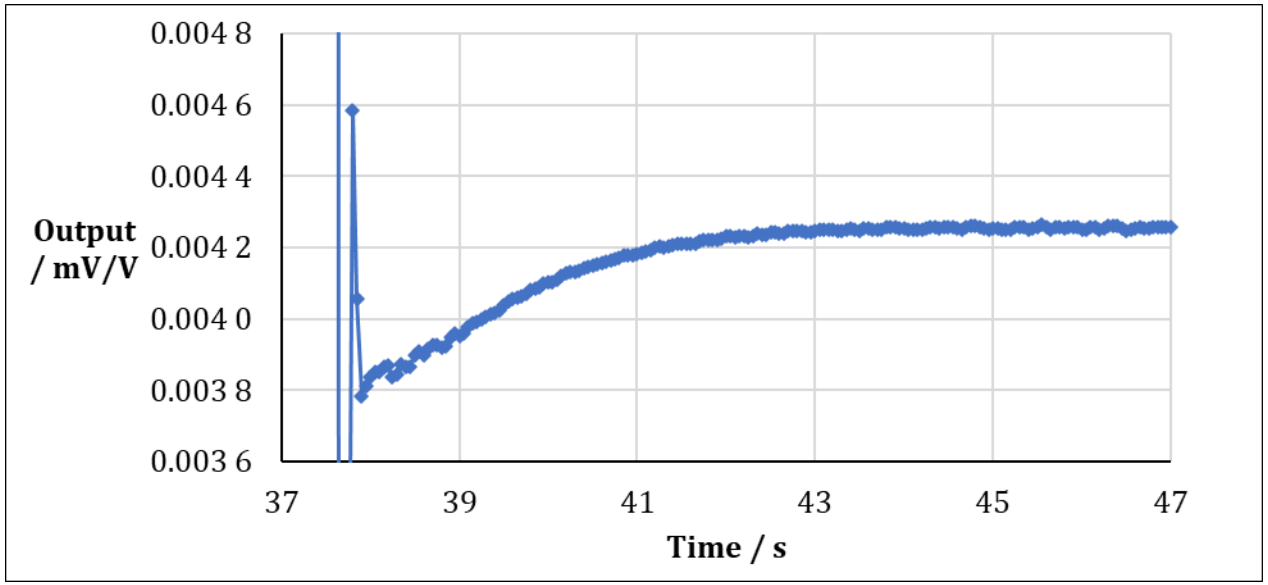
Additional requirements

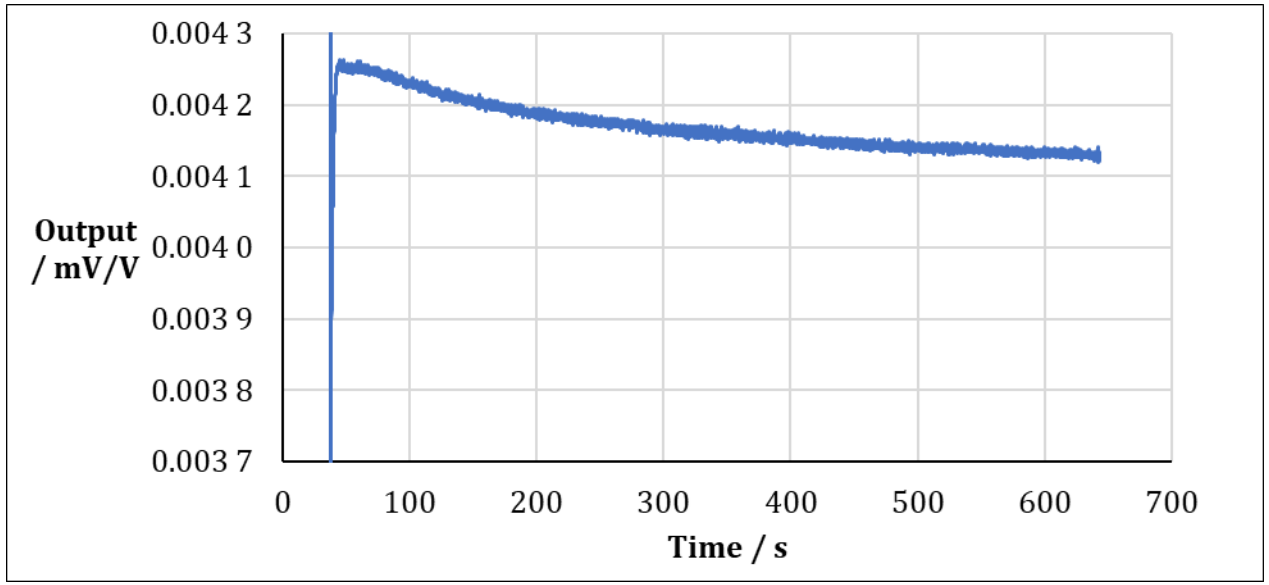
- Unloading creep test from maximum force (held for at least 5 minutes)
  - Variation in output from 1 s after unloading for next 10 minutes not to exceed 0,02 % of deflection at maximum force

Step 1 – Reference standard (creep 0,013 %)









Step 2 – Calibrate proving instrument

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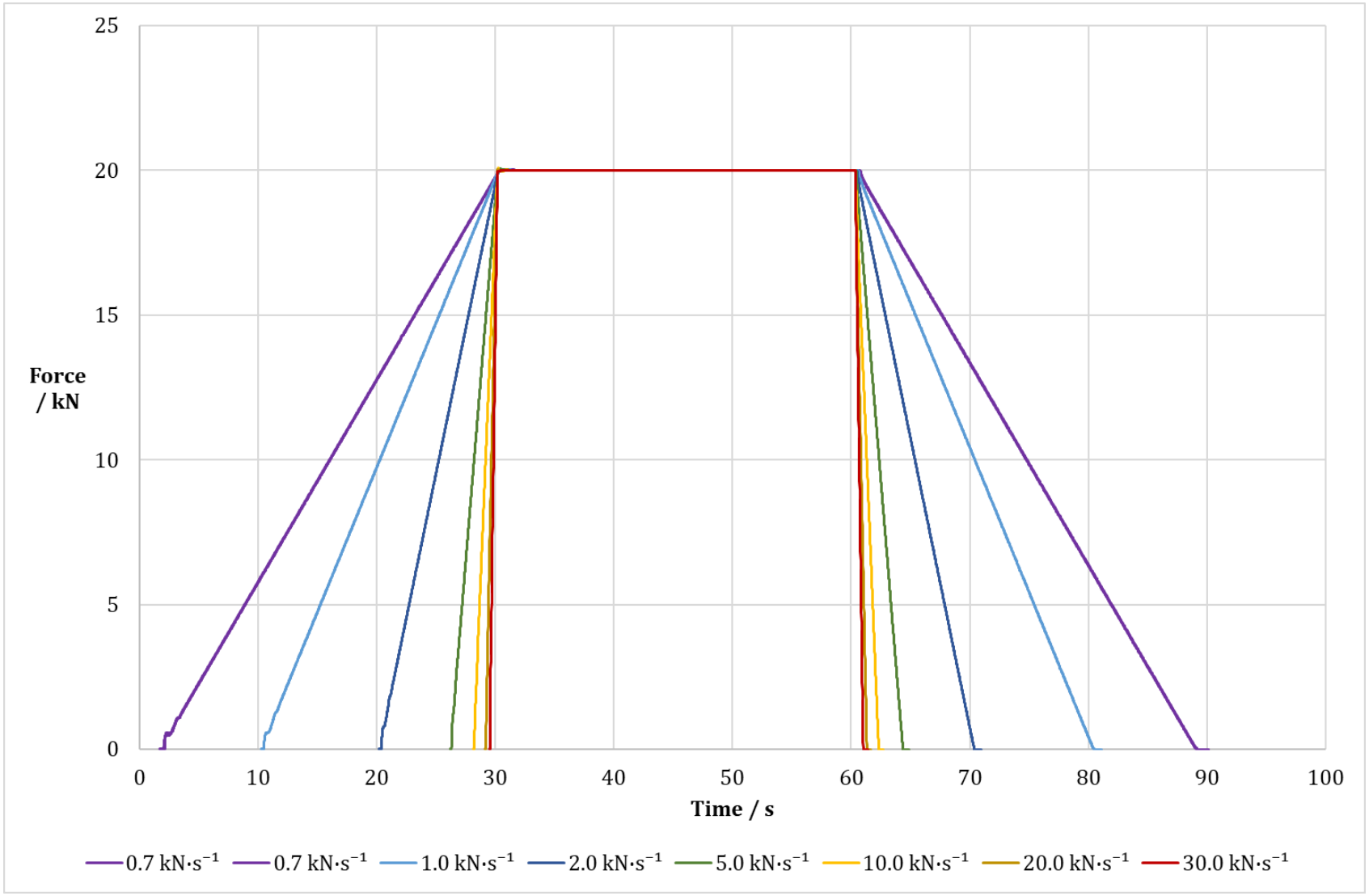
Initial requirements

- Statically calibrated to ISO 376 for interpolation, and classified
- Mechanically coupled to reference standard on machine's central axis
- Identical instrumentation and settings, same filter as for subsequent work, at least one reading per % of maximum force, capable of providing post-run time v output records in digital format for subsequent data analysis

Procedure

- Incremental ramp, 30 s dwell, decremental ramp
  - At least four different application rates, logarithmically spaced
  - At least two runs at each rate
  - Additional run with no dwell if decremental performance to be determined

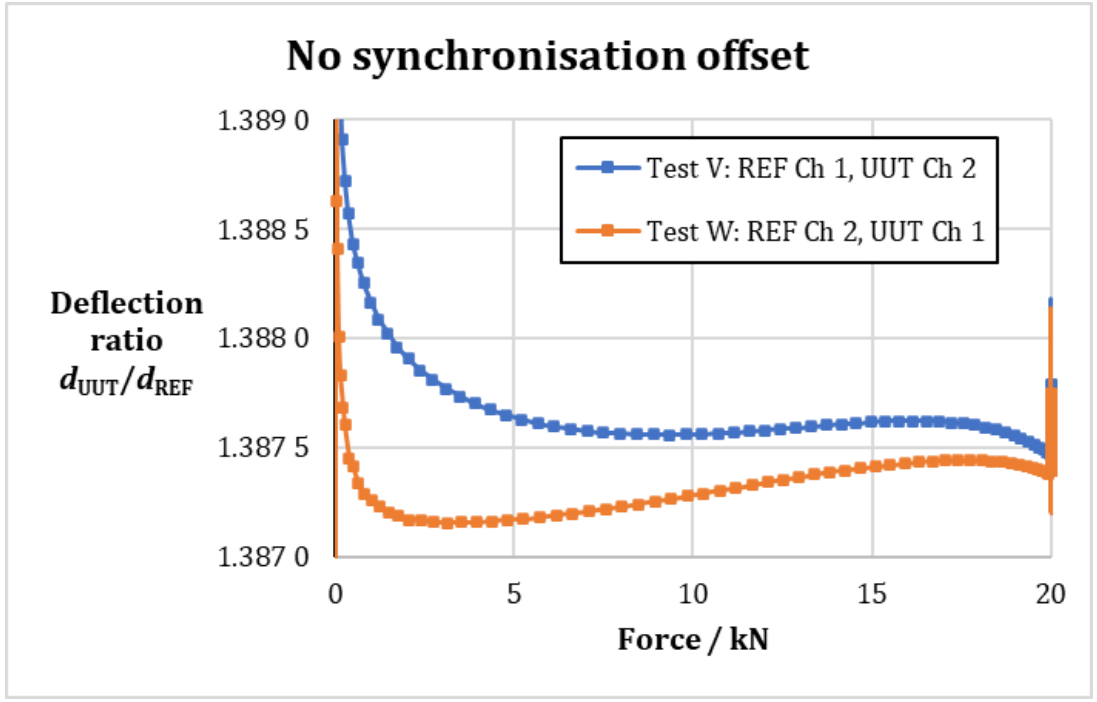
Step 2 – Example loading profiles

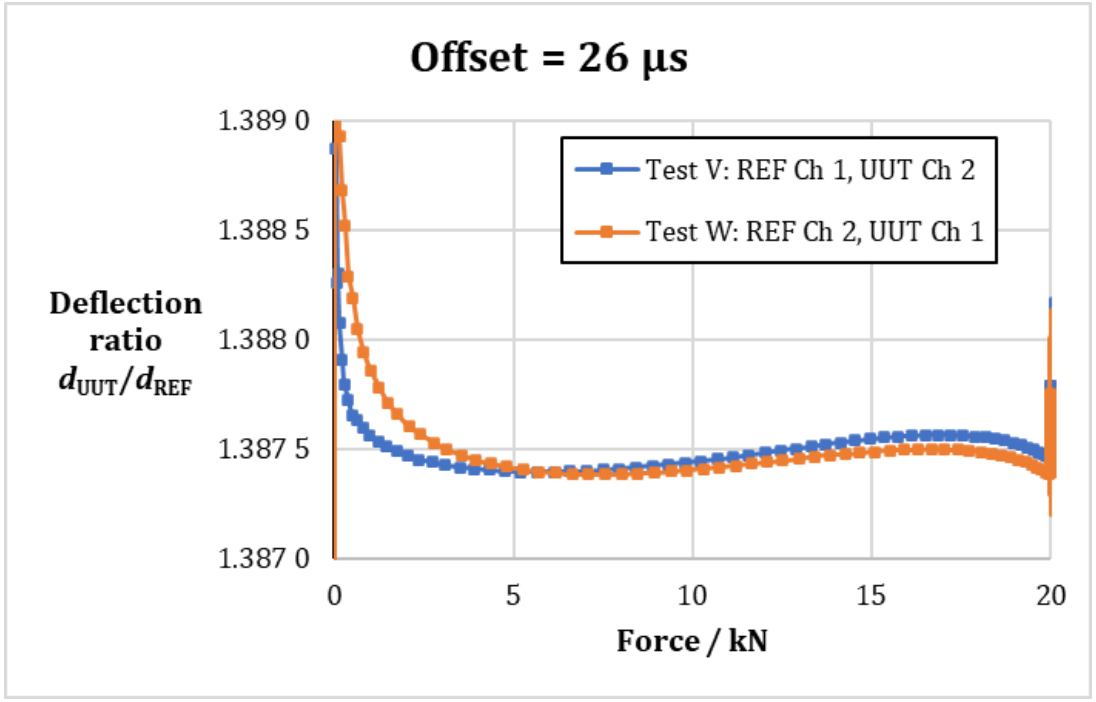


Step 2 – Calibrate proving instrument

Data analysis

- Deflections determined by subtracting initial zero outputs
- Check that outputs are correctly synchronised, e.g. by switching channels and repeating (force rate = 29 kN/s):





Step 2 – Calibrate proving instrument

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Data analysis, continued

- In each run, for each (reference standard, proving instrument) data pair, determine proving instrument sensitivity:
  - Calculate applied force from reference standard deflection and its ISO 376 static interpolation coefficients
  - Divide proving instrument deflection by applied force
- For each run, determine a best fit equation relating the proving instrument sensitivity to applied force then, from this equation, determine the sensitivity at each calibration force used during instrument's static calibration
- For each of these calibration forces, determine the spread of sensitivity values
- Determine classification based on static calibration and spread of sensitivities
- Determine uncertainty for each force application rate

Step 3 – Calibrate testing machine

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Initial requirements

- Machine capable of generating linear ramp profiles with minimal overshoot
- Signal conditioning settings (filter type, frequency) known and, ideally, settable
- Proving instrument continuously calibrated
- Both systems capable of providing post-run time v output records

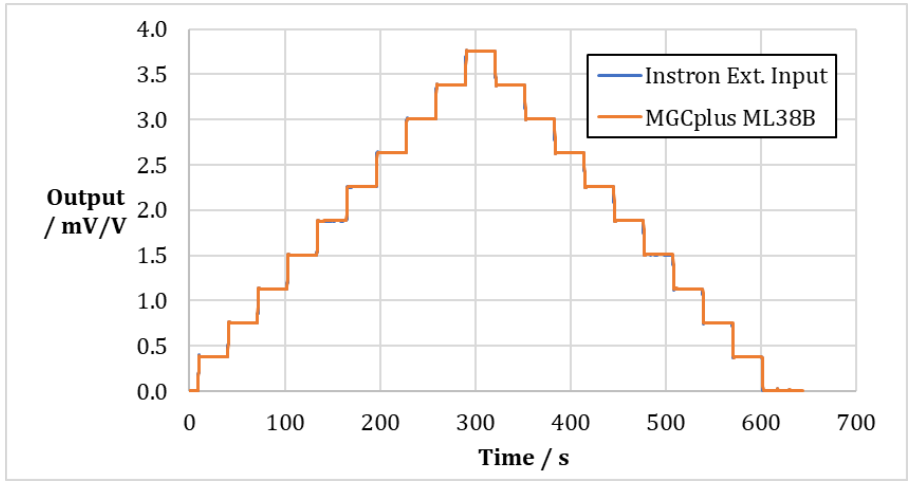
Procedure

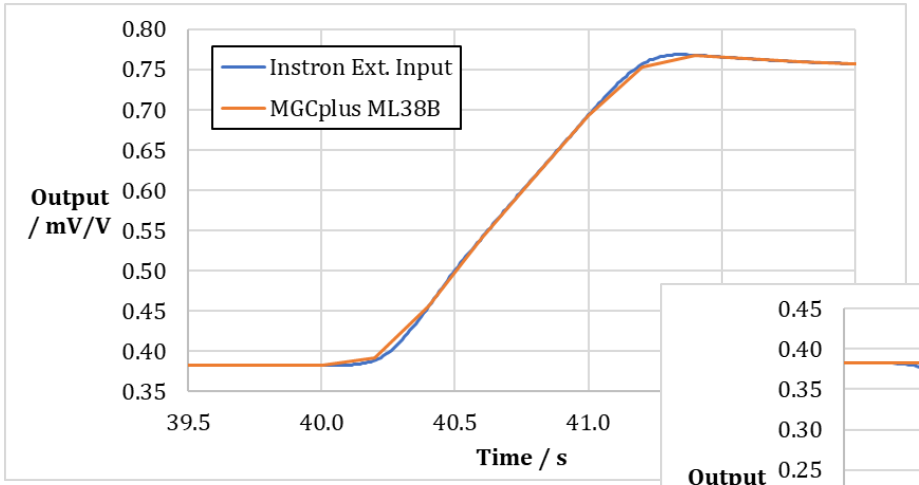
- Set machine and proving instrument filters to same type and frequency, ideally values to be used subsequently, and data rate to at least 100 readings / run
- Three pre-loads followed by zero dwell of >= 30 s, then zero indicator
- Perform two ramp tests at each rate, from 1 % to 100 % of maximum force, with (5 to 30) s dwell at maximum, with extra no-dwell test for decremental
- Final test of >= 5 incremental and decremental steps with >= 30 s dwell at maximum

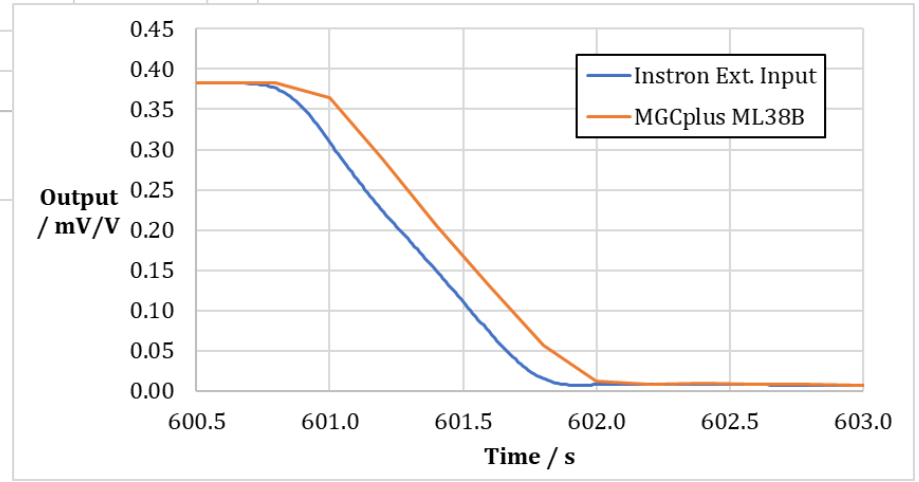
Step 3 – Calibrate testing machine

Data analysis

- Convert all proving instrument readings to force values by subtracting initial zero then using continuous calibration coefficients (from closest rate)
- Determine difference in clock speed between different data acquisition systems, most easily from results of final test:



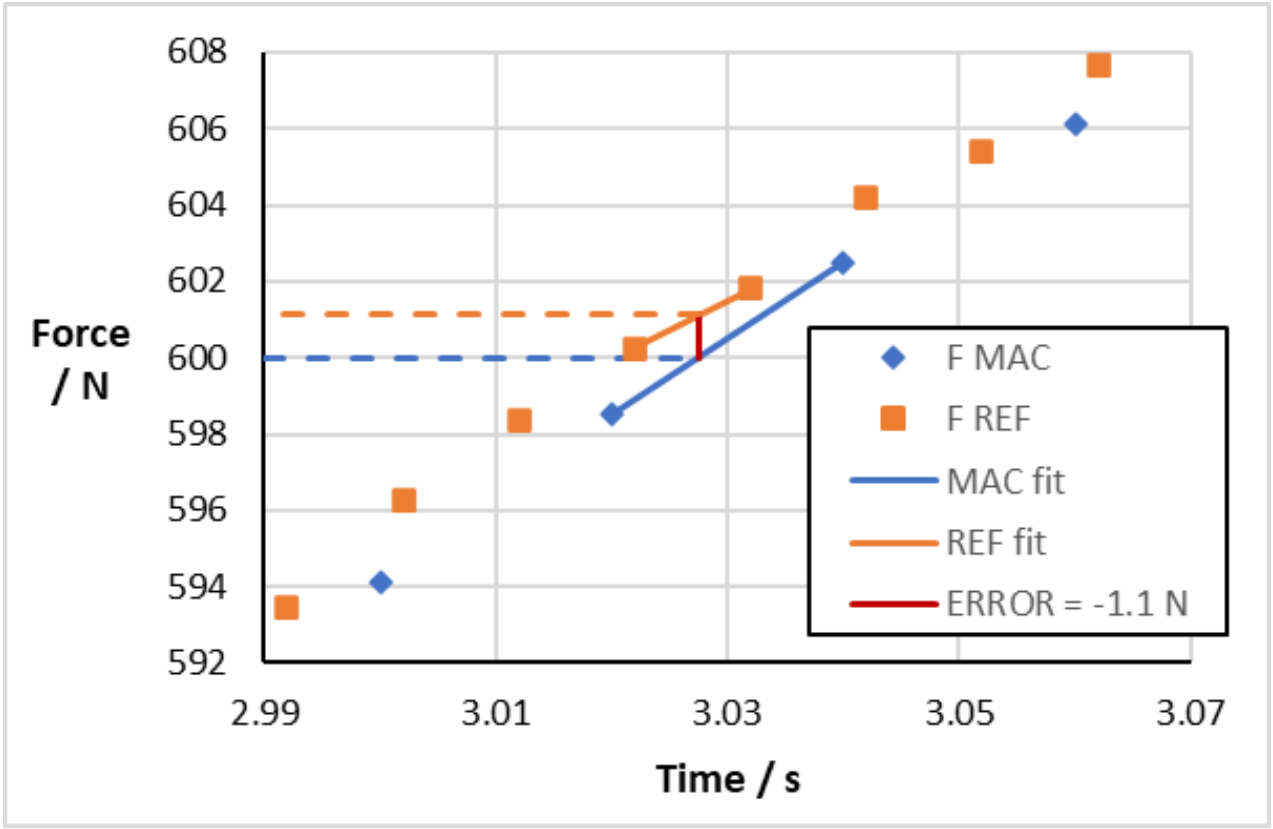




Step 3 – Calibrate testing machine

Data analysis, continued

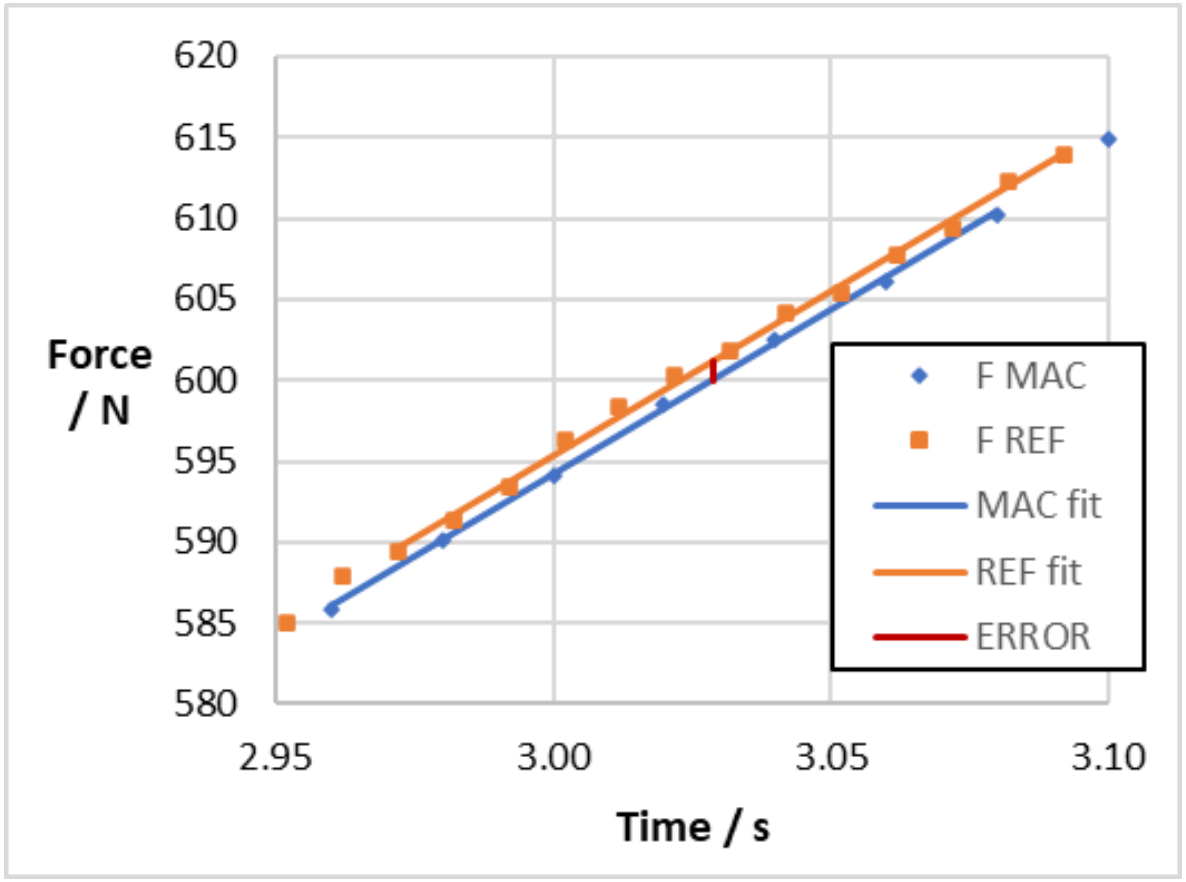
- Correct data for difference in clock speeds
- For each run, roughly synchronise testing machine and proving instrument time v force traces and determine error at each force, e.g. at 600 N:

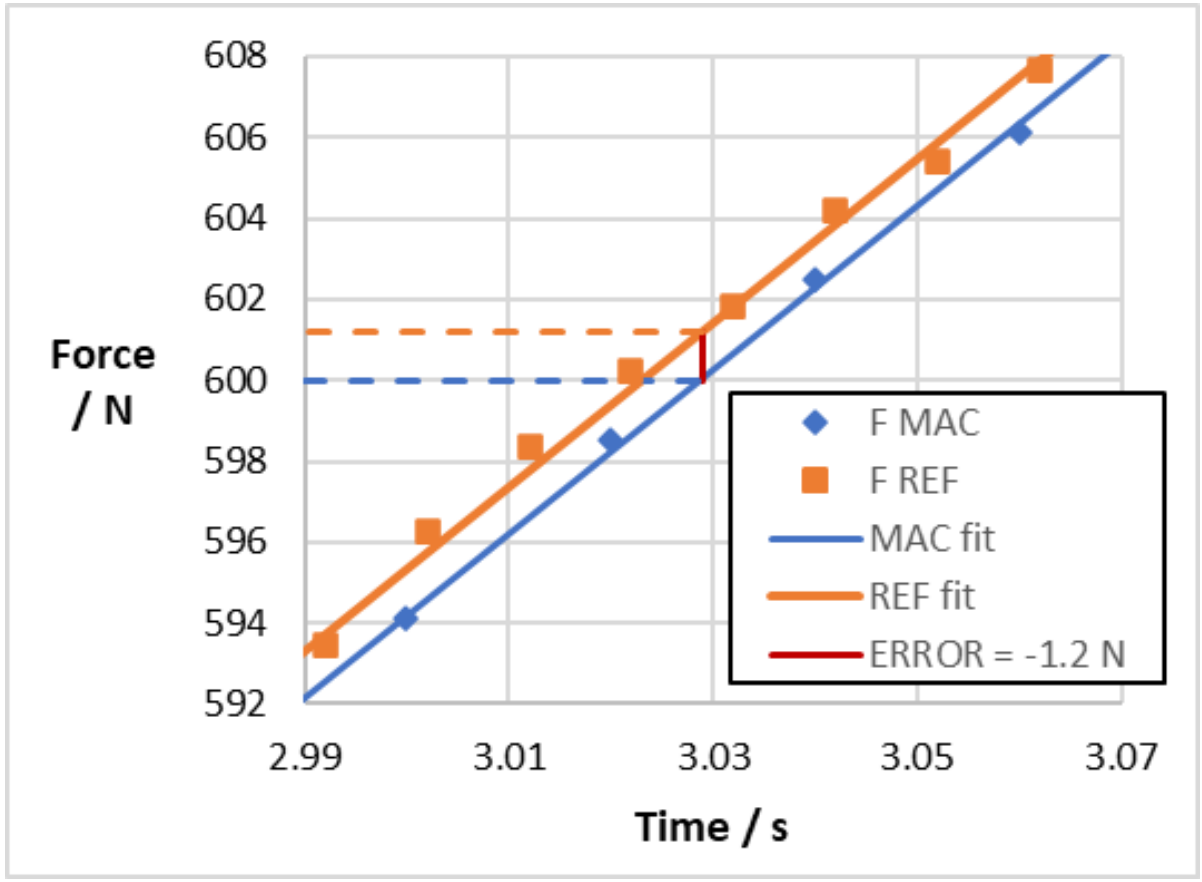


Step 3 – Calibrate testing machine

Data analysis, continued

- Or, for noisy data, interpolate over a greater range of points:

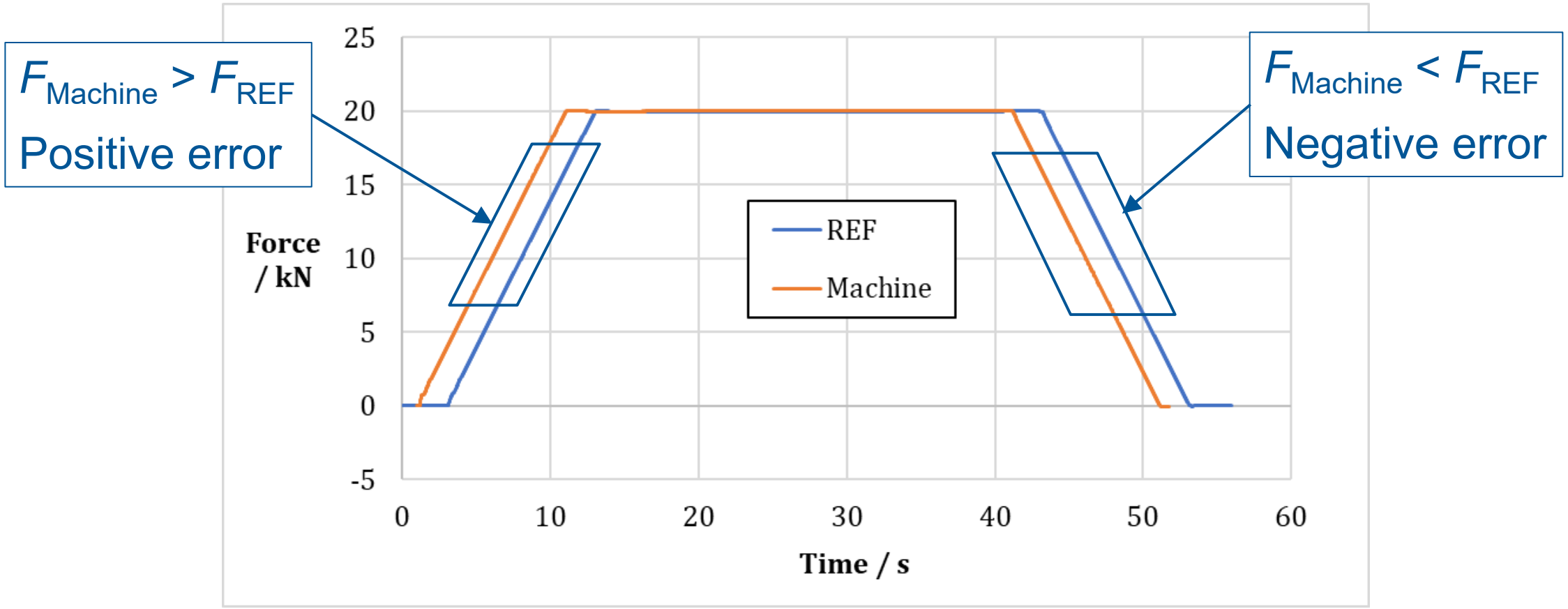




Step 3 – Calibrate testing machine

Data analysis, continued

- Plot incremental/decremental error as a function of force, then fine-tune synchronisation, e.g. by equalising the error at 95 % of maximum force



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Data analysis, continued

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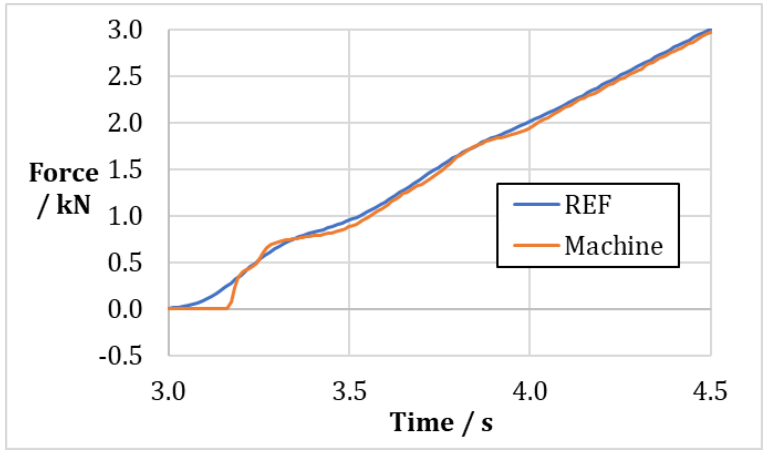

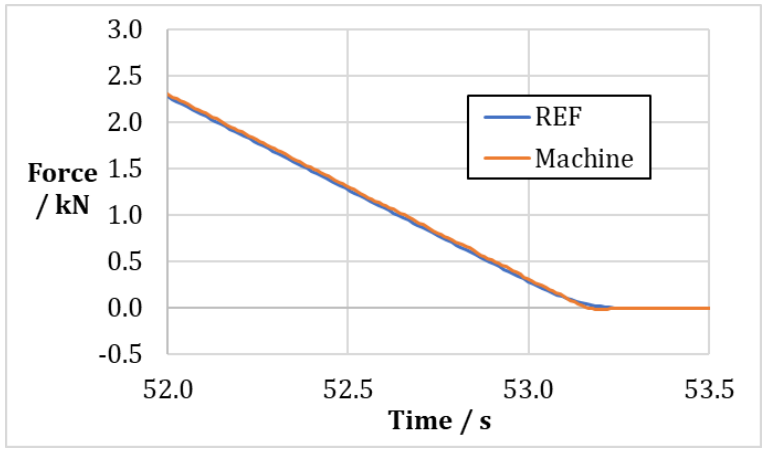

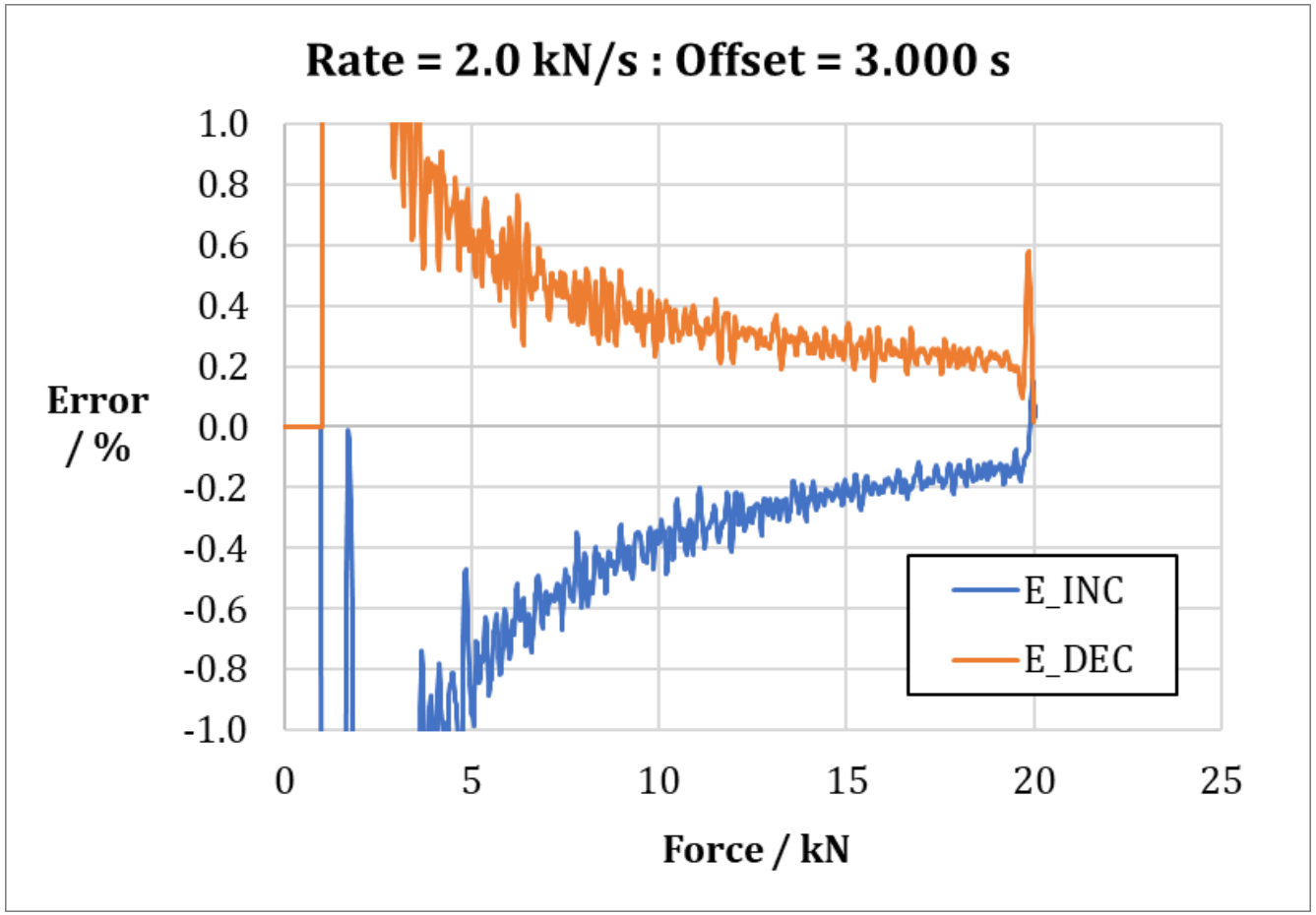

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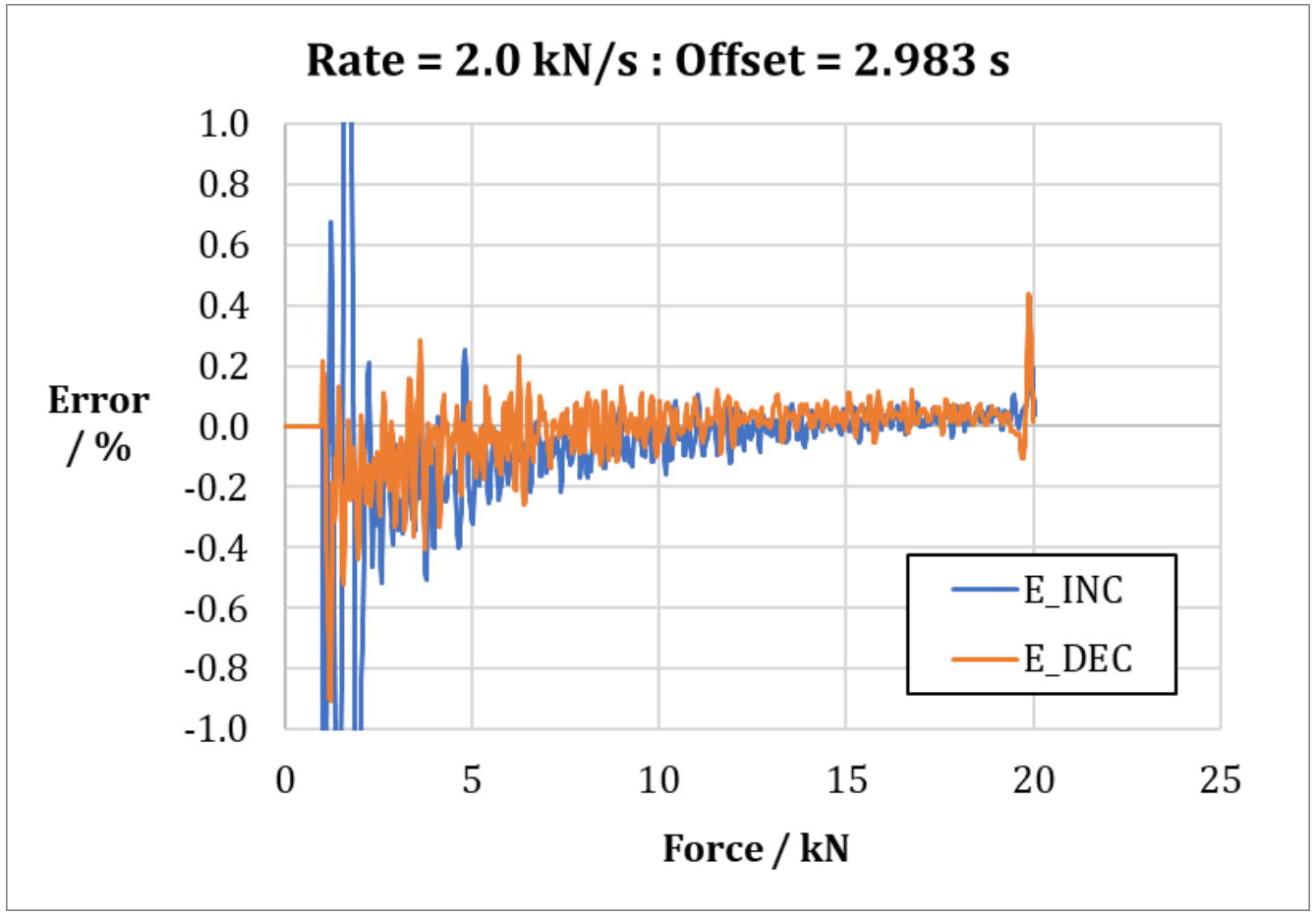
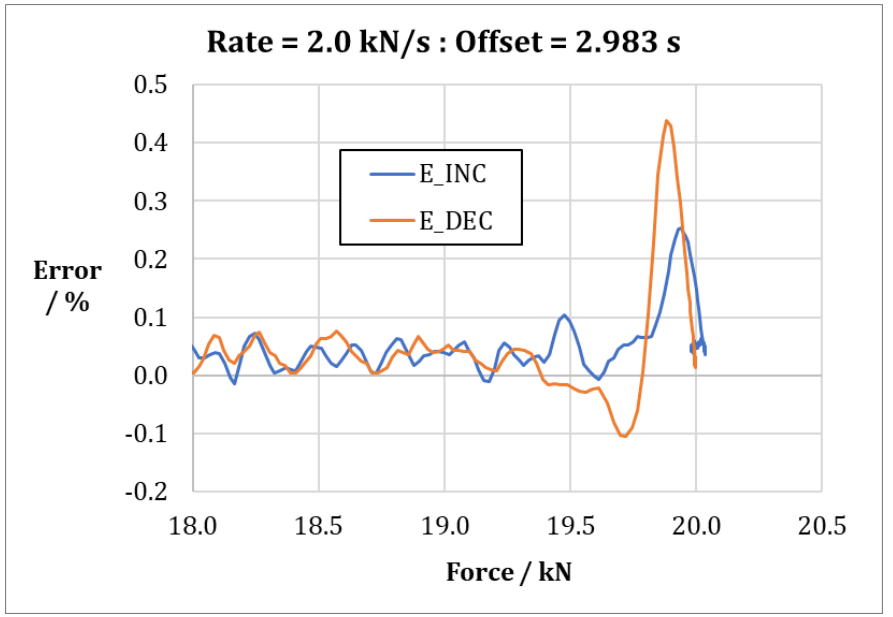
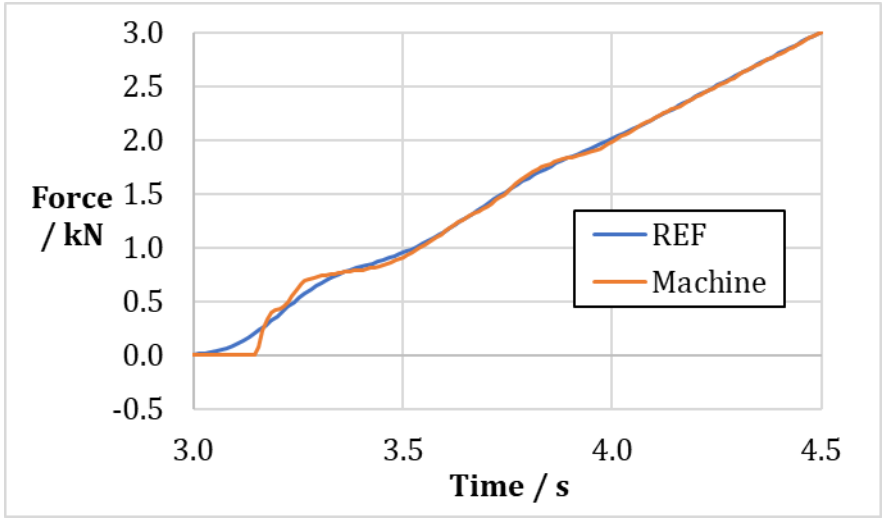
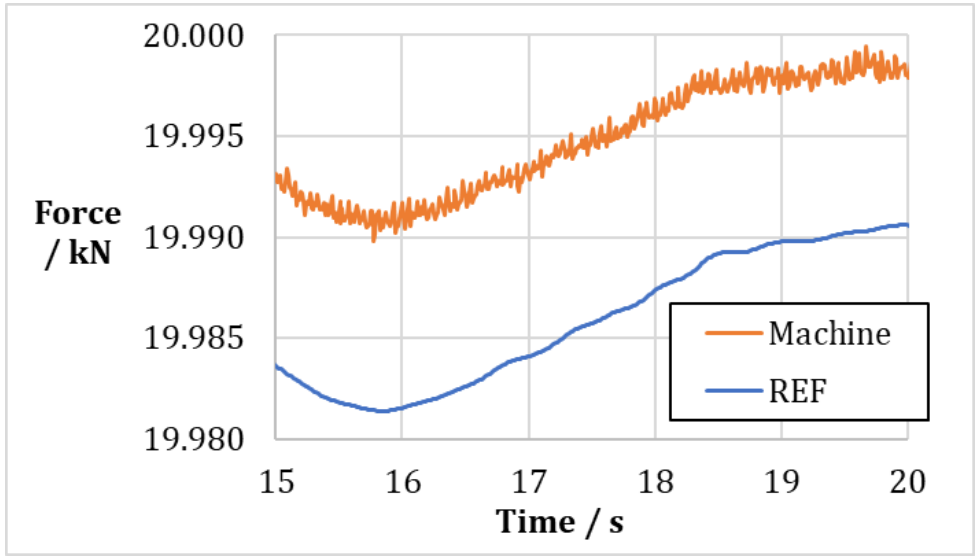
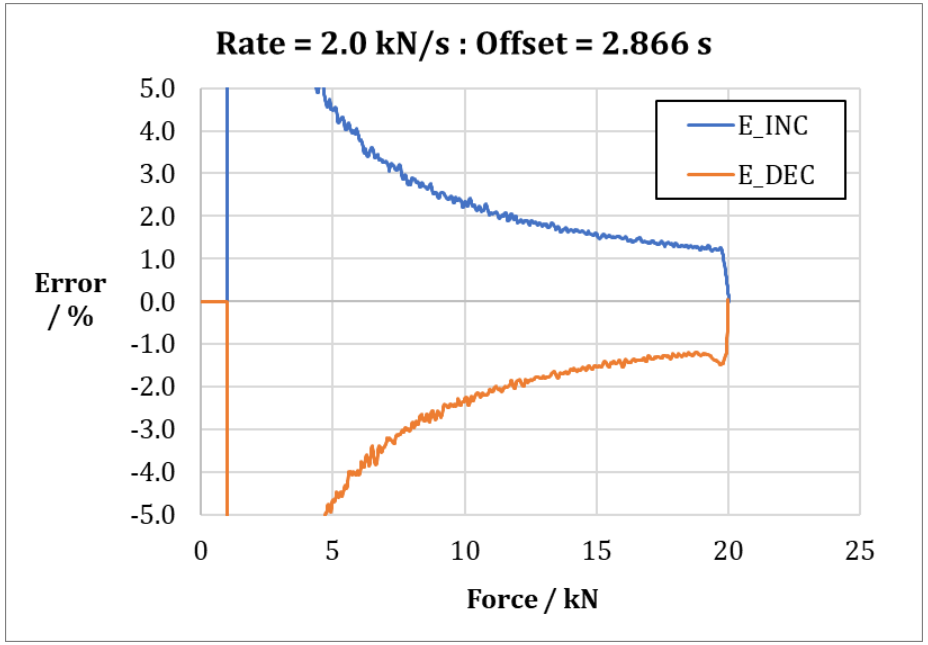


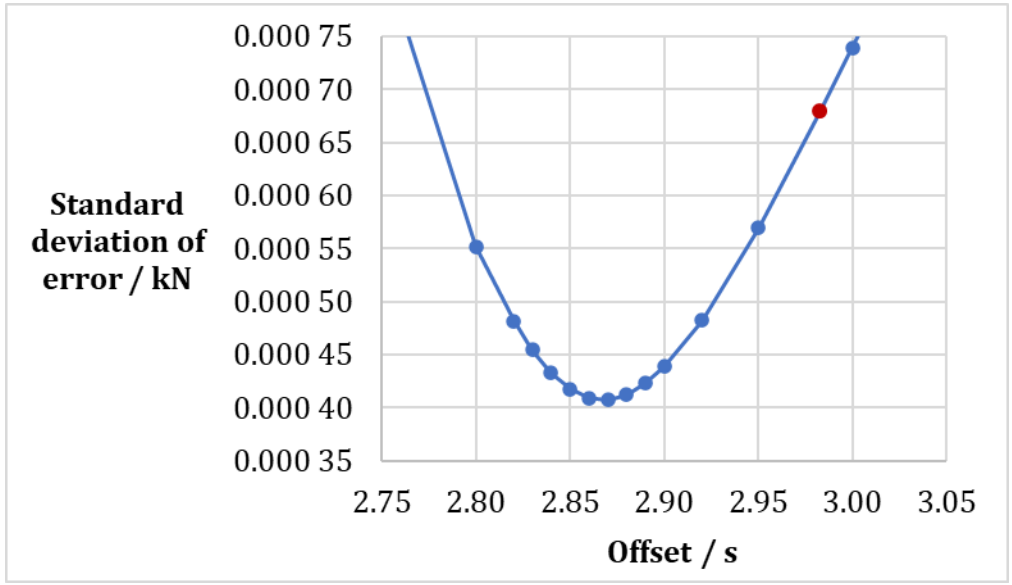


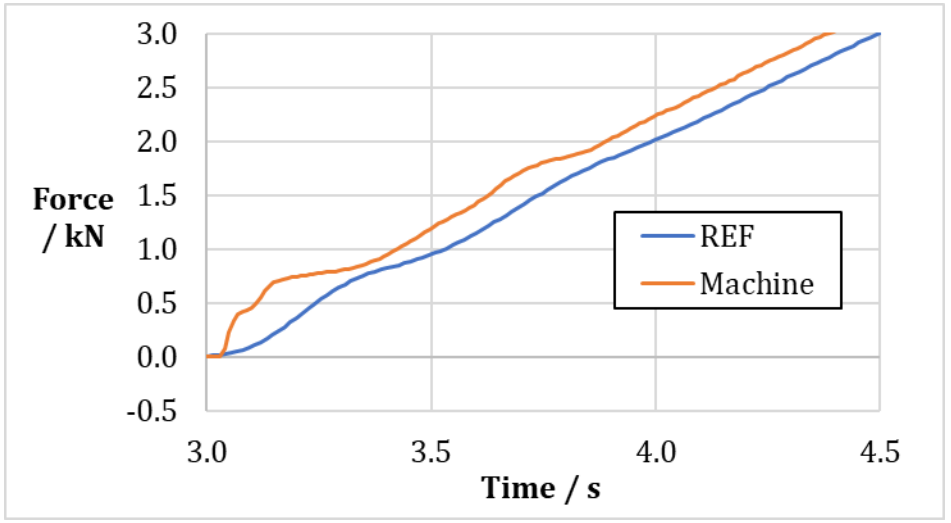


Step 3 – Alternative synchronisation method









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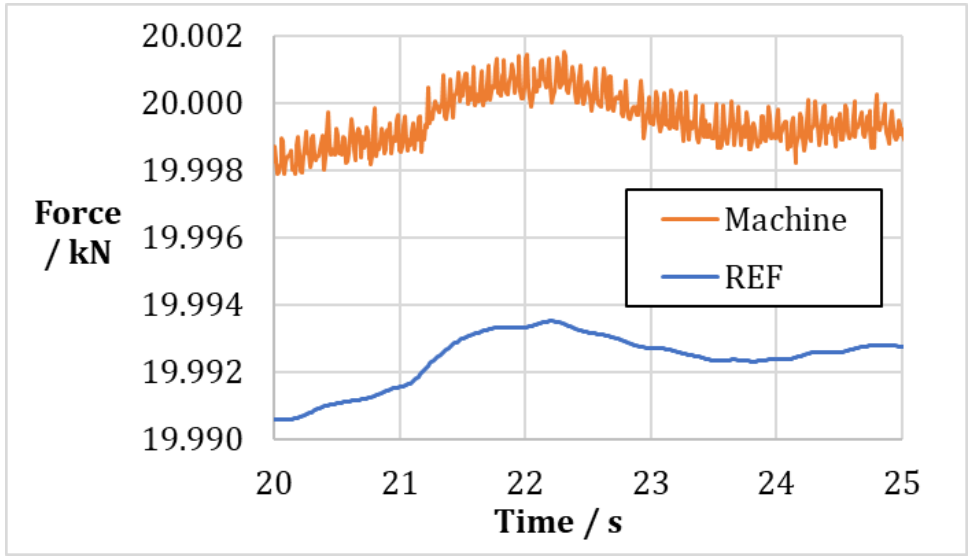

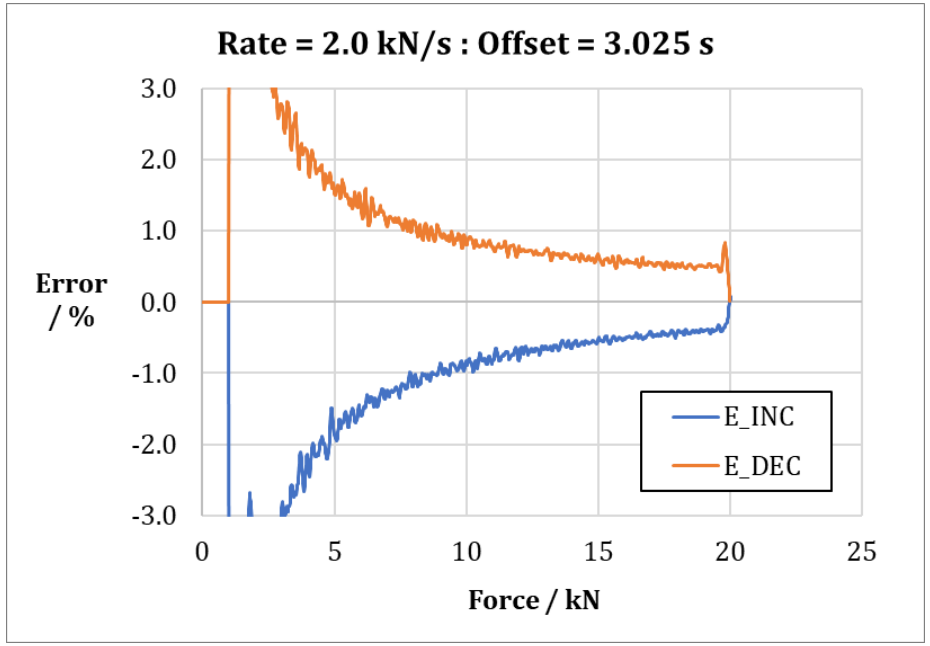

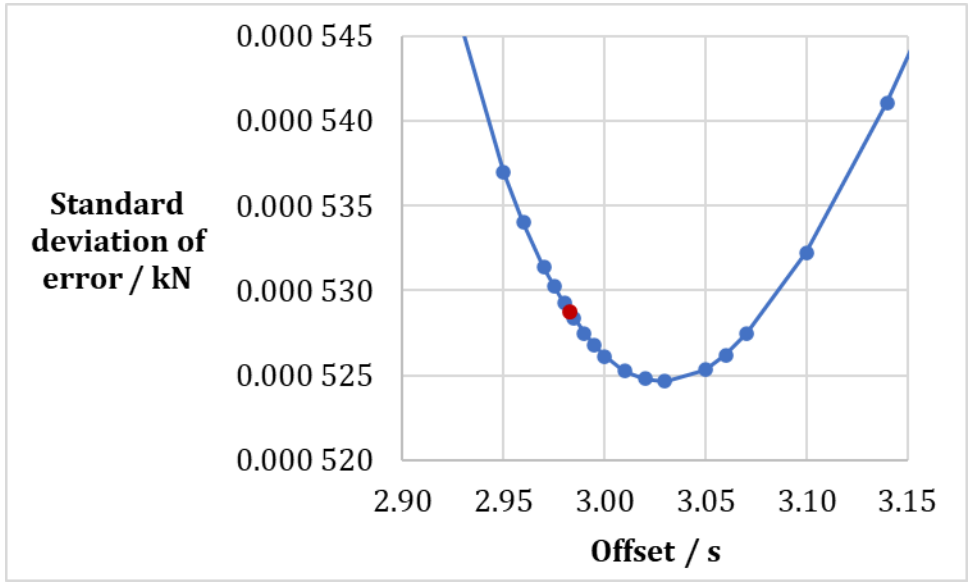

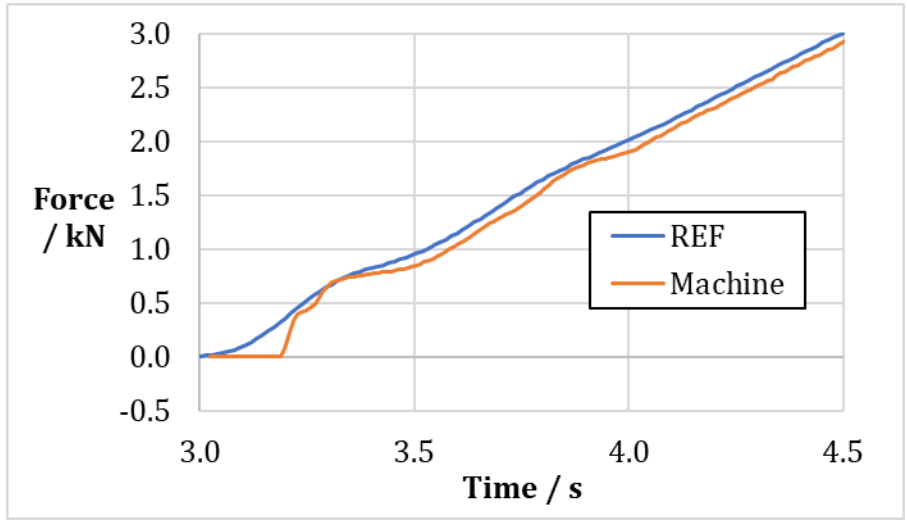

Step 3 – Calibrate testing machine

Calibration results

- Classify machine based on test results, proving instrument classification, and resolution of indicator

Uncertainty of results

- Estimate uncertainty taking at least following parameters into account:
  - Proving instrument uncertainty
  - Repeatability
  - Synchronisation of traces
  - Error estimation
  - Resolution
  - Signal to noise ratio
  - Reversibility, when requested

Conclusions

- Methodology for continuous calibration of testing machine force indicator has been developed
  - Reference standard criteria proposed
  - Proving instrument calibration procedure
  - Testing machine calibration procedure

- Issues identified to have major effect on results
  - Data synchronisation – procedure should be as automated as possible
  - Instrumentation settings

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