Swedish Metrology and Quality AB

Accred. no. 10436
Proficiency testing
ISO/IEC 17043

To participants

Revised Report on an interlaboratory comparison (ILC pressure 2022:1 rev 3).

The bag carrying 2 pieces of equipment for calibration.

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Calculations

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Content

Abstract

This report is about a calibration inter-comparison of two pressure sensors with 24 participating laboratories. Both pressure sensors were calibrated from zero to respectively 300 and 2000 bar at 5 calibration points for both increasing and decreasing pressures.

21 of 24 participants did perform a calibration on sensor 1. For sensor 2 this number was 18. The calibration information compared was the indication error and its uncertainty at all calibrations points. These data were reported in two ways, as an excel-protocol and with some delay by sending a calibration certificate. The excel-protocols form the evaluation basis after checking the conformity with the certificate.

Most of the participants calibrated the sensors at all mandatory calibration points for both increasing and decreasing pressure. Several could not reach the highest pressure and not all performed a calibration for decreasing pressure points.

For each pressure level the results for increasing and decreasing pressure are presented in two separate tables next to each other. They are followed by a graph showing the highlighted indication errors at increasing and decreasing pressure respectively and the belonging uncertainties.

RISE (Swedish national metrological institute) calibrated both sensors prior and after the circulation in two measurements series. Their average serves as assigned inter-comparison reference values and are used together with the stated reference uncertainty to calculate En-values at each measuring point for each participant. For details se appendix 2.

This report covers all together 37 calibrations made by 24 laboratories in 13 countries. Their calibration certificates were mostly in their local language sometimes completed with English.

Many uncertainty claims are comparable between participants. A few participants report considerably larger uncertainty values and a few relatively low ones which leads to following En-score.

Of a total number of 312 measurement points 267 En-values were below 1 and 45 exceeded this value. In the comments and feed-back from the participants to the draft report several problems were reported. Had those been known before a clearly improved score would have been reported with 296 En-values below 1 and 16 above.

Purpose and implementation of the comparison

This interlaboratory comparison serves as a tool to verify results reported by calibration laboratories.

It is an effective method to demonstrate technical capacity of the participant and serves as a technical base for accreditation as required by ISO/IEC 17025:2017 (SS-EN ISO/IEC 17025:2018) as specified in point 7.7.2.

Advisory group

The intercomparison has followed the recommendations of the advisory group. The advisory group has defined the set-up of instruments that should be included in the ILC pressure 2021:1 intercomparison as well as the choice of calibration points that are defined to be included in the evaluation of the results.

The advisory group consist of Aykurt Altintas Denmark, Peter Lau MNE Konsult and Håkan Källgren Swedish Metrology and Quality.

Information about the intercomparison

The information about the intercomparison was given in 3 different media:

- Linkedin
- The data base https://www.eptis.org
- On the web https://smquality.se/interlaboratory-comparisons-ilc

The information on the web was done in 2 steps. General information as ILC pressure 2021:1 published on smquality.se and enclosed to this report in annex 1.

Detailed information as a description of the intercomparison/ILC published on smquality.se
and enclosed to this report the reporting forms as appendix 1.

List of objects

The following instruments are included:

Gauge pressure 0-300 bar **Gauge pressure 0-2000 bar**

Participating laboratories and measuring scheme for the comparison

Laboratory	Calibration week
RISE, reference laboratory Sweden	
Siemens Energy AB, Sweden	34 2022
Element Metech AB Sweden	35
Element Metech A/S Denmark	36
Trescal Denmark	37
QS Grimm GmbH Germany	38
Trescal Netherlands	39
DIMED Belgium	40
Tempco s.a. Belgium	41
SWICAL swiss Calibration GmbH Schweiz	42
Lithuanian energy institute Lithuania	43
KIWA AS Norway	44
Nordtec Sweden	45
SC TRESCAL ROMANIA SRL Romania	46
Regio Metro Cert Romania	47
Astem Sp.z.o.o. Poland	50
WIKA POLSKA Spolka z ograniczona odpowiedzialnoscia spolka komandytowa Poland	52
INTERTECHNA, Sweden	02 2023
CAT SL Calibracion Asistencia Technica SL Spain	3
INSRUMENTOS WIKA, S.A Spain	4
CATIM Portugal	5
KIWA Cermet Italy	6
RISE, Sweden	7
Cartesy Germany	9
Trescal Spain	11
RISE, reference laboratory Sweden	Week 13

There were some delays at the end of the circulation. Several laboratories wanted to join even so according to plan the circulation of the sensors had finished. The circulation ended in week 13 in 2023.

Most of the participants are accredited by SWEDAC, DANAK, FINAS, DAkkS, BELAC, NORSK AKKREDITERING, SWISS ACCREDITATION, ROMANIA RENAR, ENAC, IPAC, POLSKIE CENTRUM AKREDETACSI (PCA) and LIETUVOS NACIONALINIS AKREDITACIJOS BJURAS

The reference laboratory RISE, Sweden has the status as a National Metrology Institute, NMI.

Principles concerning the calibration in general.

The reference laboratory calibrated both sensors at the beginning and after finishing the circulation.

During the whole exercise the preliminary reported results were used for checking possible drift behaviour of the sensors. The purpose was to maintain equal conditions for all participants over the total measurement period. In doubt the sensors were planned to be called back for a new reference calibration, which however was not necessary. For details see appendix 3.

Conditions and transport during the measurement period

A special case having special filters and insulation for humidity and vibrations was used for transport.

Compulsory calibration points

The participants were asked to calibrate at the following points both at increasing and decreasing pressure:

Sensor no. 1 Range: 0-300 bar,
Calibration points: 0, 60, 120, 180, 240 and 300 bar.

Sensor no. 2 Range: 0 – 2000 bar
Calibration points: 0, 300, 600, 1200, 1600 and 2000 bar.

Calibration instructions

The laboratories were allowed maximum 5 days for each calibration. In the call they were advised to use their own calibration procedures with focus on the predefined pressure points. They weren't allowed to perform any type of adjustment on the objects.

Using own procedures also meant it was up to the laboratories which measurement points over the compulsory ones they would include and further if they would report values both for in- and decreasing pressure or only the average.

Planning and administrative details

Administrative information

Address to send the required documents:
Swedish Metrology and Quality AB Håkan Källgren Dragspelsgatan 21 SE-504 72 Borås, Sweden e-mail: hakan.kallgren@smquality.se Phone: +46 705 774 931

Summary of the timeline planning in the call:

- The preliminary results (excel-protocol) should be sent to the organiser when the parcel was sent to next participant.
- One week after the calibration/measurement the calibration certificate should be sent to the evaluator of the intercomparison.
- A draft report should be dispatched to the participants 2 weeks after receiving the last calibration certificate. The organiser was not able to deliver according to this rule.
- Comments or feed-back on the draft report to the organiser were expected within 1 week.
- Final report should be finalized within 2 weeks after receiving all comments or feed-back from the participants.

Analysis of the calibration results

The evaluator used the principles of the ISO/IEC 17043:2010 in the reporting.

As an easy-to-understand measure to judge each participant result its distance to the assigned reference value is used, normalized with respect to the uncertainty in this difference. This measure the En-value is calculated for every calibration point according to equation 1).

$$E_{n,j} = \frac{x_{i,j} - x_{ref,j}}{\sqrt{U_{i,j}^2 + U_{ref,j}^2}} \qquad \text{(eq. 1)}$$

$x_{i,j}$: Single measurement result (error of indication); index *i* and *j* count the various participants and calibration points respectively.

$x_{ref,j}$: Assigned inter-comparison reference value for calibration point *j*.

$U_{i,j}$: The estimated expanded uncertainty (k=2) stated by each laboratory *i* for respective calibration point *j*.

$U_{ref,j}$: The estimated expanded uncertainty (k=2) of the assigned reference value for the same calibration point *j*.

E_n,*j*: The measured error of indication by the reference laboratory at pressure point *j*.

Inter-comparison reference value and its uncertainty

The reference values $x_{ref,j}$ are calculated as the average from the first and last calibration provided by the reference laboratory.

$$x_{ref,j} = \frac{R_{1,j}+R_{2,j}}{2} \qquad \text{(eq. 2)}$$

For each instrument

$x_{ref,j}$: The calculated inter-comparison reference value for pressure level *j*.
j: Counting pressure points 1 to 6 at increasing and 7 to 12 at decreasing pressure.
$R_{1,j}$ & $R_{2,j}$: The assigned comparison reference values provided by the reference laboratory at start and end. In the result tables only the symbol R1&R2, in the diagrams *R* is used is used for identifying the assigned reference.

At some calibration points the reported uncertainties differed slightly between the calibration at the beginning and the end. Thus, the measurement uncertainty for each calibration level was calculated as the uncertainty of the mean (equation 3).

$$U_j = \frac{\sqrt{U_{1,j}^2+U_{2,j}^2}}{\sqrt{2}} \qquad \text{(eq. 3)}$$

For each instrument

U_j: The combined uncertainty from two calibrations (at different pressure levels *j*).
Index 1: Refers to the calibration prior the circulation.
Index 2: Refers to the calibration at the end of circulation.

Given the same uncertainty for a pressure level at start and at the end the uncertainty of the reference value is identical with that stated by the laboratory in one of the calibrations. Otherwise, the reference uncertainty lies close to the middle of both.

The data supplied by the reference laboratory indicated a small drift which, however, always was within the stated uncertainty. The uncertainty of the inter-comparison reference value was then composed by adding half of the detected drift over the time for the total exercise, see equation 4.

$$U_{ref,j} = U_j + \frac{1}{2} abs\left(R_{2,j} - R_{1,j}\right) \qquad \text{(eq. 4)}$$

For details se appendix 2

The principle of the intercomparison

An absolute value of E_n of less than |1| is often used as a criterion for an acceptable measurement quality, according to ISO/IEC 17043:2010, B.4.1.1. It means a reported indication error x_i from a participant does not deviate more from the assigned reference comparison value x_{ref} than what can be expected from the calculated uncertainty in this difference.

$$E_n < 1: \quad \left|x_i - x_{ref}\right| < \sqrt{U_i^2 + U_{ref}^2} \qquad \text{(eq. 5)}$$

However, to make this measure a reliable one for an inter-comparison the reference U_{ref} must be small enough not to contribute significantly to the right side of equation 5. Due to the quadratic combination ideally U_{ref} should be in the range of 1/3 of U_i.

This is however not enough in all cases and the diagrams shall be studied and checked. If the error bars from the participants are not covering the calibrated value it shall be considered not to fulfill the general requirement in the standard

Measuring results on calibration in the ILC

The following tables and graphs present the error of indication along with the stated measurement uncertainty for each calibration point. Besides the interesting “error” and “uncertainty” also the reported “reference pressure” and the “displayed instrument values” are listed in the following tables. This presentation is chosen to allow the participants to compare the tabled data in this report with their own documentation.

It was the ambition of the organizer to directly incorporate the participants excel-protocols directly into the evaluation calculations for reporting the outcome of the comparison measurements after first having checked all data against those in the calibration certificates delivered in a separate calibration certificate. This worked mostly very well. One laboratory did not deliver a calibration certificate to check the excel-data against.

The participation numbering P1 to P24 is arbitrary and not in time order of calibration. The assigned Participant identity Pi is kept the same throughout the whole report. Some participants only delivered results for instrument 1, others only for instrument 2. Those participants do not appear in the tables or graphs. Empty lines in the tables indicate instead that for those pressure points no calibration values were provided. The probable reason was that this participant could not reach the pressure point. Their results for the lower pressure points are of course accepted.

Several participants also specified data at some other pressure points in their calibration. Some but not all non-obligatory pressure points were then incorporated in the final calibration by the reference laboratory. This part of the comparison is, however, evaluated in a separate report.

The following tables are built with increasing participant identity numbers and list at the bottom the belonging reference value based on the average of two calibrations by the reference laboratory denoted as R1 and R2.

Together with the estimated uncertainty $U_{ref,j}$ these two values are used for calculating each participants E_n-value displayed in the last column.

Both sensors were new and not used before. However, one of them was carefully adjusted for deviations from original instrument specifications.

Sensor - 300 bar

Zero point at calibration start:

Most participants presented a zero pressure for both the reference and the calibration object and thus a zero-indication error, which probably means that both instruments were zeroed before starting the calibration. This is also the procedure the reference laboratory has chosen after preloading the instruments three times before zeroing both instruments. Four participants presented instead a slight indication error (P8: -0,002, P11: 0,01, P22: 0,0029 and P23: 0,07) but all recorded error values are within their stated uncertainties. One laboratory (P17) does not present any indication error.

Zero point at calibration end:

Only18 of 21 participants also reported data for zero pressure after a measurement series, which can be evaluated for reversibility. Two participants (P8 and P9) stated results only for increasing pressures (or an average of increasing and decreasing) and one participant (P17) did not give a result at the zero point.

11 participants reported a zero-indication error and did not find any change of the zero point after the cycle and seven found a small negative reversibility effect (P3: -0,005 bar; P1, P11, P13, P23: -0,01 bar; P22: -0,015 bar and P14: -0,02 bar). Again, these changes were within the stated uncertainties. As most of the tabled data is zero, they are not shown in this report.

In table 1 and 2 the indication error, its uncertainty and the calculated E_n-value is presented for each participant.

Table 1: Calibration point 60 bar increasing pressure

Participant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	60,01	60,04	0,03	0,02	-0,64
P2	59,993	60,05	0,057	0,021	0,64
P3	60,0100	60,06	0,05	0,027	0,26
P4	59,948	60,00	0,052	0,02	0,44
P6	60,0	60,04	0,04	0,02	-0,15
P7	60,045	60,09	0,04	0,03	-0,10
P8	59,972	60,02	0,048	0,025	0,20
P9	60,00	60,00	0,00	0,08	-0,54
P10	60,0012	60,05	0,049	0,037	0,15
P11	60,0009	60,07	0,07	0,0085	2,94
P13	60,00	60,02	0,02	0,07	-0,33
P14	60,00	60,04	0,04	0,05	-0,06
P15	60,048	60,10	0,052	0,009	0,90
P16	59,9992	60,05	0,051	0,012	0,64
P17	59,99	60,06	0,01	0,12	-0,27
P18	60,075	60,10	0,03	0,012	-1,04
P19	59,793	59,84	0,047	0,01	0,38
P20	60,063	60,11	0,047	0,01	0,38
P22	60,15	60,14	-0,01	0,11	-0,51
P23	60,00	60,11	0,11	0,15	0,42
P24	60,0080	60,06	0,052	0,011	0,76
R1 & R2	60,057	60,100	0,043	0,004	

Table 2: Calibration point 60 bar decreasing pressure.

Participant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	60,01	60,035	0,025	0,02	-0,89
P2	59,993	60,04	0,047	0,021	0,17
P3	60,0100	60,065	0,055	0,027	0,44
P4	59,949	60,00	0,051	0,02	0,39
P6	60,0	60,04	0,04	0,02	-0,15
P7	60,045	60,09	0,045	0,03	0,06
P8					
P9					
P10	60,0010	60,05	0,049	0,037	0,16
P11	60,0009	60,06	0,06	0,010	1,57
P13	60,00	60,04	0,04	0,07	-0,04
P14	60,00	60,05	0,05	0,05	0,14
P15	60,048	60,10	0,052	0,009	0,90
P16	59,9992	60,04	0,041	0,012	-0,16
P17	59,99	60,05	0,06	0,12	0,14
P18	60,075	60,10	0,03	0,012	-1,04
P19	59,793	59,84	0,044	0,01	0,09
P20	60,063	60,11	0,047	0,01	0,38
P22	60,20	60,24	0,03	0,11	-0,10
P23	60,00	60,12	0,12	0,15	0,49
P24	60,0080	60,06	0,049	0,011	0,48
R1 & R2	60,057	60,100	0,043	0,004	

Comment: Empty lines in table 2 imply that the calibration was only performed with increasing pressure or only the mean from increasing and decreasing pressure was presented (P8 and P9).
The tables show variable decimal numbers. They follow in first place the resolution the participants have chosen in their excel-protocol. The displayed En-values are calculated using all decimals available both in the stated indication error and the reported measurement uncertainty. These is in the tables given with two significant numbers,

however, several statements had even three and four significant digits, which also is valid for the indication error. Thus, a calculation based on the displayed data may lead to slightly different values.

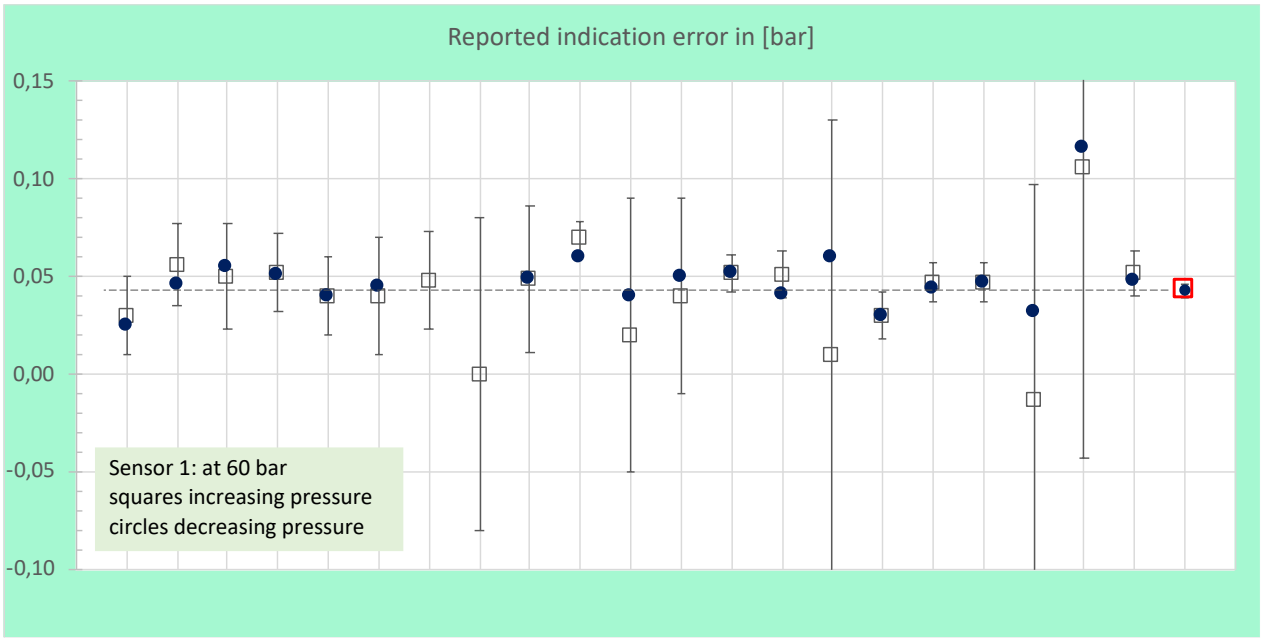

Diagram 1. Indication error from 21 participants at increasing (open squares) and decreasing (filled circles) pressure with stated uncertainty bars (at increasing pressure). The two dashed lines falling on top of each other represent the comparison reference values for increasing and decreasing pressure respectively.

As can be seen most results show no change after returning from 300 to 60 bar while others exhibit a varying difference that should indicate a hysteresis effect. As the reference values are identical this also could be due to the used reference equipment. But all changes are within the stated uncertainties.

Table 3: Calibration at 120 bar increasing pressure

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	120,03	120,10	0,07	0,02	-1,51
P2	119,998	120,11	0,112	0,039	0,18
P3	120,0225	120,14	0,118	0,036	0,36
P4	119,896	120,00	0,104	0,04	-0,01
P6	120,0	120,10	0,10	0,03	-0,14
P7	120,110	120,20	0,09	0,04	-0,35
P8	119,944	120,051	0,107	0,027	0,09
P9	119,99	120,00	0,01	0,36	-0,26
P10	120,0008	120,11	0,109	0,063	0,07
P11	120,00075	120,12	0,12	0,009	1,09
P13	120,00	120,06	0,06	0,07	-0,63
P14	120,00	120,10	0,10	0,03	-0,14
P15	120,100	120,21	0,11	0,014	0,31
P16	120,0008	120,11	0,109	0,02	0,20
P17	120,02	120,13	0,11	0,12	0,05
P18	120,149	120,23	0,08	0,015	-1,32
P19	119,744	119,86	0,116	0,015	0,62
P20	120,130	120,24	0,11	0,019	0,25
P22	120,45	120,33	-0,12	0,16	-1,38
P23	120,00	120,15	0,16	0,17	0,31
P24	120,0119	120,12	0,108	0,013	0,22
R1 & R2	120,113	120,218	0,105	0,011	

Table 4: Calibration at 120 bar decreasing pressure.

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	120,03	120,095	0,065	0,02	-1,47
P2	119,998	120,10	0,102	0,039	0,12
P3	120,0225	120,14	0,118	0,036	0,57
P4	119,901	120,00	0,099	0,04	0,05
P6	120,0	120,09	0,09	0,03	-0,22
P7	120,110	120,20	0,09	0,04	-0,17
P8					
P9					
P10	120,0012	120,11	0,109	0,063	0,19
P11	120,0008	120,12	0,12	0,009	1,87
P13	120,00	120,07	0,07	0,07	-0,38
P14	120,00	120,09	0,09	0,03	-0,22
P15	120,100	120,21	0,11	0,014	0,79
P16	120,0008	120,10	0,099	0,02	0,09
P17	120,020	120,12	0,10	0,12	0,02
P18	120,149	120,223	0,07	0,015	-1,57
P19	119,744	119,85	0,109	0,015	0,70
P20	120,130	120,24	0,11	0,019	0,62
P22	120,21	120,11	-0,09	0,16	-1,18
P23	120,00	120,16	0,17	0,17	0,41
P24	120,0119	120,11	0,098	0,013	0,07
R1 & R2	120,113	120,210	0,097	0,0085	

The values in the colored columns are the reported values from the calibration certificate in the first place.

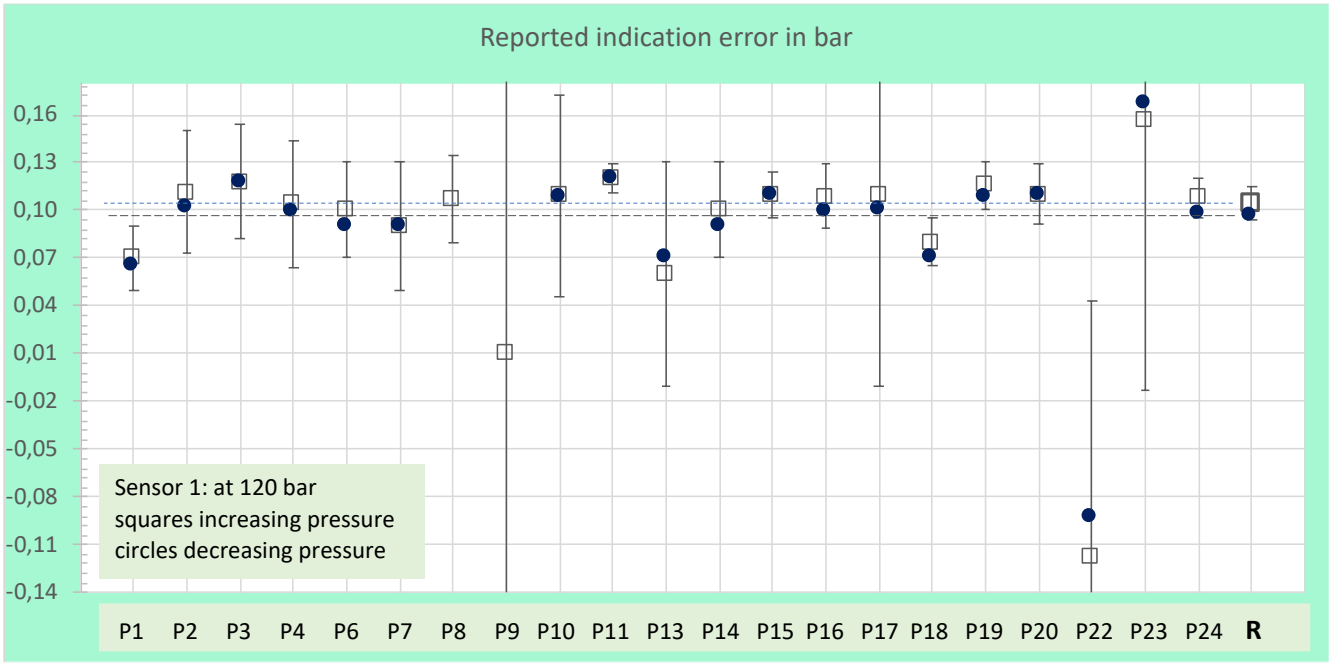

Diagram 2. Indication errors at 120 bars showing small hysteresis effects mostly in negative direction. However, all shifts are clearly within uncertainty.

Table 5: Calibration at 180 bar increasing pressure

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	180,06	180,175	0,115	0,020	-2,08
P2	180,001	180,18	0,179	0,058	0,21
P3	180,0291	180,21	0,181	0,045	0,30
P4	179,844	180,00	0,156	0,040	-0,25
P6					
P7	180,177	180,33	0,150	0,060	-0,27
P8	179,925	180,093	0,168	0,034	0,03
P9	179,99	180,00	0,010	0,36	-0,44
P10	180,0012	180,18	0,179	0,089	0,13
P11	180,0007	180,18	0,180	0,010	0,75
P13	180,00	180,14	0,140	0,070	-0,37
P14	180,00	180,15	0,150	0,030	-0,50
P15	180,149	180,32	0,171	0,019	0,18
P16	180,0025	180,18	0,177	0,029	0,31
P17	180,03	180,20	0,170	0,18	0,02
P18					
P19	179,692	179,88	0,184	0,022	0,65
P20	180,195	180,37	0,175	0,029	0,25
P22	180,25	180,08	-0,167	0,20	-1,66
P23	180,00	180,21	0,213	0,20	0,23
P24	180,0188	180,19	0,171	0,017	0,20
R1 & R2	180,168	180,335	0,167	0,015	

Table 6: Calibration at 180 bar decreasing pressure.

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	180,06	180,170	0,110	0,020	-2,33
P2	180,001	180,17	0,169	0,057	0,13
P3	180,0291	180,20	0,171	0,045	0,20
P4	179,846	180,00	0,154	0,040	-0,19
P6					
P7	180,177	180,33	0,150	0,060	-0,19
P8					
P9					
P10	180,0015	180,17	0,169	0,089	0,08
P11	180,0007	180,18	0,180	0,011	1,22
P13	180,00	180,13	0,130	0,070	-0,45
P14	180,00	180,15	0,150	0,030	-0,37
P15	180,149	180,32	0,171	0,019	0,43
P16	180,0025	180,17	0,167	0,029	0,17
P17	180,03	180,19	0,160	0,18	-0,01
P18					
P19	179,692	179,88	0,185	0,022	0,97
P20	180,195	180,37	0,175	0,029	0,43
P22	180,03	179,84	-0,192	0,20	-1,77
P23	180,00	180,22	0,223	0,20	0,31
P24	180,0188	180,18	0,161	0,017	-0,03
R1 & R2	180,168	180,330	0,162	0,010	

Comment: As can be seen the uncertainty of the reference value is not always the lowest and definitely not always 1/3 of the participant uncertainty which means the corresponding En-values might be questionable.

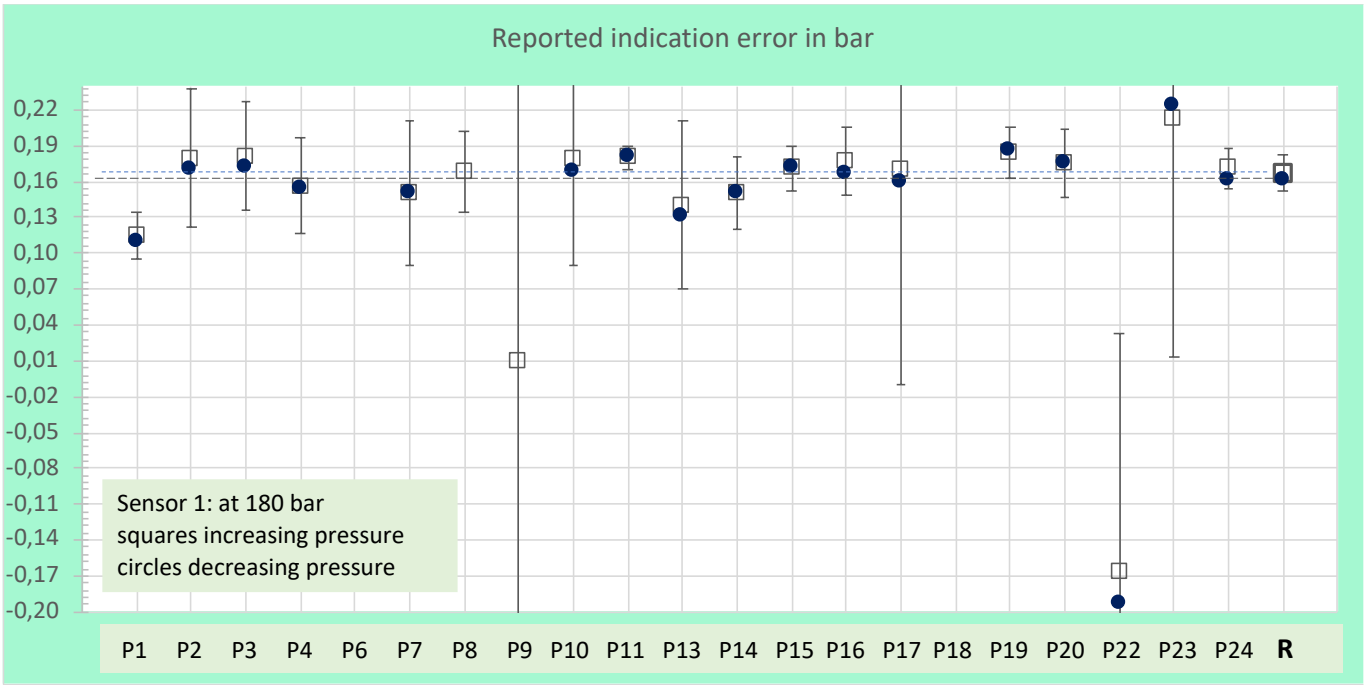

Diagram 3. Indication error from 19 participants. P18 jumped over this pressure level, P8 and P9 had data only for increasing pressure or the average of both.

Table 7: Calibration at 240 bar increasing pressure

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	240,09	240,25	0,16	0,03	-2,07
P2	240,000	240,24	0,24	0,076	0,11
P3	240,0366	240,27	0,233	0,054	0,02
P4	239,750	240,00	0,25	0,50	0,04
P6					
P7	240,244	240,45	0,21	0,08	-0,27
P8	239,888	240,122	0,234	0,038	0,05
P9	239,98	240,00	0,02	0,38	-0,56
P10	240,0016	240,24	0,238	0,11	0,06
P11	240,0006	240,25	0,25	0,012	0,84
P13	240,00	240,14	0,14	0,07	-1,27
P14	240,00	240,22	0,22	0,03	-0,34
P15	240,198	240,44	0,242	0,024	0,34
P16	240,0057	240,24	0,234	0,037	0,05
P17	240,04	240,26	0,22	0,24	-0,05
P18	240,294	240,50	0,21	0,019	-0,85
P19	239,644	239,90	0,256	0,029	0,71
P20	240,257	240,50	0,243	0,038	0,26
P22	240,36	240,07	-0,28	0,18	-2,85
P23	240,00	240,27	0,28	0,24	0,19
P24	240,0233	240,26	0,233	0,022	0,05
R1 & R2	240,223	240,455	0,232	0,018	

Table 8: Calibration at 240 bar decreasing pressure.

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	240,09	240,25	0,16	0,03	-1,92
P2	240,000	240,24	0,2402	0,076	0,20
P3	240,0366	240,266	0,229	0,054	0,08
P4	239,760	240,00	0,24	0,50	0,03
P6					
P7	240,244	240,44	0,20	0,08	-0,30
P8					
P9					
P10	240,0016	240,24	0,239	0,115	0,12
P11	240,0006	240,24	0,24	0,01	0,83
P13	240,00	240,20	0,20	0,07	-0,34
P14	240,00	240,22	0,22	0,03	-0,13
P15	240,198	240,43	0,232	0,024	0,26
P16	240,0057	240,24	0,234	0,037	0,24
P17	240,04	240,26	0,22	0,24	-0,02
P18	240,294	240,493	0,20	0,019	-1,01
P19	239,644	239,90	0,256	0,03	0,96
P20	240,257	240,50	0,243	0,04	0,45
P22	239,79	239,54	-0,25	0,18	-2,62
P23	240,00	240,26	0,27	0,24	0,18
P24	240,0233	240,25	0,227	0,022	0,08
R1 & R2	240,223	240,448	0,224	0,015	

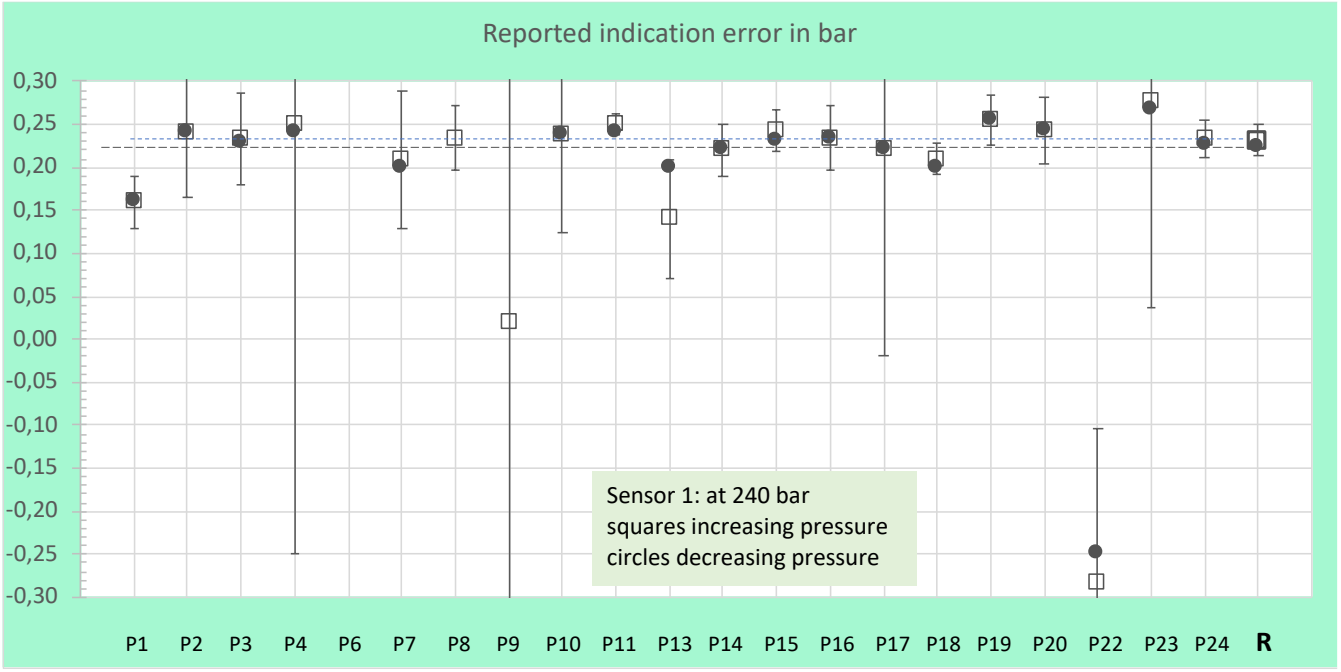

Diagram 4. Indication errors from 20 and 18 participants and reference laboratory with uncertain in increasing direction.

Table 9: Calibration at 300 bar increasing pressure

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	300,11	300,325	0,215	0,03	-2,10
P2	299,995	300,30	0,305	0,095	0,15
P3	300,0382	300,325	0,287	0,063	-0,05
P4	299,690	300,00	0,31	0,50	0,04
P6					
P7	300,309	300,57	0,26	0,10	-0,29
P8	299,872	300,176	0,303	0,043	0,28
P9	299,96	300,00	0,04	0,44	-0,57
P10					
P11	300,0006	300,31	0,31	0,02	0,70
P13	300,00	300,17	0,17	0,07	-1,65
P14	300,00	300,29	0,29	0,04	0,00
P15	300,242	300,55	0,308	0,03	0,50
P16	300,006	300,31	0,304	0,046	0,28
P17	300,05	300,33	0,28	0,30	-0,03
P18	300,366	300,633	0,27	0,021	-0,70
P19	299,595	299,92	0,326	0,04	0,86
P20	300,319	300,63	0,311	0,05	0,41
P22	300,43	300,10	-0,33	0,17	-3,63
P23	300,00	300,32	0,31	0,29	0,08
P24	300,0286	300,33	0,301	0,026	0,35
R1 & R2	300,278	300,568	0,29	0,019	

Table 10: Calibration at 300 bar decreasing pressure.

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	300,11	300,325	0,215	0,03	-1,81
P2	299,995	300,30	0,3046	0,095	0,20
P3	300,0382	300,325	0,287	0,063	0,03
P4	299,690	300,00	0,31	0,50	0,05
P6					
P7					
P8					
P9					
P10					
P11	300,0006	300,30	0,30	0,01	0,54
P13	300,00	300,23	0,23	0,07	-0,74
P14	300,00	300,29	0,29	0,04	0,11
P15	300,242	300,55	0,308	0,03	0,60
P16	300,0060	300,31	0,304	0,046	0,36
P17	300,05	300,32	0,270	0,30	-0,05
P18	300,366	300,63	0,260	0,021	-0,78
P19	299,595	299,92	0,326	0,04	0,93
P20	300,319	300,63	0,311	0,05	0,48
P22	300,20	299,86	-0,34	0,17	-3,61
P23	300,00	300,31	0,32	0,29	0,11
P24	300,0286	300,33	0,298	0,026	0,37
R1 & R2	300,278	300,563	0,285	0,024	

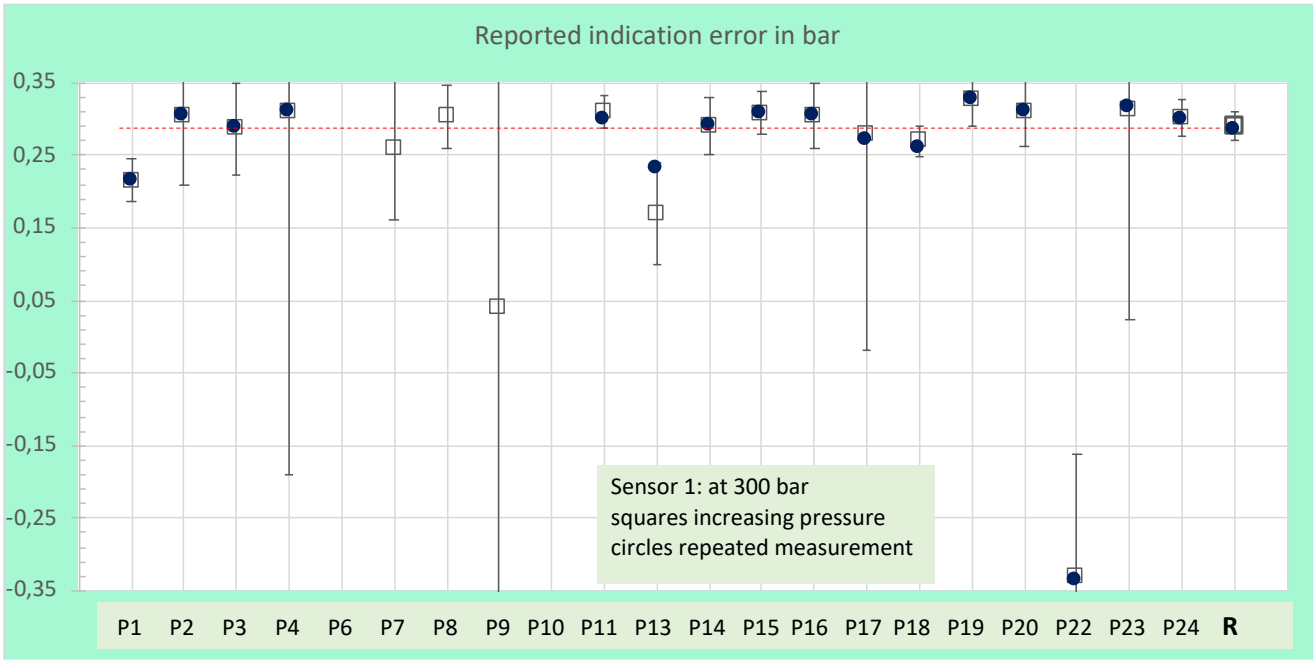

Diagram 5. Indication error from 19 participants at maximum pressure and 16 repeated values showing good agreement.

Comments: From 24 participants – 3 did not take part (P5, P12 and P21) in calibrating sensor 1. Two participants did not reach 300 bar (P6, and P10) – further three did not repeat the measurement at top (P7, P8 and P9). Most participants reported identical values at the top pressure, but a few also came up with slightly different values, possibly depending on the time for holding the pressure before reducing it.

Zero-point Sensor 2:

Eighteen participants delivered calibration data for sensor 2. At zero pressure one participant (P5) only reported a value in the excel-protocol but not in the calibration certificate, one (P7) reported a zero indication but no belonging uncertainty. Three participants (P8, P9 and P16) only delivered a value at start and non at decreasing values. Seven results do not show any change at zero level between start and end of the pressure cycle. Eight participants indicate a small difference (hysteresis) in negative direction (from -0,05 to -0,1; from 0 to -0,05 or -0,1 or -0,02; or from -0,5 to -0,7 bar; two results went in the other direction 0 to 0,04 and 0,01 to 0,05). The calculated En-values show 2 lie near -1 and 3 clearly below -1. However, those data are not shown as they must be regarded rather as a matter of used zeroing technique than a larger deviation from the reference values at start and end of the pressure cycle.

Table 11: Calibration at 300 bar increasing pressure

Participant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	300,10	299,90	-0,20	0,10	-1,07
P2	299,991	299,90	-0,091	0,11	-0,41
P3	300,053	300,05	0,00	0,15	0,10
P4	300,020	300,00	-0,02	0,50	0,00
P5	299,676	300,00	0,07	0,70	0,13
P7	300,307	300,20	-0,11	0,20	-0,37
P8	299,87	299,737	-0,14	0,27	-0,40
P9	300,33	300,00	-0,33	0,47	-0,63
P11	300,0010	299,50	-0,50	0,25	-1,69
P12	300,07	300,10	0,03	0,09	0,31
P13	300,0	300,1	0,1	0,30	0,37
P15	300,245	300,20	-0,045	0,066	-0,17
P16	300,003	299,90	-0,103	0,074	-0,54
P17	300,05	299,95	-0,10	0,30	-0,23
P18	300,265	300,20	-0,10	0,45	-0,17
P19	299,8650	300,17	0,30	1,4	0,23
P21	299,82	299,70	-0,12	0,16	-0,48
P22	300,399	300,367	-0,032	0,46	-0,03
R1 & R2	300,245	300,225	-0,020	0,13	

Table 12: Calibration at 300 bar decreasing pressure.

Participant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	300,10	299,90	-0,20	0,10	-0,46
P2	299,991	299,90	-0,091	0,11	0,19
P3	300,0353	299,95	-0,10	0,15	0,12
P4	300,080	300,00	-0,08	0,50	0,08
P5	300,180	300,00	-0,18	0,70	-0,08
P7	300,307	300,10	-0,21	0,20	-0,36
P8					
P9					
P11	300,0008	299,30	-0,70	0,19	-2,50
P12	300,07	300,10	0,03	0,09	0,97
P13	300,0	300,0	0,0	0,30	0,38
P15	300,245	300,10	-0,145	0,066	-0,15
P16					
P17	300,05	299,90	-0,15	0,30	-0,07
P18	300,265	300,100	-0,20	0,45	-0,16
P19	299,8650	299,40	0,50	1,4	0,44
P21	299,78	299,50	-0,28	0,36	-0,41
P22	301,241	300,967	-0,274	0,46	-0,32
R1 & R2	300,249	300,125	-0,124	0,13	

Comment: Indication error from 18 participants for increasing and 15 at decreasing pressure. Three participants only filled in half of the excel-protocols and the certificates only contained the average of both points.

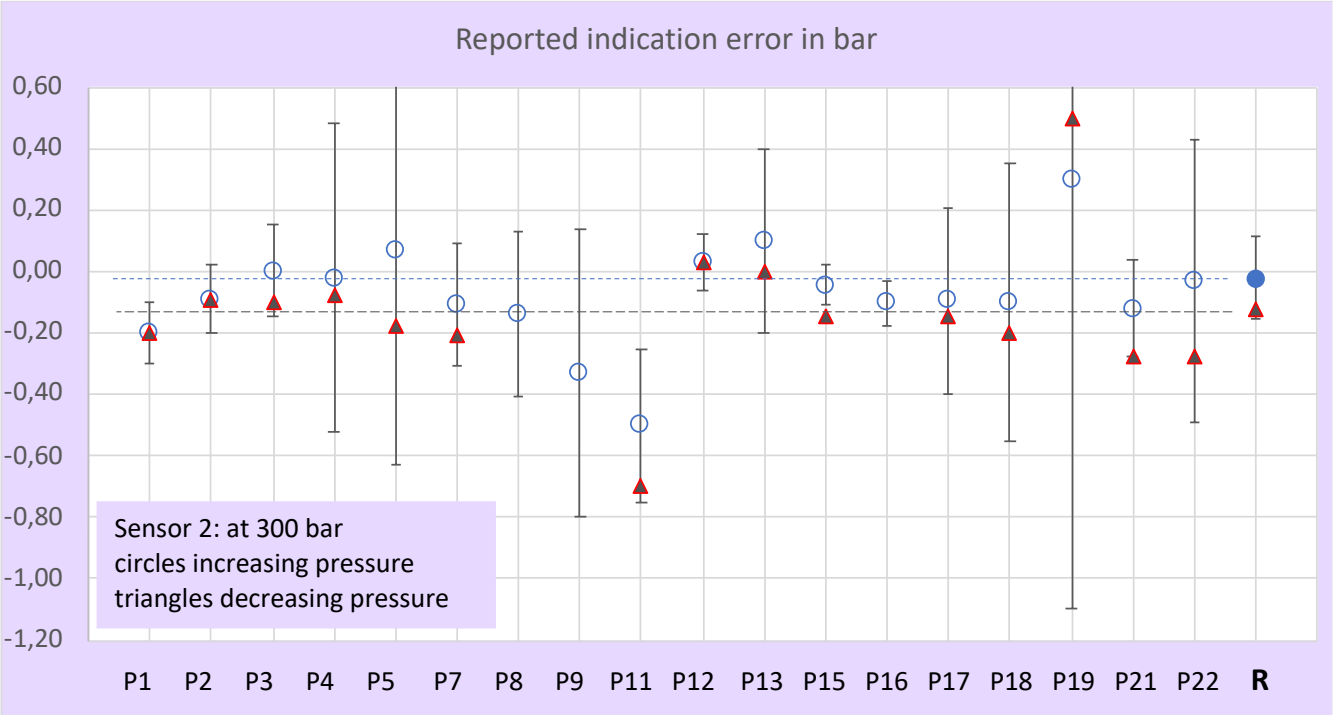

Diagram 6. Indication error from 18 participants at a pressure level of 300 bar. The staples give the reported uncertainties (at increasing pressure). The blue and green lines indicate the assigned reference values for comparison.

Comments: Several participants reported uncertainties of the size comparable with the reference laboratory or even lower. Consequently, the belonging En-values can be high if the indication error departs a little from the assigned reference value. In any case none of the En-values exceeding 1 is due to a large reference uncertainty.

Table 13: Calibration at 600 bar increasing pressure

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	600,20	600,05	-0,15	0,20	-0,59
P2	599,980	599,90	-0,08	0,20	-0,32
P3	600,124	600,096	-0,03	0,16	-0,14
P4	600,060	600,00	-0,06	0,50	-0,12
P5	599,524	600,00	0,10	1,0	0,10
P7	600,639	600,50	-0,14	0,25	-0,48
P8	599,72	599,642	-0,07	0,28	-0,22
P9	600,51	600,00	-0,51	0,74	-0,68
P11	600,0003	599,40	-0,60	0,19	-2,41
P12	600,12	600,20	0,08	0,16	0,34
P13	600,0	600,1	0,1	0,50	0,19
P15	600,496	600,60	0,104	0,084	0,55
P16	599,999	599,90	-0,100	0,11	-0,52
P17	600,10	600,00	-0,10	0,60	-0,16
P18	600,570	600,500	-0,10	0,45	-0,21
P19	599,8334	600,10	0,30	1,4	0,21
P21	599,59	599,60	0,01	0,17	0,03
P22	600,132	600,033	-0,098	0,39	-0,24
R1 & R2	600,473	600,475	0,002	0,16	

Table 14: Calibration at 600 bar decreasing pressure.

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	600,20	599,90	-0,30	0,20	-0,67
P2	599,980	599,80	-0,18	0,20	-0,23
P3	600,124	599,941	-0,18	0,16	-0,26
P4	600,060	600,00	-0,06	0,50	0,11
P5	600,313	600,00	-0,31	1,0	-0,20
P7	600,639	600,40	-0,24	0,25	-0,39
P8					
P9					
P11	600,0007	599,20	-0,80	0,22	-2,36
P12	600,12	600,20	0,08	0,16	0,79
P13	600,0	600,0	0,0	0,50	0,22
P15	600,496	600,40	-0,096	0,084	0,10
P16					
P17	600,10	600,00	-0,10	0,60	0,03
P18	600,570	600,367	-0,20	0,45	-0,17
P19	599,8330	599,53	0,30	1,4	0,29
P21	599,62	599,40	-0,22	0,50	-0,19
P22	600,233	600,100	-0,133	0,39	-0,04
R1 & R2	600,467	600,350	-0,117	0,19	

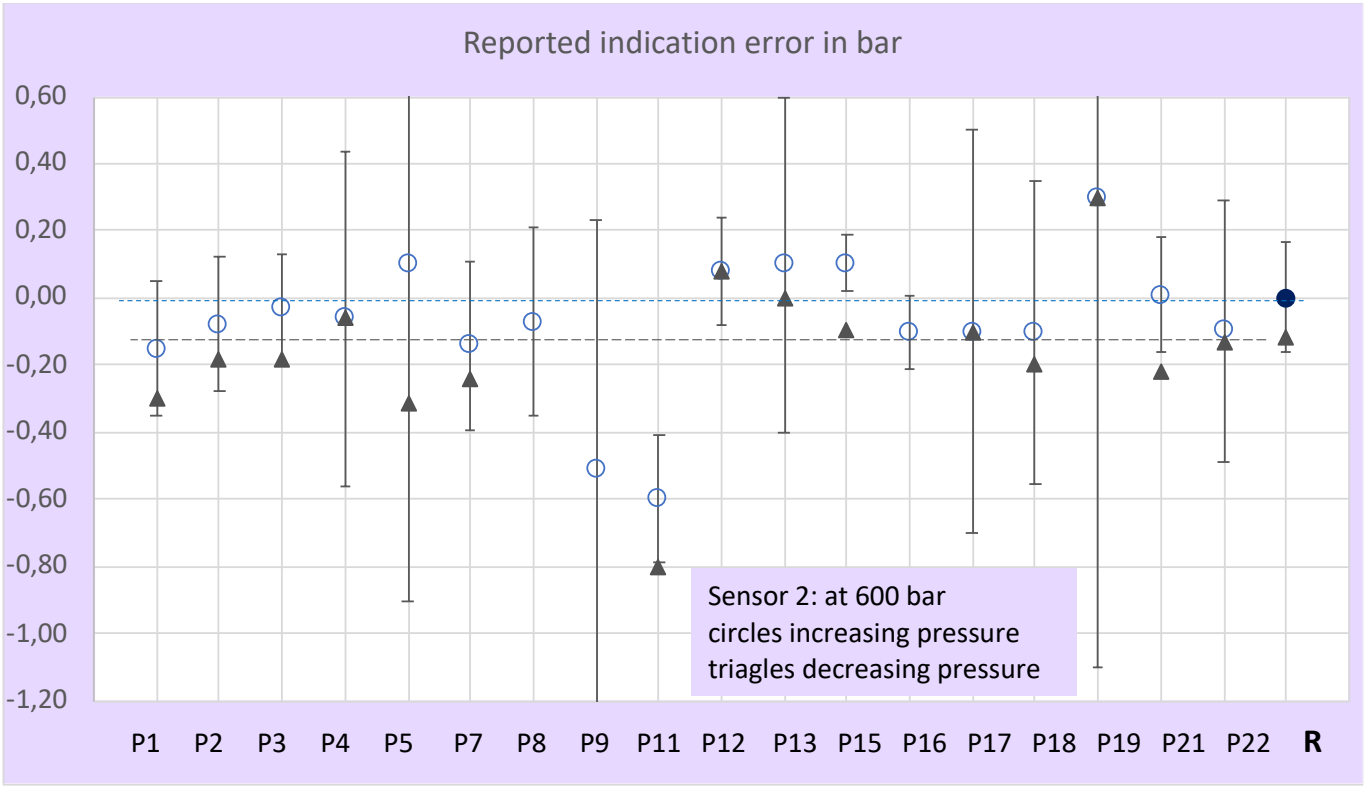

Diagram 7. Indication error from 18 participants at a pressure level of 600 bar up and down. Three only dive average values.

Comments: Here the majority exposes a clear negative hysteresis effect. Four or five participants do show such an effect.

Table 15: Calibration at 1200 bar increasing pressure

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	1200,40	1200,40	0,00	0,20	-0,67
P2	1199,895	1199,80	-0,095	0,38	-0,67
P3					
P4					
P5	1199,107	1200,00	0,50	1,8	0,16
P7	1201,292	1201,10	-0,19	0,40	-0,86
P8	1199,39	1199,536	0,15	0,31	-0,14
P9					
P11	1199,9992	1199,50	-0,50	0,22	-2,21
P12	1200,20	1200,50	0,30	0,30	0,25
P13	1200,0	1200,1	0,1	0,70	-0,14
P15	1200,940	1201,40	0,46	0,13	0,96
P16					
P17					
P18	1201,124	1201,267	0,10	0,46	-0,20
P19	1200,1095	1200,67	0,60	2,6	0,15
P21	1199,26	1199,50	0,24	0,30	0,09
P22					
R1 & R2	1200,870	1201,075	0,205	0,23	

Table 16: Calibration at 1200 bar decreasing pressure.

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	1200,40	1200,30	-0,10	0,20	-0,80
P2	1199,895	1199,80	-0,095	0,38	-0,52
P3					
P4					
P5	1199,952	1200,00	0,05	1,8	-0,05
P7					
P8					
P9					
P11	1199,9995	1199,40	-0,60	0,20	-2,54
P12	1200,20	1200,50	0,30	0,30	0,47
P13	1200,0	1200,2	0,2	0,70	0,10
P15	1200,940	1201,30	0,36	0,13	0,95
P16					
P17					
P18	1201,124	1201,133	0,00	0,46	-0,26
P19	1200,1100	1200,23	0,10	2,6	-0,01
P21	1199,22	1199,30	0,08	0,44	-0,10
P22					
R1 & R2	1200,870	1201,000	0,130	0,21	

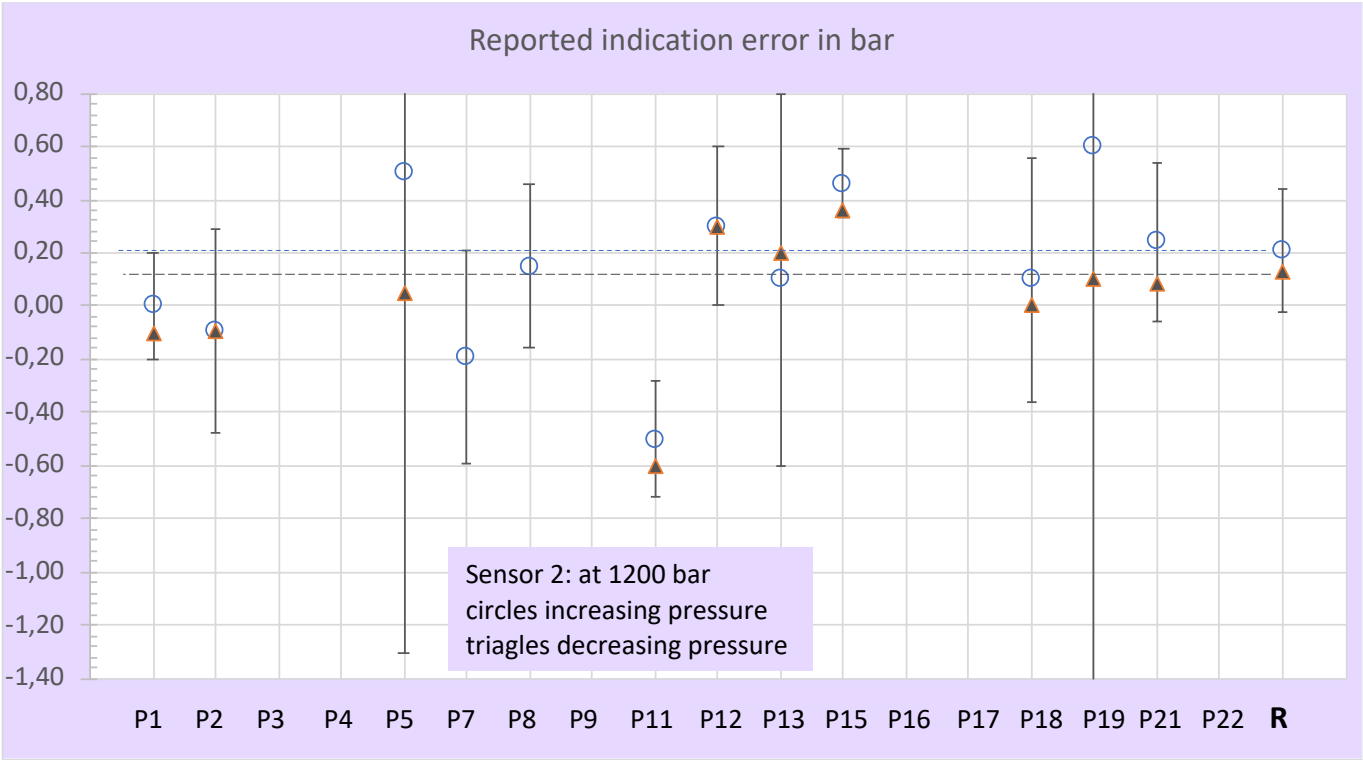

Diagram 8. Reported indication error from 12 participants at a pressure level of 1200 bar upwards and downwards pressure. The rest could probably not reach this pressure level.

Table 17: Calibration at 1600 bar increasing pressure

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	1600,60	1600,70	0,10	0,20	-1,20
P2	1599,797	1600,00	0,203	0,51	-0,49
P3					
P4					
P5	1599,182	1600,00	0,70	2,1	0,10
P7					
P8	1599,14	1599,604	0,46	0,31	-0,06
P9					
P11	1599,9986	1599,90	-0,10	0,23	-1,72
P12	1600,23	1600,80	0,60	0,40	0,25
P13					
P15	1601,210	1602,10	0,89	0,17	1,35
P16					
P17					
P18	1601,519	1602,033	0,50	0,51	0,03
P19	1600,5449	1601,10	0,60	2,6	0,04
P21	1598,93	1599,50	0,57	0,36	0,20
P22					
R1 & R2	1601,093	1601,575	0,482	0,25	

Table 18: Calibration at 1600 bar decreasing pressure.

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	1600,60	1600,60	0,00	0,20	-1,20
P2	1599,797	1600,00	0,203	0,51	-0,35
P3					
P4					
P5	1599,417	1600,00	0,58	2,1	0,08
P7					
P8					
P9					
P11	1599,9990	1599,70	-0,30	0,23	-1,98
P12	1600,23	1600,80	0,60	0,40	0,40
P13					
P15	1601,210	1602,00	0,790	0,17	1,19
P16					
P17					
P18	1601,519	1601,833	0,30	0,51	-0,19
P19	1600,5450	1601,03	1,50	2,5	0,43
P21	1598,96	1599,40	0,44	0,37	0,07
P22					
R1 & R2	1601,093	1601,500	0,408	0,27	

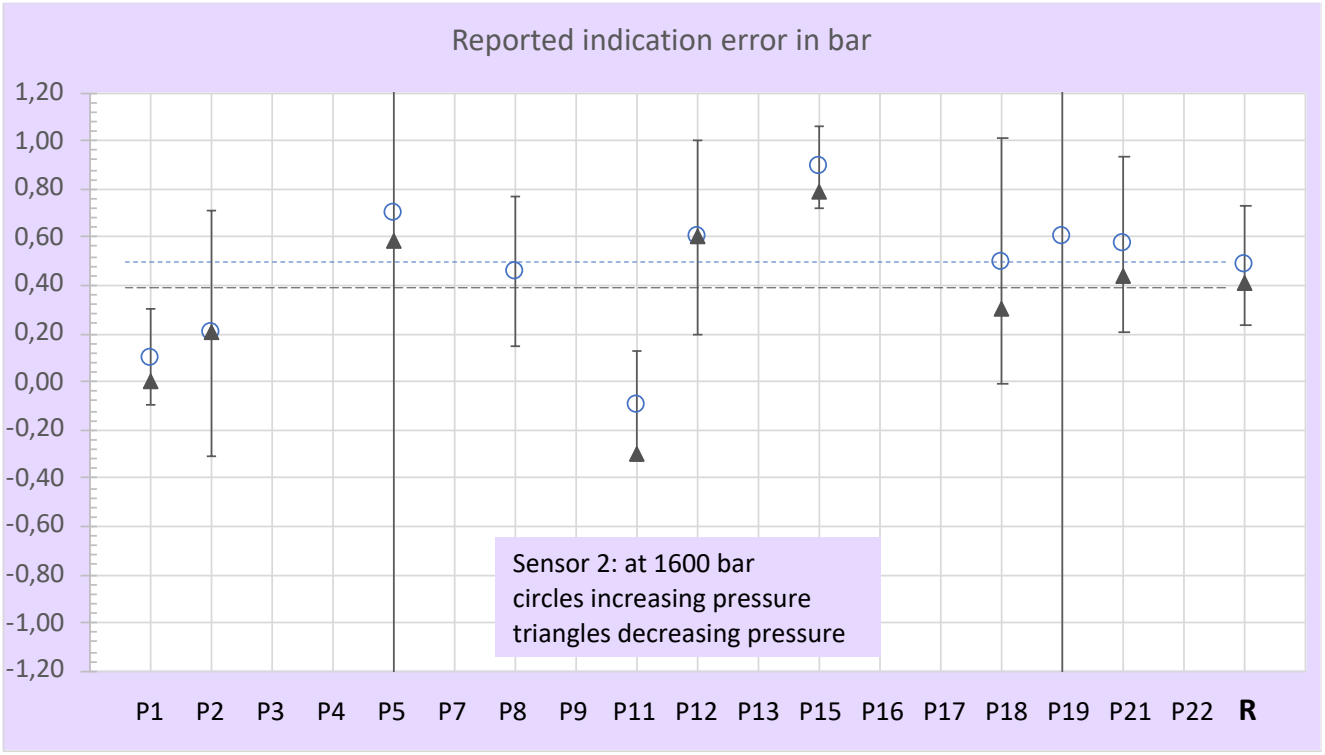

Diagram 9. Reported indication error from 10 participants at a pressure level of 1600 bar. All shifts between upwards and downwards pressure are within stated uncertainties.

Table 19: Calibration at 2000 bar increasing pressure

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	2000,70	2001,00	0,30	0,20	-1,39
P2	1999,755	2000,30	0,545	0,63	-0,42
P3					
P4					
P5	1999,478	2000,00	0,50	2,4	-0,14
P7					
P8					
P9					
P11	1999,9981	2000,10	0,10	0,21	-1,87
P12					
P13					
P15	2001,460	2002,70	1,24	0,21	0,99
P16					
P17					
P18	2001,774	2002,633	0,90	0,50	0,09
P19	1999,6554	2001,30	1,60	6,5	0,12
P21	1998,63	1999,40	0,77	0,43	-0,14
P22					
R1 & R2	2001,280	2002,125	0,845	0,34	

Table 20: Calibration at 2000 bar decreasing pressure.

Partici-pant no	Applied reference pressure	Measured object pressure	Stated indication error	Stated measurement uncertainty	En-Value
	[bar]	[bar]	[bar]	[bar]	
P1	2000,70	2000,95	0,25	0,20	-1,26
P2	1999,755	2000,30	0,545	0,63	-0,28
P3					
P4					
P5	1999,508	2000,00	0,49	2,4	-0,10
P7					
P8					
P9					
P11	1999,9985	2000,00	0,00	0,24	-1,80
P12					
P13					
P15	2001,460	2002,60	1,14	0,21	0,99
P16					
P17					
P18	2001,774	2002,533	0,80	0,50	0,09
P19	1999,5450	2001,43	1,90	6,5	0,18
P21	1998,63	1999,40	0,77	0,43	0,05
P22					
R1 & R2	2001,280	2002,025	0,745	0,34	

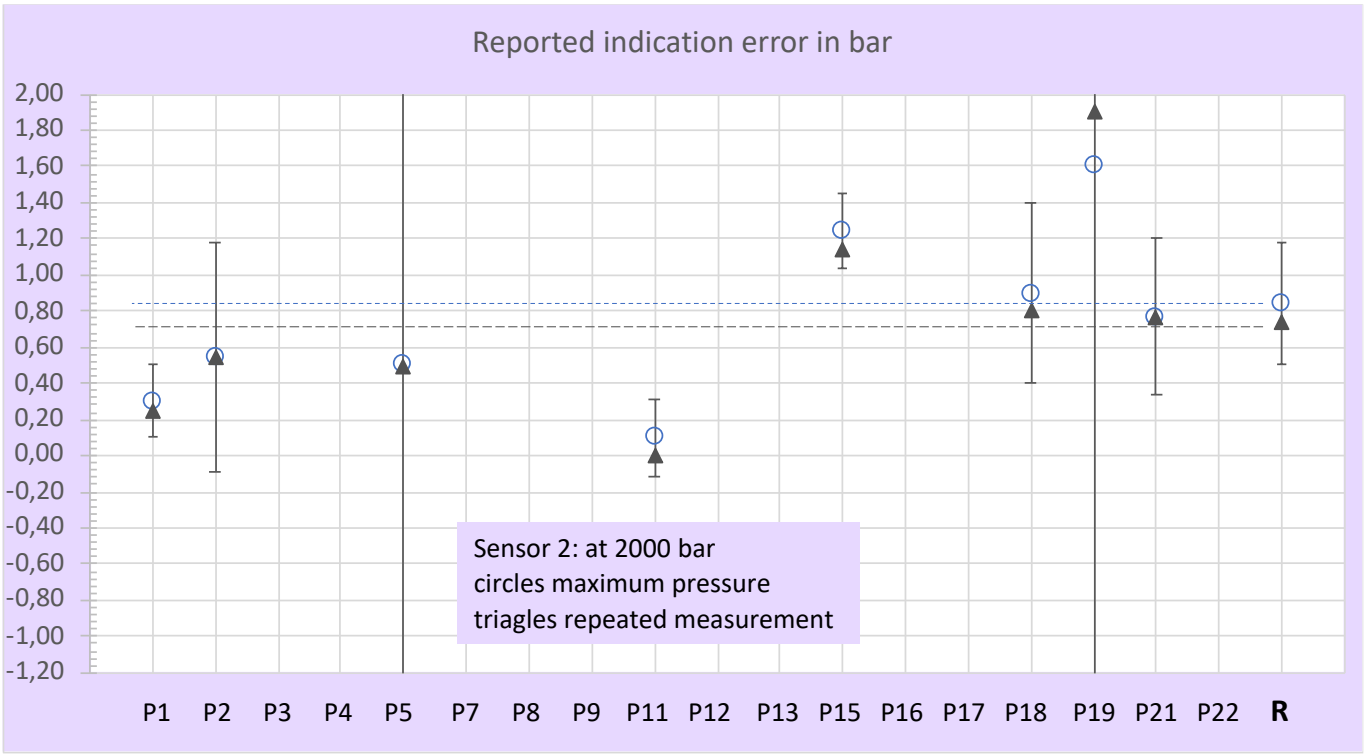

Diagram 10. Reported indication error from 8 remaining participants at a pressure level of 2000 bar.

Comments on the calibration certificates

-- not a part of the intercomparison

Most of the laboratories report measurement error, but others correction.

Most of the laboratories indicate two results for the highest applied pressure even if the value and uncertainty are the same.

Most of the laboratory's report used bar as unit but some reported in mbar (uncertainty).

Several laboratories included diagrams related to errors on increasing and decreasing pressures.

Some laboratories documented tolerance and error in percentage on different points.

Some laboratories were explaining the relations between reference value and instrument value and others indicated the result as deviation without explanation the exact meaning.

One laboratory also mentioned the density of used oil.

The difference in height between the reference and the calibrated object is documented in distance by several laboratories and even with photos.

Most of the laboratories specified their uncertainty with 2 digits in the certificate, but some laboratories gave both 1 or 3 significant digits, and even 4 digits were presented in the excel-protocol, probably due to a calculation formula.

Most of the laboratories gave both a reading and uncertainty at zero at zero while others did not indicate anything at the zero point.

The number of repetitions is indicated in many cases even if only the average value is reported. Others documented several columns using all measured values.

Some laboratories specify in their certificate only the average value for both increasing and decreasing pressure with a common uncertainty, but the excel-protocol revealed eventually differences in up- and downward direction.

Some laboratories gave all calibrated points and the mean value for each pressure level and a hysteresis indication.

Some laboratories even delivered a diagram where the hysteresis is demonstrated.

Some laboratories refer to the specification from the manufacturer even if this was not asked in the intercomparison and decided if the equipment would pass or fail the specification.

Information also was given on the decision rule that was not requested by the organizer but was done in different ways by some laboratories such as:

- Referring to the principles described on their web site.
- Explaining in a diagram.
- Explaining the application in words.

All laboratories have an accreditation by their national accreditation body.

Additions and changes to the DRAFT report

There were important comments about details in the draft report from 8 laboratories that should have changed the number of En values as it can be seen under final conclusions below.

Most of them can not be implemented in the final report as some of them were based on conclusions by the laboratories from the draft report. Those should be handled during the laboratories evaluation of results according to the requirements in the standard.

Those comments and conclusions are summarized in appendix 4.

There are some minor editorial changes in rev 3 of the report.

Final conclusions

In this inter comparison most of the participants could demonstrate a capacity to calibrate and give relevant values in relationship to their uncertainties.

The uncertainty claims vary between participants that can be seen in the tables above.

The summarized results in greater detail are as follows:

Sensor 300 bar including all pressure levels 189 results.	If discovered problem were known
• 126 En values below 0,5	134 below 0,5
• 25 En values in the range 0,5-0,8	44 in the range 0,5-0,8
• 10 En values in the range 0,8-1	12 in the range 0,8-1
• 28 En values above 1	15 above 1

Sensor 2000 bar including all pressure levels 123 results.

• 88 En values below 0,5	103 below 0,5
• 11 En values in the range 0,5-0,8	12 in the range 0,5-0,8
• 7 En values in the range 0,8-1	7 in the range 0,8-1
• 17 En values above 1	1 above 1

Evaluation of the results of the participants.

The participants shall evaluate their results according to ISO/IEC 17025:2017 7.7.3

It is then recommended to evaluate according to descriptions above including the fact where:

- U_{ref} is in the range of 1/3 of U_i.
- The size of En-values
- En- values in relation to CMC values
- The error bars in the diagrams

Acknowledgement

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We also acknowledge the primary calibrations by RISE Sweden that supported the ILC with reference calibrations.

Annex 1 ILC pressure 2022:1

Published on https://smquality.se/

Annex 2 *D*escription of the intercomparison/ILC

Published on https://smquality.se/

Appendix 3 Reporting forms

	Intercomparison ILC-Pressure	2022:1			Code for the box	504
Reporting form for preliminary calibration results						
	Laboratory:				Comparison ID	
	Name:					
	e-mail:					
	Date of reporting:					
	Calibration intercomparison Pressure gauge 1: Keller LEX 1 (max 300 bar)					If you re
					Date of calibration	
		Range 0 to 300 bar	PART NO 303030.0037			
	Pressure Gage 1		⇩			
	Sugested calibration points	(Average) Reference value	(Average) Measured value	Instrument error	Measurement uncertainty	
	[bar]	[bar]	[bar]	[bar]	[bar]	
	0					
	60					
	120					
	180					
	240					
	300					
	300					
	240					
	180					
	120					
	60					
	0					
	Calibration intercomparison Pressure gauge 1: Keller LEX 1 (max 2000 bar)					
					Date of calibration	
		Range 0 to 2000 bar	PART NO 303030.0705			
	Pressure Gage 2		⇩			
	Sugested calibration points	(Average) Reference value	(Average) Measured value	Instrument error	Measurement uncertainty	
	[bar]	[bar]	[bar]	[bar]	[bar]	
	0					
	300					
	600					
	700					
	1600					
	2000					
	700					
	1600					
	1200					
	600					
	300					
	0					
	Date of receipt of calibration objects					
	Date of dispatch					
	Used reference equipment					
	Traceability to					

Appendix 2 --Intercomparison reference values stability and uncertainty.

The two tables below present the calibration results received from the reference laboratory called R1 before and R2 after the round robin.

Table A Compact overview of the calibration result for sensor 1 up to 300 bar.

Sensor 1	1. Calibration R1		2. Calibration R2		Combined reference value			
Pressure level	Determind error for comparison	Determined uncertainty	Determind error for comparison	Determined uncertainty	Average error for R1 & R2	Combined Uncertainty excl. drift	Drift	Uncertainty including drift
[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]
0	0,000	0,001	0,000	0,001	**0,000**	**0,001**	0,000	**0,001**
60	0,043	0,004	0,043	0,003	**0,043**	**0,004**	0,000	**0,004**
120	0,102	0,009	0,107	0,008	**0,105**	**0,009**	0,005	**0,011**
180	0,162	0,010	0,172	0,009	**0,167**	**0,010**	0,010	**0,015**
240	0,227	0,015	0,237	0,010	**0,232**	**0,013**	0,010	**0,018**
300	0,287	0,020	0,292	0,013	**0,290**	**0,017**	0,005	**0,019**
300	0,277	0,020	0,292	0,013	**0,285**	**0,017**	0,015	**0,024**
240	0,222	0,015	0,227	0,010	**0,224**	**0,013**	0,005	**0,015**
180	0,162	0,010	0,162	0,009	**0,162**	**0,010**	0,000	**0,010**
120	0,097	0,009	0,097	0,008	**0,097**	**0,009**	0,000	**0,009**
60	0,043	0,004	0,043	0,003	**0,043**	**0,004**	0,000	**0,004**
0	0,000	0,001	0,000	0,001	**0,000**	**0,001**	0,000	**0,001**

Each error value listed in the table for R1 and R2 is the mean of two measurement series. The finally used reference values for the comparison are in turn the average of R1 and R2 (equation 2). From the difference between R2 and R1 a possible “drift” of the sensors can be assumed thus indicating the stability of the sensor over time. As can be seen this drift is mostly within the stated combined uncertainty. Excluding the drift, the uncertainty of the reference values is calculated as the combined uncertainty (equation 3) from two results. Also taking the possible drift into account the uncertainty of the reference values is enlarged by adding half of the calculated drift (equation 4).

Table B. Compact overview of the calibration result for sensor 2 up to 2000 bar.

Sensor 2	1. Calibration R1		2. Calibration R2		Combined reference value			
Pressure level	Determind error for comparison	Determined uncertainty	Determind error for comparison	Determined uncertainty	Average error for R1 & R2	Combined Uncertainty excl. drift	Drift	Uncertainty including drift
[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]
0	0,000	0,01	0,000	0,06	**0,000**	**0,043**	0,000	**0,043**
300	0,010	0,13	-0,050	0,07	**-0,020**	**0,104**	-0,060	**0,134**
600	0,040	0,12	-0,035	0,13	**0,002**	**0,125**	-0,075	**0,163**
1200	0,255	0,22	0,155	0,13	**0,205**	**0,181**	-0,100	**0,231**
1600	0,490	0,29	0,475	0,18	**0,482**	**0,241**	-0,015	**0,249**
2000	0,815	0,37	0,875	0,23	**0,845**	**0,308**	0,060	**0,338**
2000	0,715	0,37	0,775	0,23	**0,745**	**0,308**	0,060	**0,338**
1600	0,440	0,29	0,375	0,18	**0,408**	**0,241**	-0,065	**0,274**
1200	0,155	0,22	0,105	0,13	**0,130**	**0,181**	-0,050	**0,206**
600	-0,053	0,12	-0,180	0,13	**-0,117**	**0,125**	-0,127	**0,189**
300	-0,097	0,13	-0,150	0,07	**-0,124**	**0,104**	-0,053	**0,131**
0	0,000	0,01	-0,100	0,06	**-0,050**	**0,043**	-0,100	**0,093**

To better se the influence of the drift on the calculated uncertainty three significant digits are shown.

Appendix 3 - Supporting checks of stability

A prerequisite on an inter-comparison with objects send around is that they are stable over time. The actual stability of course can only be stated by the reference laboratory results R2 compared to R1. In case however, that a considerable change in participants result would occur, the plan was to stop the circulation for an intermediate recalibration by the reference laboratory. With this ambition the "stability" of both sensors over the time of the comparison was monitored by following up the reported indication error at two pressure levels immediately after each participant had finished its calibration. The diagrams below show the error indication values for sensor 1 in timely order with the first and last symbol referring to the reference laboratory. The two dashed lines imply a ±2 *Uj*-band from *R1j*. The dotted line is a prognostic trendline which is automatically updated every time a new result is added.

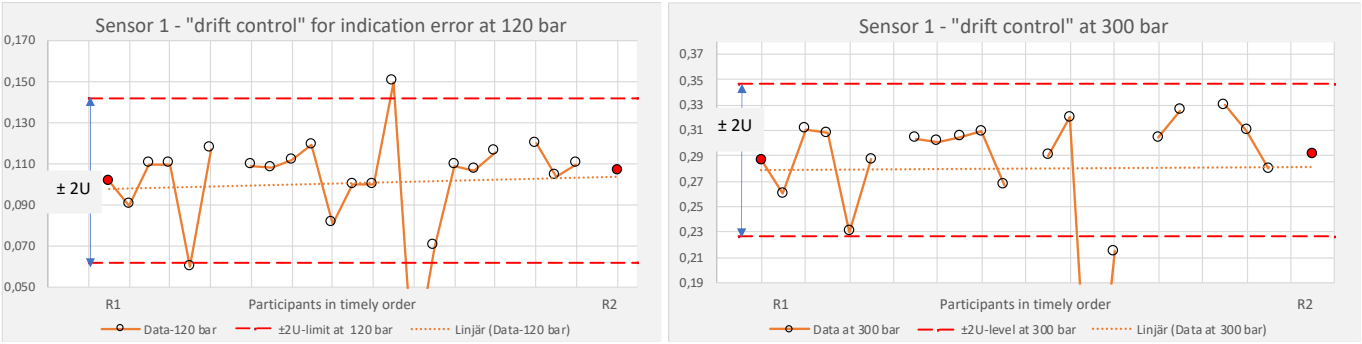

Diagram XY1 and XY2. Following up the preliminary reported participant results for sensor 1 as an example

The two reference points and the rather horizontal trendlines at both levels indicate that no serious change has happened. The missing points indicate that this participant did not deliver a calibration result for this sensor. The situation is the same for sensor 2 (1200 and 2000 bar) but not shown here. Instead, the reference data for all pressure levels $R1_j$ and $R2_j$ are shown both for increasing and decreasing pressure.

A more real drift estimation is shown in the two diagrams below based on the data from the reference laboratory

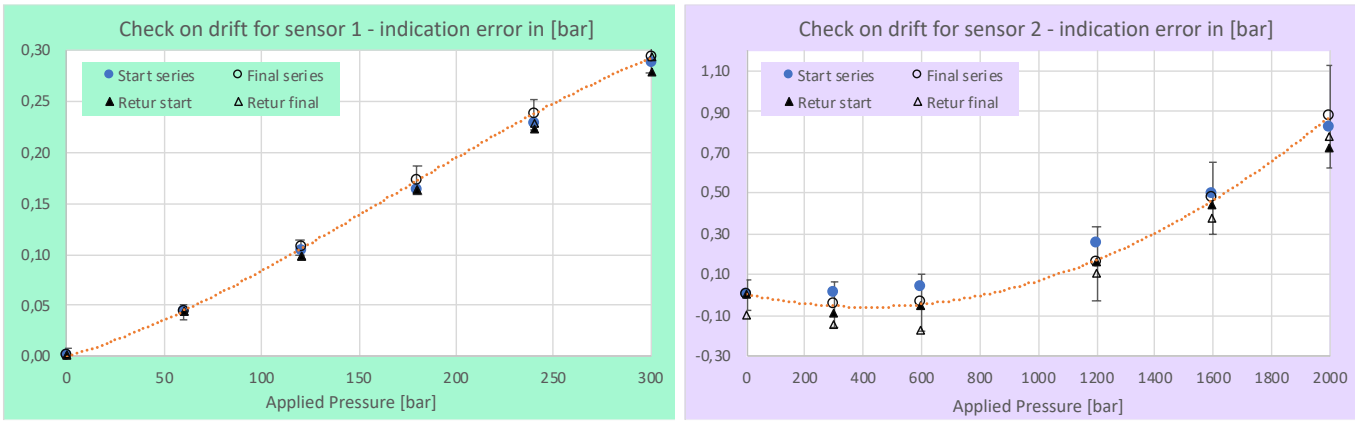

Diagram XY3 and XY4. Drift control of both sensors over the total pressure range based on the reference laboratory data. The indication error as a function of pressure load for instrument 1 and 2 in two series for increasing and degreasing pressure

Both a hysteresis and a possible drift are within the stated measurement uncertainty (here for final series at increasing pressure).

Appendix 4 – Measures taken after receiving all participants comments and feed-back on the draft report.

After several urgings by the organizer to come in with a feed-back after having taken part of the draft report 11 of 24 the participants confirmed that all their data was correct and that they did not have any special comments. The rest submitted questions, suggestion and informed on detected shortcomings in their results, which are reflected below.

One Participant (P20) discovered some deviation in his own reference equipment and has therefore increased its uncertainty somewhat. This change could however not be introduced in this final report.

Another laboratory (P2) found a falsely tenfold uncertainty in the report at a decreasing pressure point compared to that at increasing pressure. This, most likely a writing mistake, has been corrected.

Some participant suggested to change the headline "Measured object pressure" to just "Indicated pressure". The idea was that all would have the same resolution for the object under calibration. However, as several laboratories performed more than one or two series of calibration, they also reported the error indication with an additional decimal.

Some participants commented that they did not reveal any hysteresis effect for sensor 2. This might of course be due to the reference equipment having a similar behaviour thus hiding the hysteresis of the calibrated sensor.

One participant (P11) replied that they did not perform a zeroing of the sensors (probably depending on misinterpreting the exhortation not to perform any adjustments) which implied that they had an overlay of roughly -0,5 bar throughout the whole pressure range of sensor 2. This of course resulted in large negative En-values. The zeroing, however, is normally part of the calibration procedure. If it had be done, which was checked by evaluating the data again after removing this offset the En-values had been perfectly suitable within a range of -0,02 to -0,64 at most. For sensor 1 the not corrected offset of roughly 0,01 bar also generated several En values over 1. With a correct zeroing only two En-values larger than 1 had occurred with a rest between 0,2 and 0,67. This update, however, cannot be made in the report after the draft had been published. It is just a general reflection caused by the large En-values in the draft report.

Another participant P18 reported in their comments to the draft report that their uncertainty judgement lacked a component and send an updated calibration certificate. Again, after publishing this cannot be corrected. One can however state that this problem in practice did not affect the results of sensor 2. But it had large influence on the low-pressure points for sensor 1. Of 5 En-values larger than 1 only one would still be left over this limit and all other values would be reduced had this problem been detected earlier.

Thus, one can state that an intercomparison like this can be very helpful to detect shortcomings that are difficult to trace otherwise.

Further participants P8 and P9 realized and commented that they did not report values for decreasing pressure points in their certificates but only their average. Therefore, no hysteresis effect could be shown. Most participants as well as the reference laboratory presented both the separate indication errors and their average. The participants though were asked to do and report the calibration according to their own methods.

Participant P1 informed that they discovered problems in the calculation of their own reference values and send an updated excel-protocol with preserved sensor data but corrected reference values. For sensor 2 this did not really influence the calculated En-values. On the contrary for sensor 1 the change in reference pressure between 0 and maximum 0,05 bar at 300 bar drastically reduced the En-values (to -0,42 to -1,07 from -0,64 to -2,1 in the draft). But again, this discovery cannot be adopted in the final report.

One participant P17 did not state an indication error. Instead, a deviation from the reference were reported in the calibration certificate. The direction of the deviation was yet not specified, which lead to that for sensor 1 “deviation” meant error and thus gave a correct sign, whereas for sensor 2 it actually meant the opposite correction and thus gave a wrong sign for the indication error. This was clearly seen in the excel-protocol where this was pre-defined. In the certificate however the term deviation always led to a positive sign meaning an absolute value. From a measurement point it seems reasonable to include this corrected mistake into the final report.

References:

- ISO/IEC 17043:2010 Conformity assessment – General requirements for proficiency testing
- ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories
- ISO 13528 Statistical methods for use in proficiency testing by interlaboratory comparison.
- Evaluation of measurement data – Guide to the expression of uncertainty in measurement, GUM (JCGM 100:2008)
- EA-4/02 M:2022Evaluation of Uncertainty of Measurement in Calibration t
- International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM)