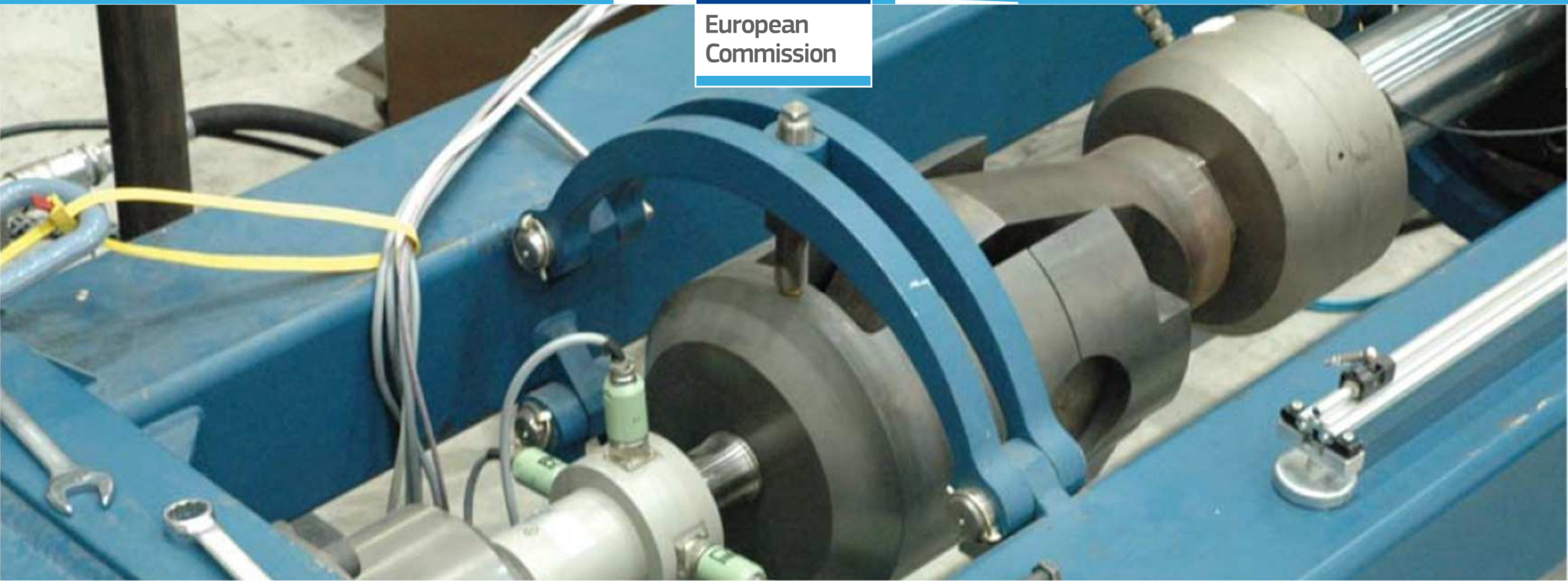

JRC TECHNICAL REPORTS

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F. Javier Molina, Pierre Pegon,
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2013

Report EUR 26134 EN

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http://www.jrc.ec.europa.eu/

EUR 26134 EN

ISBN 978-92-79-32950-0

ISSN 1831-9424

doi:10.2788/13850

Luxembourg: Publications Office of the European Union, 2013

Printed in Italy

Procedure for load cell calibration at ELSA Reaction Wall

F. Javier Molina, Pierre Pegon, Marco Peroni, Bernard Viaccoz and Patrick Petit

1 Abstract

This report describes the procedure currently applied for the calibration of the load cells used for the mechanical experiments in the ELSA laboratory. The procedure is based on the international norm ISO 7500-1 and the definitions there proposed. The calibration experiment consists of applying a number of load cycles simultaneously on the object load cell in series with a traceable measuring proving instrument externally calibrated (reference load cell). The accuracy of the measures of the object load cell is the most important result of the test delimiting the maximum difference between both instruments. Other important results of the test are the resolution, repeatability and reversibility of the object load cell. All these error parameters determine the quality of the object instrument at the state of the calibration test. In order to extend the validity of the calibration test to the experiments performed with that load cell when connected to amplifiers different from the one of the calibration test, an additional gain test of the signal conditioning chain is also undertaken at ELSA after the calibration test.

2 Introduction

This report is intended to explain the basic concepts involved in the procedure currently used for internal calibration of load cells at the reaction wall facility of the European Laboratory for Structural Assessment (ELSA). Before any main experiment, this procedure is applied to the load cells that are going to be used as a way to guarantee the quality of their measurements. The procedure includes the use of a traceable calibrated load cell as a reference measurement with respect to the measurement from the load cell being calibrated, as it is required in the standards, but includes some technical details that are specific to the needs of ELSA. The calibration is based on the comparison of the measurement from both load cells while they are submitted to a series of quasi-static force cycles as applied by a hydraulic actuator.

3 Symbols and their meanings

The terminology used in this report (Table 1) is based on the one introduced by ISO 7500-1 (2004), even though the method and the symbols have been adapted to the particular needs and practical convenience in our laboratory.

The load cell to be calibrated in a calibration test is called “object” load cell. The force measured by the object load cell with its amplifier and recording system will be called “indicated force”.

The force measured by the force-proving system is called “true force”. The force-proving instrument used during a load cell calibration test at ELSA is typically a HBM reference load cell with its MGC+ amplifying unit, AD converter and recording unit. According to ISO 7500-1, this whole force-proving system shall comply with the requirements specified in ISO 376 and be traceable to the international system of units. This recording system is synchronised with the object load cell recording system and the data of both systems is used for the comparisons done at the calibration test.

Table 1. Description of symbols.

Symbol	Unit	Meaning
F	kN	Measured force at the force proving system (“true force”) in the force-increasing (loading) branch.
F'	kN	Measured force at the force proving system (“true force”) in the force-decreasing (unloading) branch.
F_i	kN	Measured force at the object load cell measuring system (“indicated force”) in the force-increasing (loading) branch.
F_i'	kN	Measured force at the object load cell measuring system (“indicated force”) in the force-decreasing (unloading) branch.
F_N	kN	Maximum nominal capacity of the object load cell
A	kN	Resolution of the indicated force.
a	%	Relative resolution of the indicated force.
F_o	kN	Zero error of the indicated force
f_o	%	Relative zero error of the indicated force
Q	kN	Accuracy of the indicated force (with respect to the true force).
q	%	Relative accuracy of the indicated force.
V	kN	Reversibility of the indicated force.
v	%	Relative reversibility of the indicated force.
B	kN	Repeatability of the indicated force.
b	%	Relative repeatability of the indicated force.

4 Determination of the resolution

4.1 RESOLUTION OF THE INDICATED FORCE AT THE OBJECT LOAD CELL

The indicated force F_i is considered as the final value that is recorded after the analogue signal of the object load cell is amplified, sampled at a known sampling frequency, converted into a digital value by the AD converter, averaged (based on a specified number of samplings) and recorded at a the recording frequency. Firstly, the resolution of the AD converter depends on its number of bytes. In the case of ELSA, the converter has 16 bits, which may guarantee a resolution of the order of twice the capacity of force divided by (2^16=65536). However, the indicated force uses to have an oscillation (noise) much larger than the resolution of the converter. In such a case, according to ISO 7500-1, we may define the resolution of the indicated force as half of the peak-to-peak oscillation amplitude of F_i

$$A(F) = \frac{F_i^{MAX} - F_i^{MIN}}{2} \tag{1}$$

for a constant true force F. If during the test, the force was not kept constant at any moment, but it was changing at a slow rate, we take a short lapse of the time history of the signal, during which the variation can be assumed to be linear with respect to the time, apply a linear regression to the measured forces/time there and use equation (1) in the form

$$A(F) = \frac{e^{MAX} - e^{MIN}}{2} \tag{2}$$

where “e” means the deviation of the measurement with respect to that linear regression straight line.

In our case, in reality, for non-zero physical force, the actuator needs to be under servo control in order to apply that force and this definition (2) is implicitly considering the oscillation due to the control errors at the testing bench as part of the resolution of the measurement. If this would result in an exaggeratedly large value of the resolution, the formula should be applied only at zero physical force, which is the original definition in ISO 7500-1.

It must be also noticed that formula (1), if applied for non-zero physical forces, assumes that the resolution of the true force F is much smaller (better) than the resolution of the indicated force. The resolution of the true force maybe found in its certificate or maybe also estimated in the same manner as for the indicated force, at least for zero physical force.

The relative resolution is defined as

$$a(F) = \frac{A(F)}{|F|} * 100\ (\%) \tag{3}$$

5 Alignment of the force proving instrument

In our calibration tests, after checking in an initial stage the measurements for keeping low bending moments, we normally assume that the alignment of the force measuring instruments is good and the torsional orientation of the force proving instrument does not affect the measurements.

When the object load cell is part of the piston of an actuator, the force for the calibration test is applied by the same actuator by mounting it in our calibration bench on which the reference load cell is installed. The alignment of the actuator is done in two phases:

1) The aligning bolts at the connection to the reference load cell are released as well as the aligning bolts at the cylinder of the actuator. Then, a significant tension force of more than half of the capacity of the actuator is applied by it and, while keeping this tension, the alignment bolts at the cylinder are regulated to avoid any measured moment (vertical or horizontal) on the reference load cell, while the three bolts are applying force on the cylinder. At this position, the bolts at the cylinder are considered aligned and must be clamped.
2) An iterative process that requires several attempts is now applied in order to find the best regulation of the alignment bolts at the joint element to the reference load cell. At every attempt, starting from zero force, the bolts are set in a trial position with the three of them in contact with the joint element, but with very small pressure on it. Then, an amount of compression force is applied by the actuator and the values of measured moment (vertical and horizontal) are written. By variation of the position of the bolts at the beginning of every attempt, a regulation should be found producing the minimum values of the moment while a significant compression force is applied. At this position, the bolts at the connection to the reference load cell are considered aligned and must be also clamped.

6 Zero Error

The value of the indicated force is typically set to zero at the beginning of each test, before any physical force is applied, but when all the electrical devices are already switched on. As a consequence, the zero error F_0 at a calibration test is very small and its value changes in a random manner if the test is repeated.

The relative zero error is defined based on the nominal capacity F_N of the object load cell:

$$f_0 = \frac{F_0}{F_N} * 100\ (\%) \tag{4}$$

Since the zero error of our analogue instruments is a consequence of electrical offset, at the moment of using the object load cell in an application setup, the zero error will have a different behaviour from the one at the calibration setup. In order to have a reliable estimation of the zero error at the application setup, if it is required, a particular estimation should be done at that final configuration.

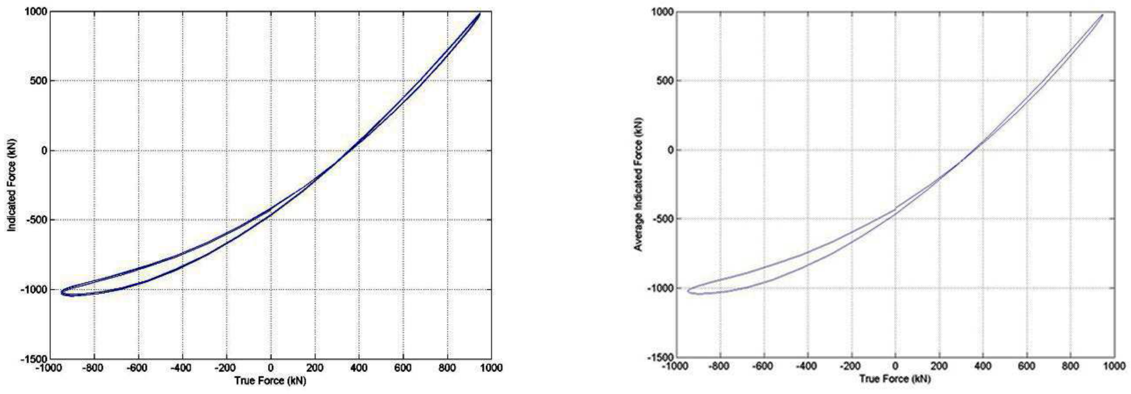
7 Range of validity of the calibration

Typically in our laboratory, the object load cell of a calibration test is part of an actuator and the capacities of the actuator and of its load cell have the same value. Then, for practical reasons during the calibration test, the force is applied by that very actuator. However, the need to avoid any risk of force saturation in the actuator during the test, obliges to limit the maximum applied force to a limit lower than the nominal maximum, say for example a 95% of the capacity of the load cell and the actuator, either in tension as in compression if applicable. Of course, in that case the validity of the calibration test extends only to that maximum tested force limit as it should be specified in the calibration report.

On the other hand, regarding the lower limit of validity of the calibration, the force applied during the calibration test covers also values up to the zero. However, some of the quality parameters that are computed as an error relative to the value of the force, for example the relative accuracy, for values of the force that are close to zero, tend to infinite and this would be out of the proposed standard calibration class. For this reason, it may be decided to define a lower limit of in the range of force for the validity of the calibration, so that the calibration results can be assigned to a standard class.

8 Assessment of the load-cell force indicator

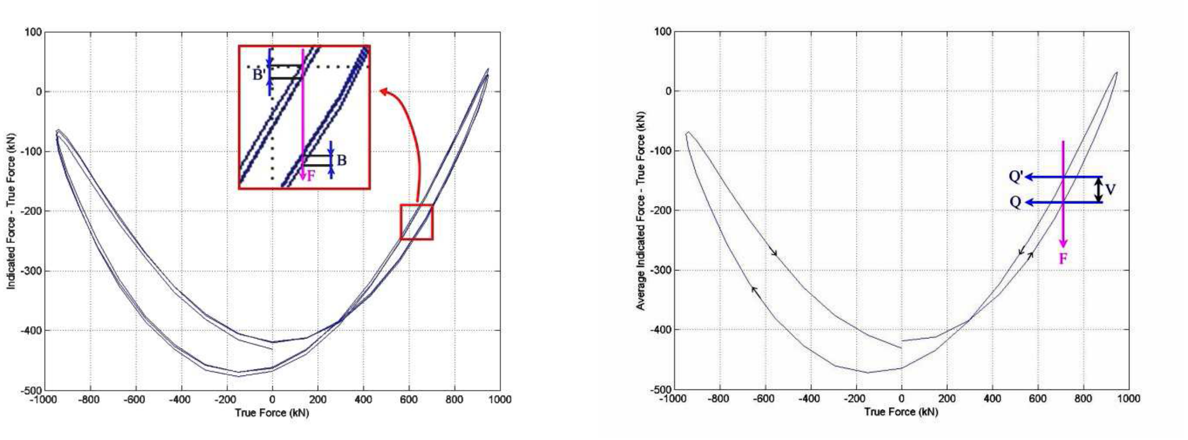
Once the calibration setup is ready and the actuator with its load cell is aligned with the reference cell as described before, the calibration test can be executed. Starting from a central position in the gap of the joint element of the piston to the reference load cell (without physical force at the load cells), the zero of the indicated force is set and the loading is started. The force is applied first towards the established positive maximum for the calibration test, then, towards the negative minimum and, finally, back to the zero while the indicated and true force values are synchronously recorded. This cycle is repeated for at least three times. A representation of the hypothetic cycles in the Fi/F plane is done at Figure 1a, while in the b part of the same figure the representation is done for the averaged values of every force at every similar point among the cycles.



a) Measured values in all the cycles *b) Averaged values among the cycles*

Figure 1 – Load cycles plotted in the F_i/F plane (hypothetic example).

In order to observe better the differences between the two forces, the same representations are repeated in Figure 2, but substituting the indicated force by its difference with respect to the true force.



a) Measured values in all the cycles *b) Averaged values among the cycles*

Figure 2 – Load cycles plotted in the (F_i-F)/F plane (hypothetic example).

Based on these graphs, several measurement errors are defined in the following sections.

8.1 ACCURACY

The accuracy error is understood as a systematic term in the error at the load cell and is given by the difference between the averaged value of the indicated force and the value of the true force. In general, the accuracy is a function of the true force and has different value at the loading

$$Q(F) = \overline{F_i} - F \tag{5}$$

and unloading branches of the loop

$$Q'(F) = \overline{F_i}' - F \tag{6}$$

The graphical interpretation of these variables is visible in Figure 2b. The associated values of relative accuracy are, respectively

$$q(F) = \frac{Q(F)}{F} * 100 \quad (\%) \tag{7}$$

and unloading branches of the loop

$$q'(F) = \frac{Q'(F)}{F} * 100 \quad (\%) \tag{8}$$

8.2 REVERSIBILITY

The reversibility error is understood as the systematic difference between the values of the indicated force at the loading and unloading branches of the loop, for the same true force,

$$V(F) = Q'(F) - Q(F) \tag{9}$$

with its graphical interpretation being visible in Figure 2b. The relative reversibility error is given by

$$v(F) = \frac{V(F)}{F} * 100 \quad (\%) \tag{10}$$

8.3 REPEATABILITY

The repeatability error is understood as the random variation of the indicated force among the different cycles and for the same true force. It is defined in the loading branch of the cycles as

$$B(F) = F_i^{MAX} - F_i^{MIN} \tag{11}$$

and in the unloading branch of the cycles as

$$B'(F) = F'^{MAX}_i - F'^{MIN}_i \tag{12}$$

It is also graphically interpreted in Figure 2a. The relative repeatability is defined as

$$b(F) = \frac{B(F)}{F} * 100 \quad (\%) \tag{13}$$

9 Class of the object load cell for a given range

The standard ISO 7500-1 classifies the quality of the calibrated testing machine by defining the maximum admissible absolute value of the relative errors at every quality class 0.5, 1, 2 or 3. Those maximum values are reproduced in this table.

Table 2. — Maximum permissible characteristic values of the force-measuring system.

Class of machine range	***Relative accuracy*** $\lvert q \rvert$	***Relative repeatability*** b	***Relative reversibility*** $\lvert v \rvert$	***Relative zero error*** $\lvert f_o \rvert$	***Relative resolution*** a
0.5	0.5	0.5	0.75	0.05	0.25
1	1.0	1.0	1.5	0.1	0.5
2	2.0	2.0	3.0	0.2	1.0
3	3.0	3.0	4.5	0.3	1.5

Since most of the relative errors tend to infinite when the true force goes to zero, the range for which the relative errors should be within those limits is sometimes established between 20% and 100% of the nominal range.

In the case of our calibration tests, the procedure does not follow the norm in all its terms. It is instead based on an adaptation of it in order to make the calibration more efficient for our application. Anyway, having into account this limitation, a quality class can also be reported at the end of the test only for indicative purposes. Two additional limitations must be kept in mind when assigning a quality class in our calibration tests:

1) As previously mentioned, the upper limit that is tested is typically slightly lower than the 100% of the capacity of the actuator.
2) As it has been also mentioned, the zero error at the application test can be very different from the one at the calibration test and this should assessed separately.

10 Content of the calibration report

The calibration report should contain at least the following data:

- Identification of the force-proving system with details of its certificate including validity and class of the instrument, sampling frequency, applied averaging of samplings and recording frequency.
- Identification of the object load cell, amplifying system, ADC and its setup, sampling frequency, applied averaging of samplings and recording frequency.
- Range of validity: maximum and minimum force for which the conclusions apply, either in the positive and the negative parts.
- Indication of the room temperature. It should be a value between 10 and 35 °C.
- Maximum absolute value of the observed errors defined in the previous sections.

11 Gain test of the signal conditioning chain of the load cell

Once the calibration test has been performed on a load cell in ELSA and the results are satisfactory, an additional test is performed that should confirm the linearity of the amplifier and analogue/digital converter (ADC) connected to the cell as well as serve as a record of the gain factor that they provide at this calibrated condition. The record of such gain factor for that calibrated load cell has an especial utility, as we will now describe. At ELSA, this test is called “memo” test of the gain of the conditioning chain.

Typically, after some days or months, the calibrated load cell will be mounted in an experimental setup in order to perform an experiment on a specimen. In such application setup, the load cell may be connected to a signal conditioning chain (amplifier and ADC) that is different from the one used during the calibration test. Thus, in order to reproduce a measurement system equivalent to the one that was calibrated by the calibration test, we will assume that the load cell sensor itself has not changed since then, but the gain factor of the new conditioning chain needs to be adjusted. The adjustment of such gain factor is done in three phases:

1) Perform a first test of the new conditioning chain in order to check its linearity and determine its gain factor.
2) Modify appropriately the digital conversion factor at the configuration file of the conditioning chain, so that it will theoretically reproduce the gain factor recorded at the "memo" test at the calibration setup.
3) Perform a second test of the new conditioning chain in order to check that the obtained gain factor is substantially close to the one reported at the "memo" test.

In order to perform a test on the conditioning chain of the force measurement system, the load cell sensor must substituted by a reference Wheatstone bridge of resistors. For example in ELSA we use an HBM K3607 350 Ohm full bridge set at 2.0 mV/V typically. This instrument has a selector with different positions that give several levels of unbalance from -100% (-2.0 mV/V) up to +100% (+2.0 mV/V) with increments of 10%. The test consists of recording the indicated force F_i in kN at the output of the conditioning chain for all the range of unbalanced positions (percentage values) allowed by the instrument. Then, from the percentage values, to the indicated force values, a linear regression is applied and the slope is the resulting gain of the conditioning chain in kN/%. If by case the bridge sensitivity of the substituted cell was around 2.0 mV/V at full capacity, the obtained gain would be around the full capacity value of the cell (in kN) divided by 100, but this is not normally the case.

12 Example of calibration test results

As an example of the ideas described in this report, this section will show the results of a calibration test performed at ELSA on the load cell of a 1000 kN capacity actuator. The actuator load cell, which is the object of the calibration test, was mounted in series with the reference load cell, which is the force proving instrument, and the alignment was done as explained before in this report. Then, three triangular cycles (with constant force speed) where applied by the actuator with a total duration of about 10 minutes for the whole test (Figure 3).

The indicated force coming from the object load cell was recorded at the acquisition done at the master controller of the actuator. This acquisition used a recording period of 50 ms (20 Hz) and every recorded value was the average of 25 measurements based on a sampling of 2 ms (500 Hz).

The true force coming from the HBM reference cell was recorded at the MGC+ conditioning and recording system. This acquisition used a recording period of 50 ms (20 Hz) without any averaging of measurements.

In order to have the possibility of synchronising both independent acquisitions, the MGC+ system has been programmed to produce as an output an analogue copy of the true force, which is introduced into the acquisition of the actuator controller through an additional channel. The comparison of the digital record of the true force at the MGC+ system and the one coming from its copy at the actuator controller, allows to synchronise both acquisitions. This is performed by an optimising process on the parameters that should transform one signal into the other. The non-linear minimization of the error is performed by the function “fminsearch” in MATLAB using as parameters, in the “x” axis, a time delay and a time scale factor and, in the “y” axis, an offset and a proportionality factor on the value of the signal. Once the optimising is done, the effects of the time delay and time scale are corrected (by means of interpolation) in the actuator acquisition and all the force measurements from both acquisitions can be compared on the same time basis (Figure 3). From this moment the copy of the true force is not used anymore in the rest of the analysis since it may contain other errors that may modify the computed parameters.

As it has been mentioned in the section relative to the alignment, the HBM cell has 4 sensors from which the mean value is used as reference true force. Figure 4 shows in the upper part the evolution of the signal at the single sensors together with the mean reference one. In the lower part, one can see the difference of force between sensors 1 and 2 (as an indication of the moment in the vertical plane) and between sensors 3 and 4 (as an indication of the moment in the horizontal plane).

Figure 5 shows the plot of the indicated force at the object load cell versus the true force at the reference HBM cell. However, the discrepancies between these two measurements are not properly observed in this kind of representation. They will be analysed in the following graphs.

12.1 RESOLUTION

For every one of the three force cycles, at the loading and unloading branches of the positive and negative parts, the resolution of the indicated force is computed following the method described in the relative section of this report. The loading branch was divided in 10 intervals (without considering the areas close to the minimum and the maximum), a linear regression was applied to the values of the indicated force with respect to the time and equation (2) was applied to obtain the resolution, while equation (3) was applied for the relative resolution. All the obtained values are plotted in Figure 6. From this test, the obtained absolute resolution of the object load cell was 0.13 kN or smaller as seen in the figure. On the other hand, the relative resolution may grow too much for low levels of true force as shown in the figure. For the calibration report, we have decided that only the values for an absolute true force larger than 100 kN will be considered, so that the values of the relative parameters are kept acceptable for the validity range of the calibration. The relative resolution is 0.03% in these conditions.

12.2 REPEATABILITY

Distinguishing the loading and unloading branches at the positive and negative parts of the cycle, at every branch, for ten values of the true force, the absolute and relative repeatabilities of the indicated force among the three cycles have been respectively computed according to equations (11) (or (12)) and (13). The results are shown in Figure 7.

12.3 ACCURACY

The accuracy is a measure of the difference between the true and the indicated force. Firstly, this difference is plotted in Figure 8 for every single loop at the loading or unloading branches in the positive and negative parts. Then, in Figure 9, according to equations (5) (or (6)) and (7) (or (8)), the accuracy is computed based on the average value of the indicated force among the cycles.

12.4 REVERSIBILITY

Finally, according to equations (9) and (10), the reversibility at the positive and negative sides of the cycle is computed based on the difference of the accuracy between the loading and unloading branches (Figure 10).

12.5 CALIBRATION TEST REPORT

The resulting test report for the object load cell is reproduced in this section. As described before in this report, it contains the identification of the object and the reference load cells and, as result of the test, the maximum value of the computed errors for the defined range of validity. As an additional result, it also shows the obtained linear regression between true force and indicated force. When the slope of such linear regression differs from 1 in more than 0.001, we may decide to introduce a correction in the digital conversion factor at the ADC of the indicated force and repeat the test in order to improve its results. As in the case of the current test, a preparative calibration test is always performed just in order to obtain that multiplying factor that must be introduced in the measuring setup before the definitive calibration test.

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           CALIBRATION TEST REPORT

CALIB2013 ELSA: Load-Cell Tests at Calibration Bench.
actuator 18: MOOG 1.0MN +-450mm DUAREM
c15: Load cell calibration 22/04/2013

Reference load cell
                         type: HBM STZ/MPZ0512007/1 MN
                serial number: 161640033
      calibration certificate: 32200 DKD-K-00101 2012-05-11
           electric amplifier: MGC+ 801181784/1
             recording period: 50 ms
             averaging is of 1 samplings per record

Object load cell
                         type: MOOG actuator
                serial number: actuator 18
            master controller: 187
             recording period: 50 ms
             averaging is of 25 samplings per record

Object load cell capacity:                   1000 kN
Range of validity of the calibration:
  -89% TO -10%  (-890 TO -100 kN)
              AND   10% TO 90%  (100 TO 896 kN)

Absolute accuracy:                                   3.3 kN
Absolute repeatability:                              0.21 kN
Absolute reversibility:                              2.2 kN
Absolute resolution:                                 0.13 kN

Relative accuracy:                  q = 2%
Relative repeatability:             b = 0.056%
Relative reversibility:             v = 0.51%
Relative resolution:                a = 0.03%

Linear regression:

   Indicated Force = 0.999953 * (True Force) +1.52807
                             (errstd=1.72, errmax=4.55 kN)
   Relative offset:       1.52807 / 1000 * 100 = 0.15%
   Factor to eventually multiply
             by sensitivity: 1/0.999953 = 1.00005
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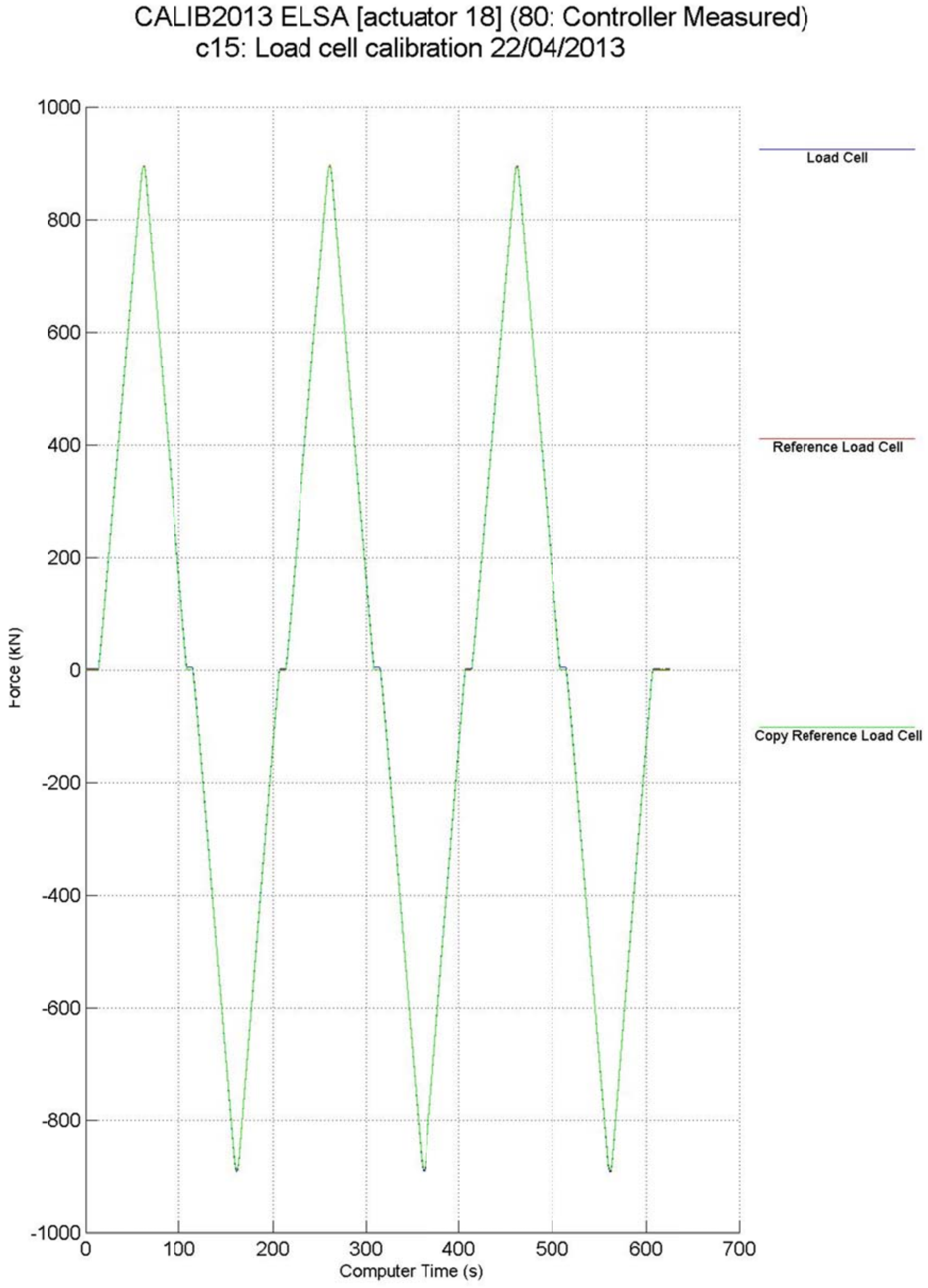


Figure 3 – Synchronised time history of different measurements of the force from both acquisitions.

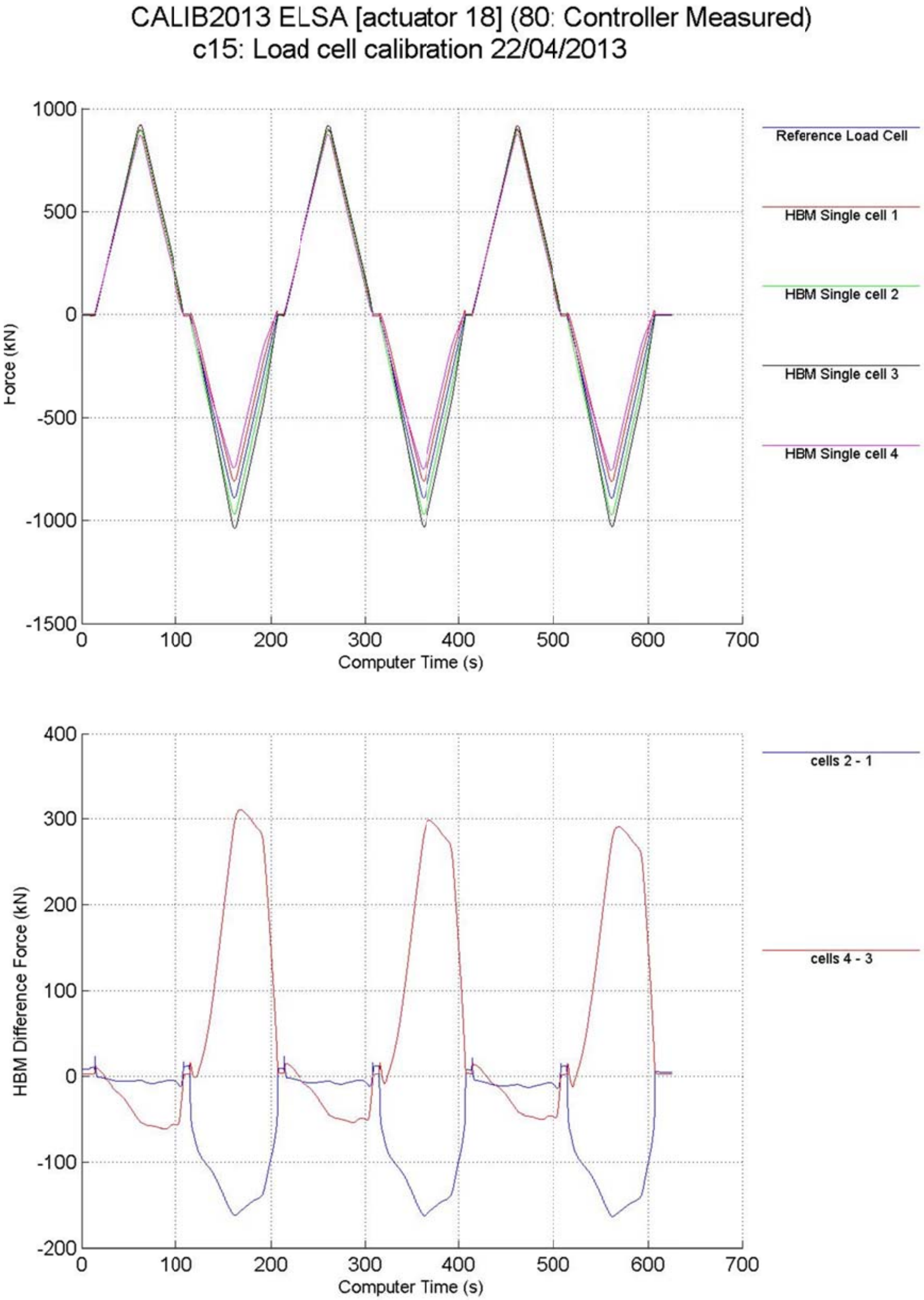


Figure 4 – Time history of force measurements at the HBM reference instrument. Average signal and single sensors (upper graph). Differences between single sensors (lower graph).

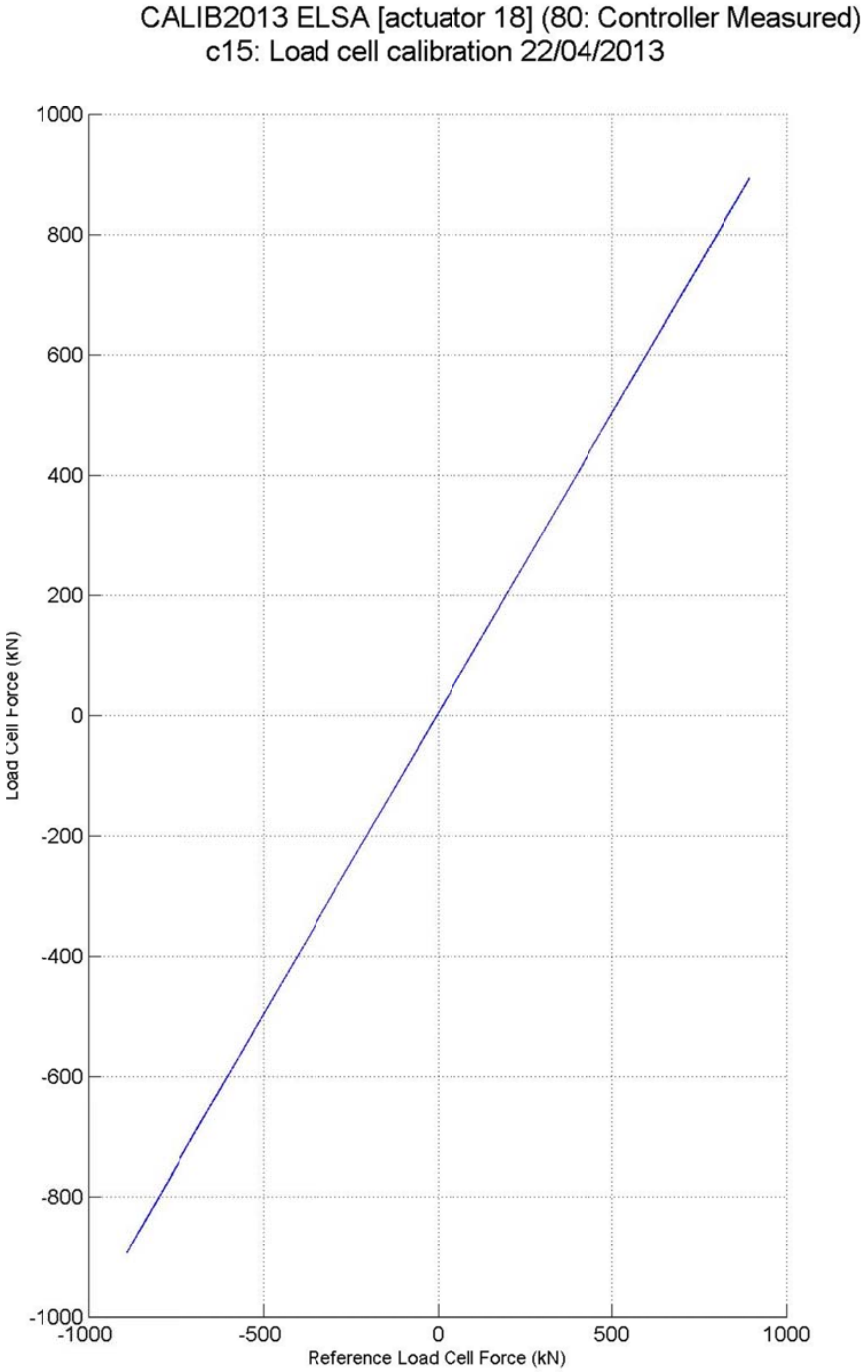
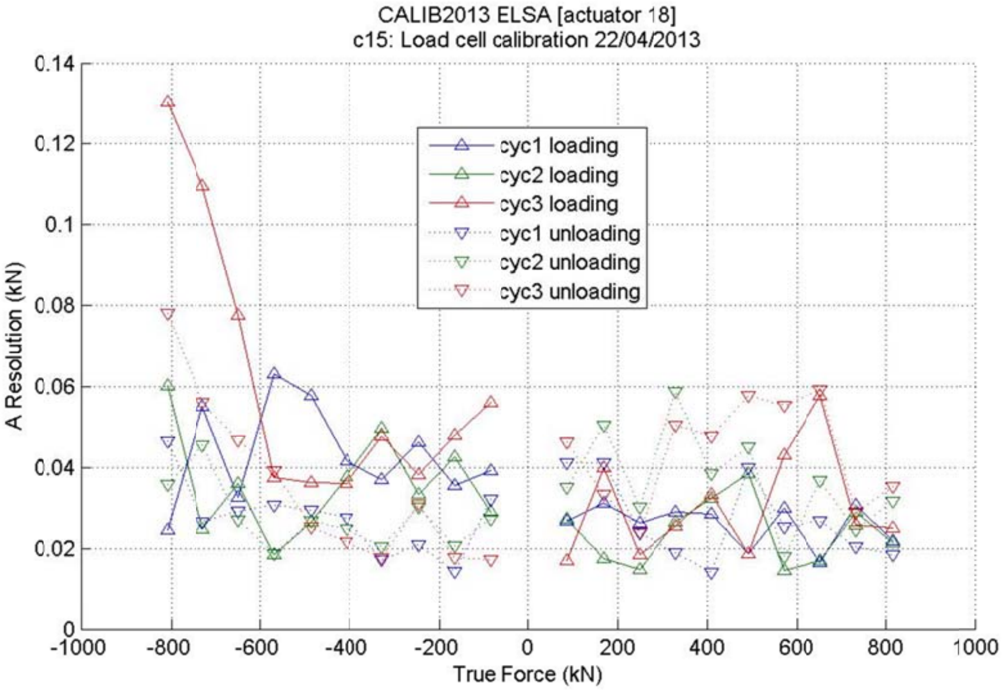


Figure 5 – Indicated force versus true force.



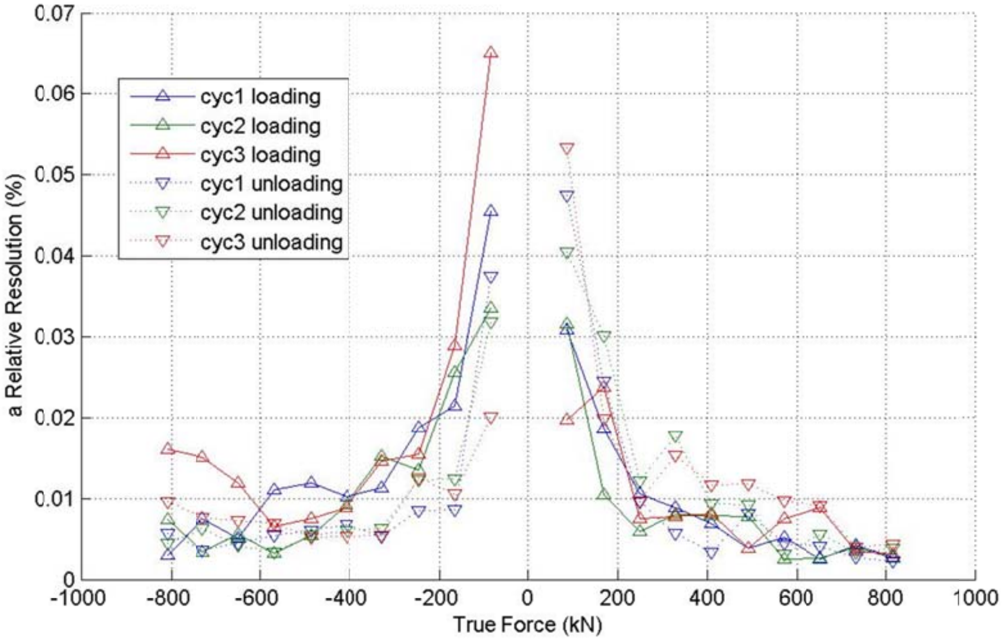


Figure 6 – Computed resolution of the indicated force at every single cycle at fixed values of the true force.

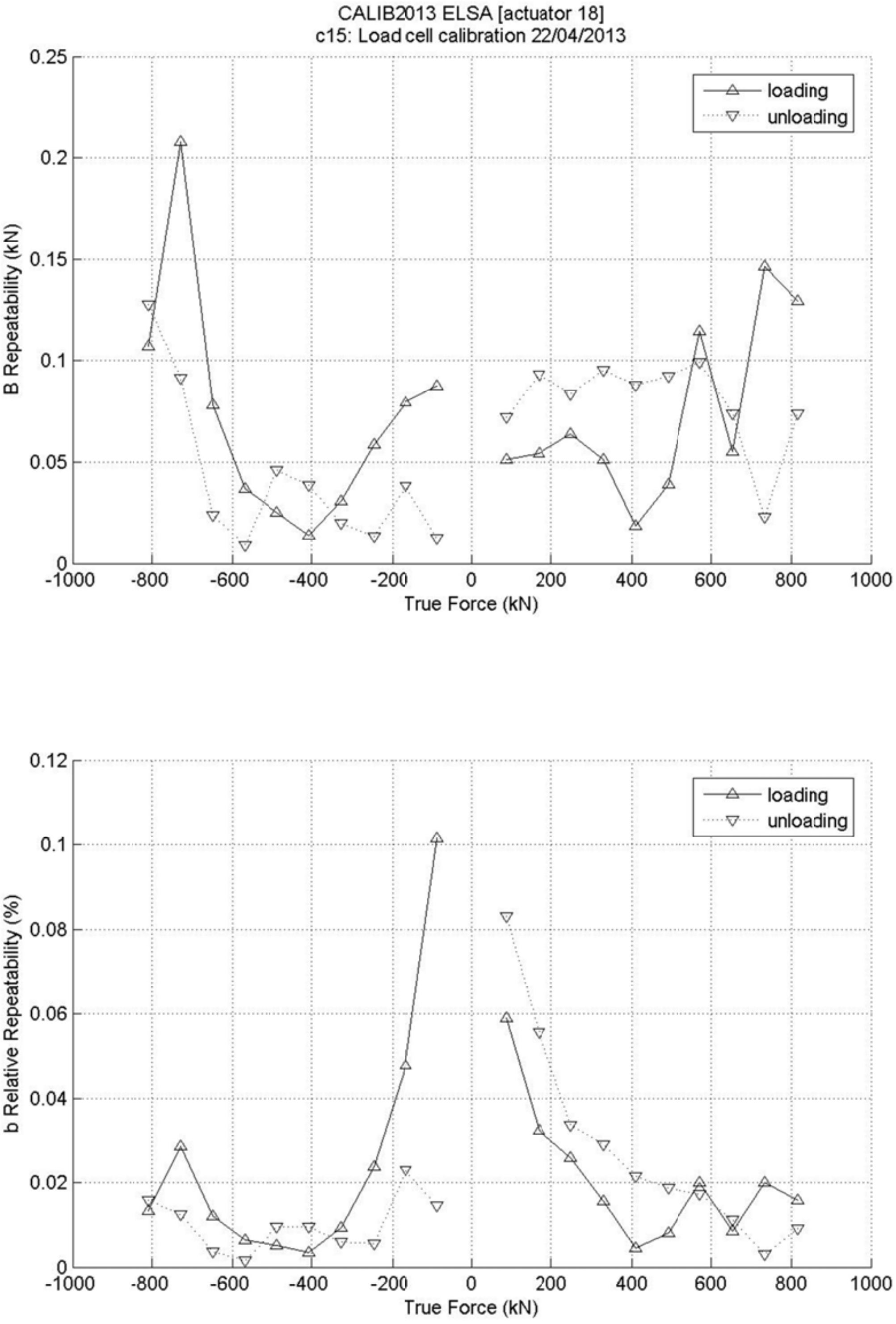


Figure 7 – Repeatability of the indicated force among the cycles at fixed values of the true force.

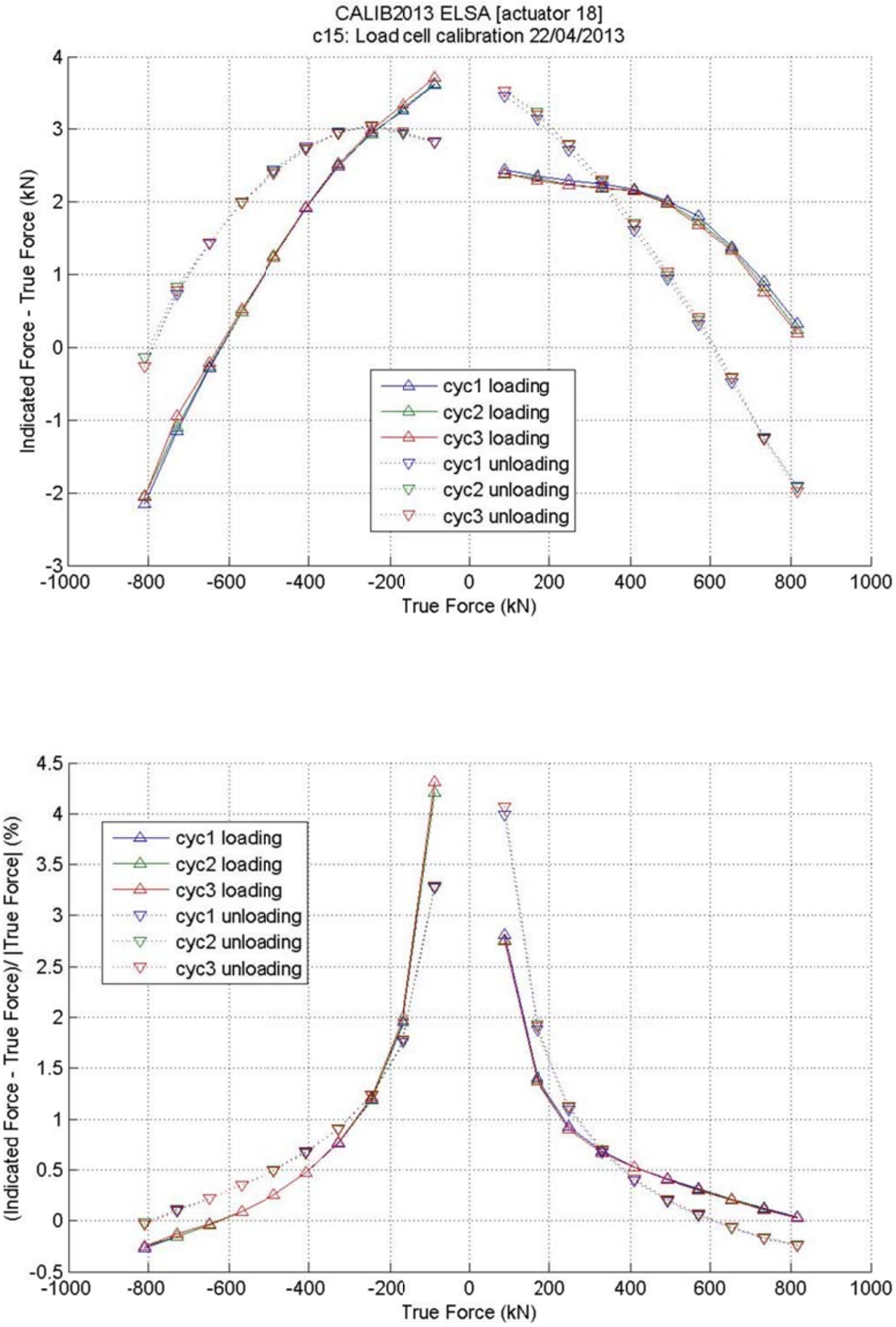


Figure 8 – Difference of indicated and true force at every single cycle at fixed values of the true force.

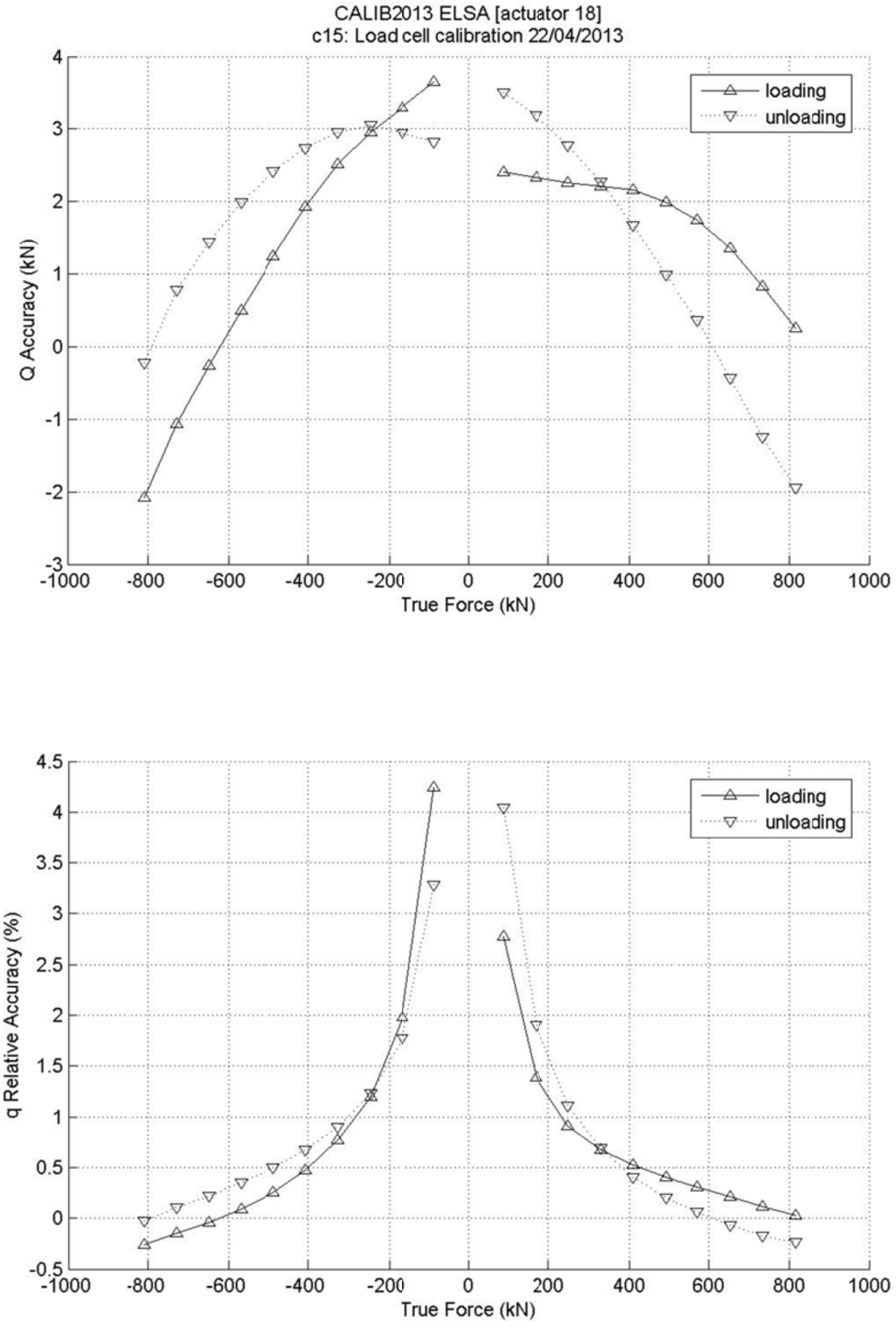


Figure 9 – Accuracy of the indicated force with respect to the true force among the cycles.

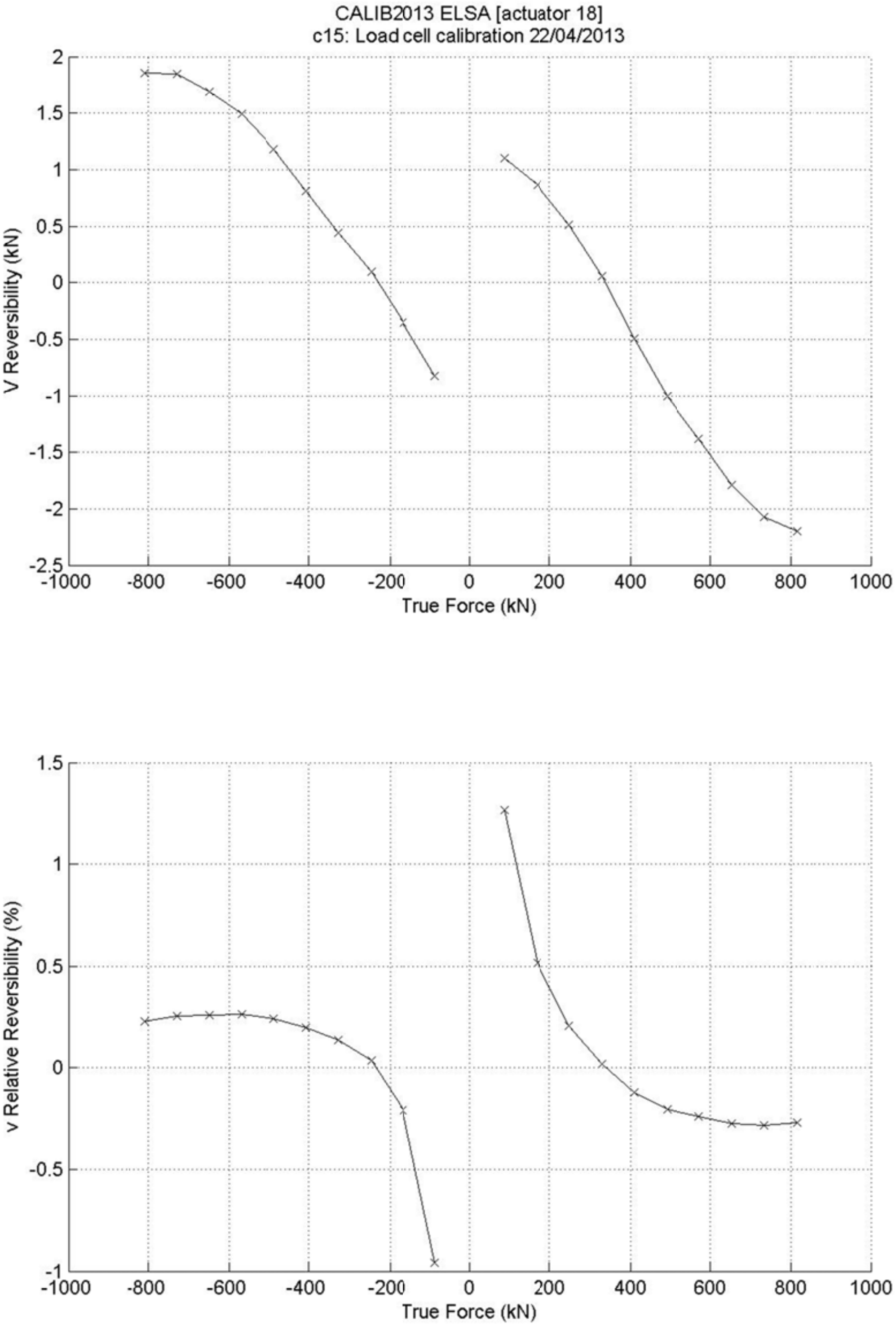


Figure 10 – Reversibility of the indicated force among the cycles.

13 Example of “memo” gain test results

As it is usual in ELSA, just after the calibration test described in the previous section, a “memo” gain test on the signal conditioning chain of the object load cell was performed following the principles contained in the relative section in this report.

To this purpose, an acquisition was made of the indicated force but substituting the physical load cell by a reference Wheastone bridge with different positions of unbalance from -100% to 100% in steps of 10%. The measurements were treated by computing the average of the indicated force at every step and obtaining the linear regression of the averaged values with respect to the unbalance position of the resistor bridge (Figure 11). The report of this test, as contained in this section, shows the formula of the obtained linear regression. The coefficient of proportionality 7.63939 in the formula at the memo test should be reproduced as closely as possible in a future gain test for the conditioning chain of this load cell before using it in an application experiment. This condition allows to have at the application test similar quality of the measurements as in the reported calibration test.

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          FORCE GAIN TEST REPORT

CALIB2013 ELSA Load-Cell Tests at Calibration Bench.
actuator 18 MOOG 1.0MN +-450mm DUAREM
c16 Force gain memo after calibration 22/04/2013

Reference resistor bridge device:
     HBM Kalibriergerat K3607 F. Nr. 41050
     350 Ohm full bridge, 2.0 mV/V <=> 100%

Linear regression:

   Indicated Force = 7.63939 * (resistor position%) -0.169528
                             (errstd=0.0504, errmax=0.16 kN)
```

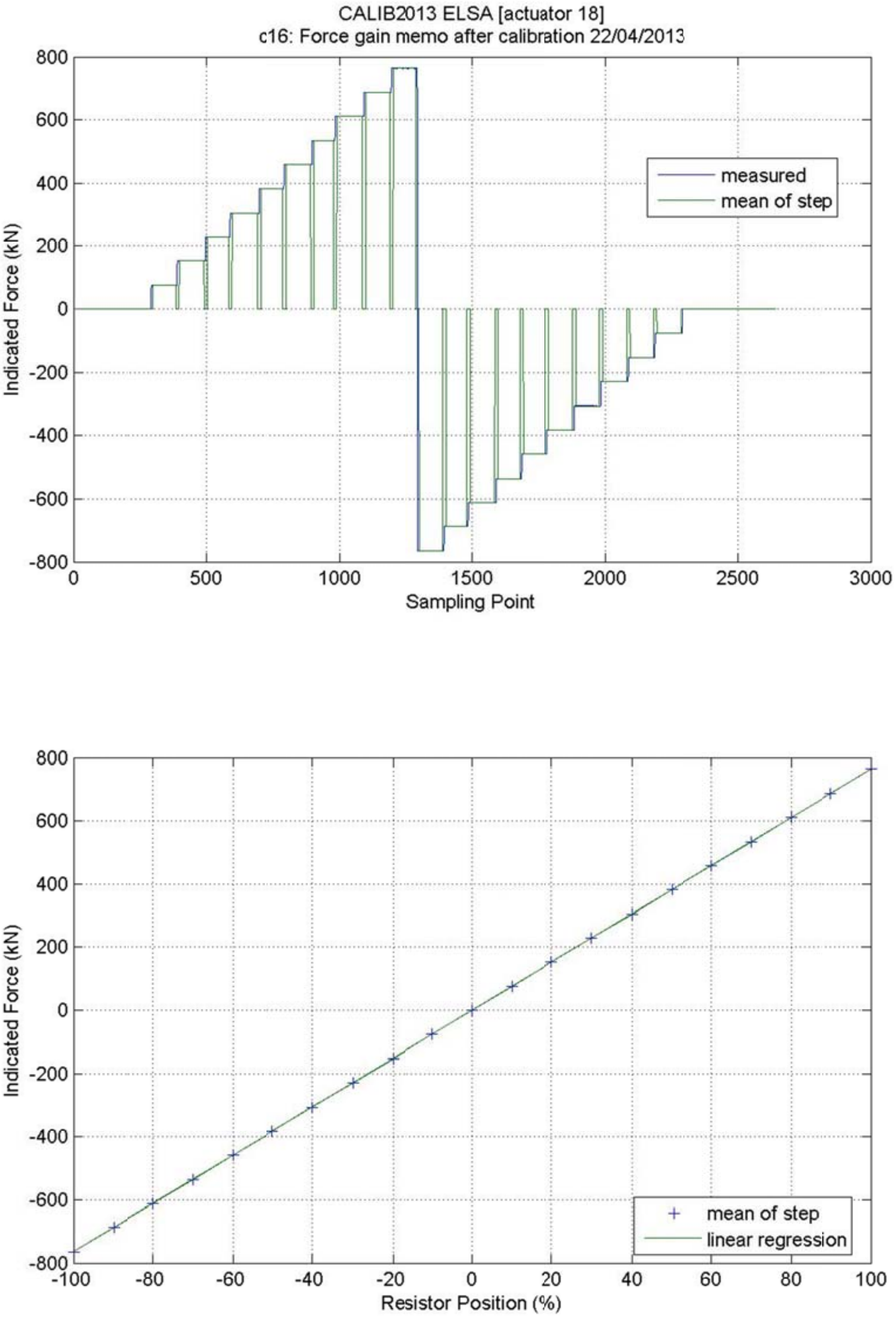

Figure 11 – History of measured values and average for every step (upper graph) and linear regression of averaged values with respect to resistor position (lower graph).

14 Conclusions

The procedure for calibration of load cells currently applied at ELSA is based on the standard ISO 7500-1 (2004). This procedure verifies the quality of the measurements of the object load cell by comparison to the ones of a reference load cell that is externally calibrated regularly in a traceable way. Because of the operational way in ELSA, the calibration test on a load cell is performed on a calibration bench with a measurement conditioning chain different from the one that will be used at the application experiment of that load cell afterwards. This obliges to perform a “memo” gain test on the conditioning chain just after the calibration test on the cell. The quality of the measurements shown at the calibration test will be reproduced at the application experiment only if the gain of the conditioning chain is maintained constant. The maintenance of the gain and the linearity of the conditioning chain are checked by additional gain tests at the setup of the application experiment. Another difference with respect to the referenced norm is in the estimation of the zero error, which, for the tests performed at ELSA, has to be done necessarily at the final setup of the application experiment.

15 Acknowledgment

The work presented in this report was developed within the SAFECONSTRUCT institutional action n. 32003 of the IPSC of the EC-JRC.

16 References

-ISO 7500-1:2004, Metallic materials - Verification of static uniaxial testing machines - Part 1: tension / compression testing machines - Verification and calibration of the force-measuring system, CEN, Brussels, August 2004.

European Commission
EUR 26134 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen

Title: **Procedure for load cell calibration at ELSA Reaction Wall**

Authors: F. Javier Molina, Pierre Pegon, Marco Peroni, Bernard Viaccoz and Patrick Petit

Luxembourg: Publications Office of the European Union

2013 – 30 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424

ISBN 978-92-79-32950-0

doi:10.2788/13850

Abstract

This report describes the procedure currently applied for the calibration of the load cells used for the mechanical experiments in the ELSA laboratory. The procedure is based on the international norm ISO 7500-1 and the definitions there proposed. The calibration experiment consists of applying a number of load cycles simultaneously on the object load cell in series with a traceable measuring proving instrument externally calibrated (reference load cell). The accuracy of the measures of the object load cell is the most important result of the test delimiting the maximum difference between both instruments. Other important results of the test are the resolution, repeatability and reversibility of the object load cell. All these error parameters determine the quality of the object instrument at the state of the calibration test. In order to extend the validity of the calibration test to the experiments performed with that load cell when connected to amplifiers different from the one of the calibration test, an additional gain test of the signal conditioning chain is also undertaken at ELSA after the calibration test.

LB-NA-26134-EN-N

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Publications Office

ISBN 978-92-79-32950-0

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