APLAC

PRESSURE

INTERLABORATORY COMPARISON

APLAC M019 - JULY 2008

TABLE OF CONTENTS

1. INTRODUCTION

This report summarizes the results of interlaboratory comparison on pressure calibration by laboratories accredited by bodies that are members of the Asia Pacific Laboratory Accreditation Cooperation (APLAC).

The first pressure program M006 was coordinated by NATA in 1999. The second pressure program M019 was coordinated by Korea Laboratory Accreditation Scheme (KOLAS) and provided financial support by Ministry of Knowledge Economy from 2007 until 2008.

2. PURPOSE

The purpose of the Asia Pacific Laboratory Accreditation Cooperation (APLAC) is to build up and maintain mutual confidence in national calibration services in order to reach and maintain a state of mutual agreement on the equivalence of the operation of the accreditation bodies and of the certificates issued by their accredited laboratories.

APLAC interlaboratory comparisons also result in a flow of know-how between the participating accreditation bodies and help establish a common high level of measuring capability within the region.

3. DESIGN OF THE PROGRAM

This calibration interlaboratory comparison was guided by APLAC PT001. In order to maintain the 12 month schedule, participating laboratories were divided into two groups and assigned Loop A and B. Two artifacts with same ranges/values were prepared and sent around simultaneously.

Korea Testing Laboratory (KTL) acted as the reference laboratory. The reference laboratory calibrated the artifacts at the beginning, and end of the program and at regular intervals.

4. ARTIFACTS

The artifacts used in this program are oil pressure gauge. They needed to have sufficient resolution, repeatability and stability to be suitable for laboratories working to an uncertainty of 0.01% of reading.

The artifacts to be circulated refer to the spec below:-

- Range : 0 ㎫ to 100 ㎫, gauge pressure
- Uncertainty : ± 0.01 % of reading
- Resolution : 0.1 ㎪
- Type : Quartz Reference Pressure Transducer
- Maker : DH Instruments (USA)

5. PARTICIPANTS

Thirty one laboratories from nine accreditation bodies participated in the program. But six laboratories give up in the middle of the program. The results from twenty five laboratories were submitted. A circulation schedule appears in Appendix B and lists the participating accreditation bodies and the dates of receipt and dispatch.

A copy of the Instructions to Laboratories appears in Appendix A. Laboratories were asked to calibrate the artifacts in accordance with the instructions and to report their results on proforma Result Sheets (refer Appendix A). No formal calibration report was requested.

After participating accreditation bodies had submitted their results, the organizing body shall send Interim Reports for each participating laboratory to their accreditation body to provide early feedback on their laboratories' performance. In order to keep confidential the identity of the participating laboratories, Random codes numbers are assigned to the laboratories.

6. STABILITY AND TRACEABILITY

Traceability of Korea Testing Laboratory (KTL) was achieved from Korea Research Institute of Standards and Science (KRISS) which is National Measurement Institute (NMI), Korea. Before the program was started, KTL had calibrated the artifacts with KRISS. A total of four calibrations were performed. The maximum drift of two artifacts was 1.4 ㎪.

The artifacts were calibrated after every one or two economies throughout the program. The average drift between any two successive reference laboratory calibrations was 0.4 ㎪ (refer Appendix C)

7. REFERENCE VALUES

The reference values are derived from the mean of the calibrations carried out by Korea Testing Laboratory, before and after each cycle of one or two countries (refer Appendix B).

8. SUMMARY OF RESULTS

A convenient and internationally accepted method of judging the quality of each measurement result is by calculating the error normalized (E_n) with respect to the stated uncertainty:-

$$E_n = \frac{Lab\,Value - Ref\;Value}{\sqrt{(U_{Lab})^2 + (U_{Ref})^2}}$$

where U_{Lab} is the uncertainty reported by the participating laboratory and U_{Ref} is the uncertainty of the reference value. Both uncertainties are at a 95% confidence level. Values of $|E_n| > 1$ require investigation and corrective action by both the laboratory concerned and its accreditation body.

The artifacts were set up in gauge pressure mode. The zero and other functions were deactivated. Consequently, each result was zero corrected using the following formula:-

$$P_C = R_i - Z_o - \frac{(Z_n - Z_o) \times i}{n+1}$$

where:-

P_C is the results with zero-correction

R_i is the i th reading in the run

Z_o is the reading before the run

Z_n is the reading after the run

n is the total number of readings in the run

Difference (Lab-Ref), uncertainty and E_n ratio were expressed in table. The difference between the laboratory's result and the reference value is plotted along with bars indicating their uncertainty of the measurement.

A total of six laboratories couldn't complete the program. Five of them did not have the capabilities required. One of them fails to perform calibration because their dead weight piston gauge was leaking.

SUMMARY OF LAB-REF (MPa)

No. \ Code	REF	A0401	A0402	A0403	A0404	A0701	A0702	A0801	A0802	A0803
20	0	-0.0032	-0.0007	0.0036	-0.0005	0.0017	-0.0007	-0.0283	-0.0177	-0.0559
40	0	-0.0043	-0.0024	0.0036	-0.0126	0.0016	-0.0009	-0.0433	-0.0261	-0.1141
60	0	-0.0044	-0.0045	0.0054	-0.0111	0.0007	0.0035	-0.0448	-0.0329	-0.1742
80	0	-0.0053	-0.0066	0.0072	-0.0167	-0.0004	0.0007			-0.2378
100	0	-0.0051	-0.0036	0.0093	-0.0215	-0.0002	0.0026			-0.3022
80	0	-0.0051	-0.0069	0.0076	-0.0114	-0.0031	0.0007			-0.2370
60	0	0.0021	-0.0040	0.0049	-0.0073	-0.0036	-0.0009	-0.0446		-0.1739
40	0	-0.0036	-0.0023	0.0027	-0.0069	-0.0026	-0.0013	-0.0456	-0.0074	-0.1138
20	0	-0.0034	-0.0010	0.0024	-0.0011	-0.0015	-0.0008	-0.0298	0.0033	-0.0560

No. \ Code	A0804	B0101	B0102	B0103	B0201	B0202	B0203	B0301	B0303	B0501
20	0.0097	0.0002	0.0026	-0.0003	0.0051	0.0064	-0.0013	0.0000	-0.0019	-0.4497
40	0.0106	0.0012	-0.0014	-0.0004	0.0030	0.0060	-0.0023	-0.0033	-0.0018	-0.3639
60	0.0107	0.0025	-0.0150	-0.0004	-0.0013	0.0077	-0.0029	-0.0101	-0.0018	-0.3592
80		0.0029	-0.0183	-0.0013	-0.0042	0.0054	-0.0049	-0.0195	-0.0024	-0.3152
100			-0.0397	-0.0014	-0.0051	0.0011	-0.0055	-0.0301	-0.0028	
80		0.0030	-0.0148	-0.0011	-0.0044	0.0057	-0.0049	-0.0200	-0.0021	
60		0.0023	-0.0059	-0.0001	-0.0018	0.0078	-0.0032	-0.0104	-0.0017	-0.2965
40	0.0066	0.0011	0.0018	-0.0001	0.0024	0.0058	-0.0030	-0.0048	-0.0017	-0.2655
20	0.0072	0.0002	0.0036	-0.0003	0.0051	0.0068	-0.0025	-0.0003	-0.0017	-0.2640

No. \ Code	B0503	B0504	B0601	B0602	B0603	B0701
20	-0.0025	0.0002	-0.0012	-0.0005	-0.0008	0.0013
40	-0.0055	0.0008	-0.0016	-0.0006	-0.0009	0.0010
60	-0.0120	0.0009	-0.0014	0.0003	-0.0009	0.0016
80	-0.0194	0.0004	-0.0025	-0.0002	-0.0017	0.0010
100	-0.0259	-0.0002	-0.0025	0.0007	-0.0019	0.0014
80	-0.0208	0.0002	-0.0024	0.0000	-0.0017	0.0010
60	-0.0138	0.0007	-0.0014	0.0001	-0.0008	0.0015
40	-0.0082	0.0005	-0.0016	-0.0008	-0.0010	0.0009
20	-0.0055	-0.0001	-0.0010	-0.0007	-0.0008	0.0012

SUMMARY OF UNCERTAINTIES (MPa)

No. \ Code	REF	A0401	A0402	A0403	A0404	A0701	A0702	A0801	A0802	A0803
20	0.0015	0.0036	0.0039	0.0026	0.0269	0.0013	0.0020	0.0065	0.0210	0.0023
40	0.0024	0.0068	0.0070	0.0052	0.0270	0.0020	0.0035	0.0130	0.0210	0.0040
60	0.0034	0.0199	0.0093	0.0078	0.0285	0.0029	0.0042	0.0195	0.0210	0.0060
80	0.0044	0.0124	0.0101	0.0104	0.0288	0.0038	0.0058			0.0080
100	0.0054	0.0152	0.0122	0.0130	0.0269	0.0048	0.0070			0.0100
80	0.0044	0.0124	0.0101	0.0104	0.0285	0.0039	0.0058			0.0080
60	0.0033	0.0199	0.0093	0.0078	0.0284	0.0029	0.0042	0.0195		0.0061
40	0.0023	0.0068	0.0070	0.0052	0.0271	0.0020	0.0035	0.0130	0.0210	0.0041
20	0.0015	0.0036	0.0039	0.0026	0.0270	0.0013	0.0020	0.0065	0.0210	0.0021

No. \ Code	A0804	B0101	B0102	B0103	B0201	B0202	B0203	B0301	B0303	B0501
20	0.0026	0.0018	0.0100	0.0012	0.0053	0.0046	0.0015	0.0110	0.0010	0.4900
40	0.0052	0.0034	0.0200	0.0028	0.0053	0.0092	0.0024	0.0220	0.0018	0.4900
60	0.0077	0.0050	0.0300	0.0042	0.0056	0.0139	0.0037	0.0330	0.0029	0.4900
80		0.0066	0.0400	0.0056	0.0056	0.0185	0.0047	0.0430	0.0044	0.4900
100			0.0500	0.0070	0.0056	0.0231	0.0059	0.0540	0.0063	
80		0.0066	0.0400	0.0056	0.0057	0.0185	0.0048	0.0430	0.0044	
60		0.0050	0.0300	0.0042	0.0058	0.0139	0.0037	0.0330	0.0029	0.4900
40	0.0052	0.0034	0.0200	0.0028	0.0053	0.0092	0.0025	0.0220	0.0018	0.4900
20	0.0026	0.0018	0.0100	0.0012	0.0053	0.0046	0.0014	0.0110	0.0012	0.4900

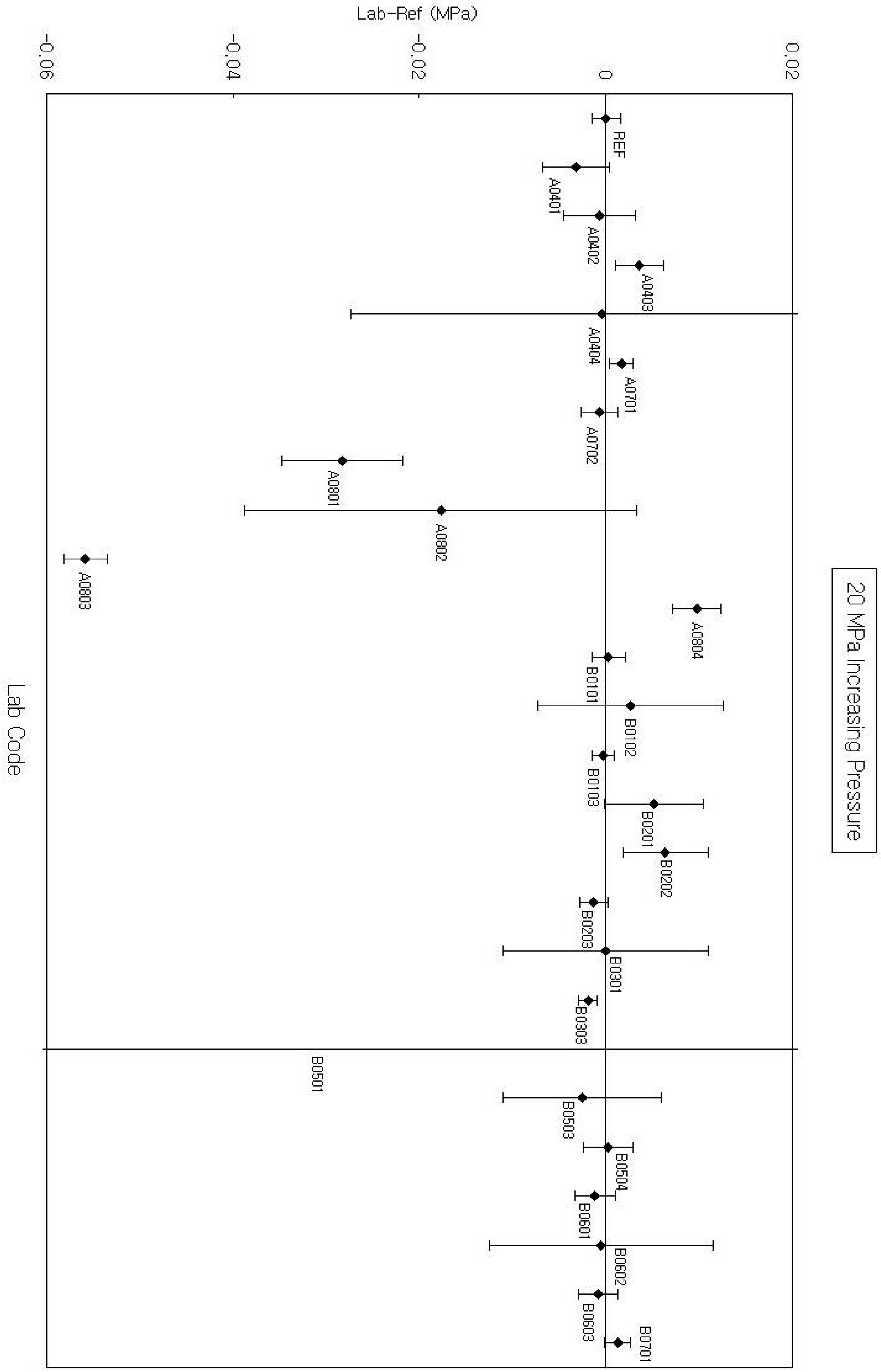
No. \ Code	B0503	B0504	B0601	B0602	B0603	B0701
20	0.0085	0.0026	0.0022	0.0120	0.0021	0.0014
40	0.0100	0.0052	0.0028	0.0120	0.0029	0.0026
60	0.0130	0.0080	0.0049	0.0120	0.0044	0.0036
80	0.0160	0.0083	0.0070	0.0120	0.0058	0.0048
100	0.0200	0.0087	0.0070	0.0120	0.0072	0.0060
80	0.0160	0.0085	0.0070	0.0120	0.0058	0.0048
60	0.0120	0.0078	0.0049	0.0120	0.0044	0.0036
40	0.0090	0.0052	0.0028	0.0120	0.0030	0.0026
20	0.0074	0.0027	0.0022	0.0120	0.0021	0.0014

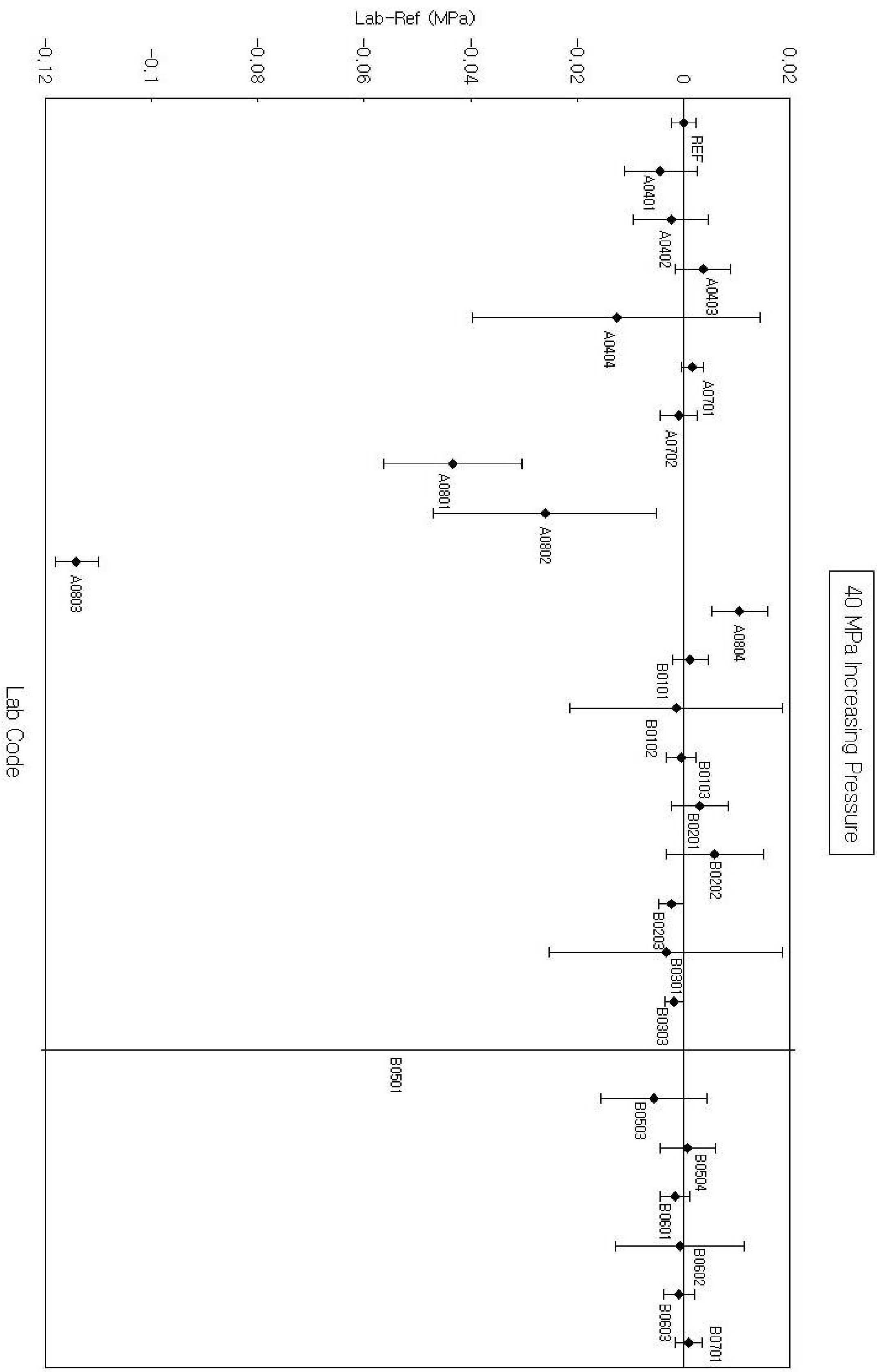
SUMMARY OF E_n RATIO

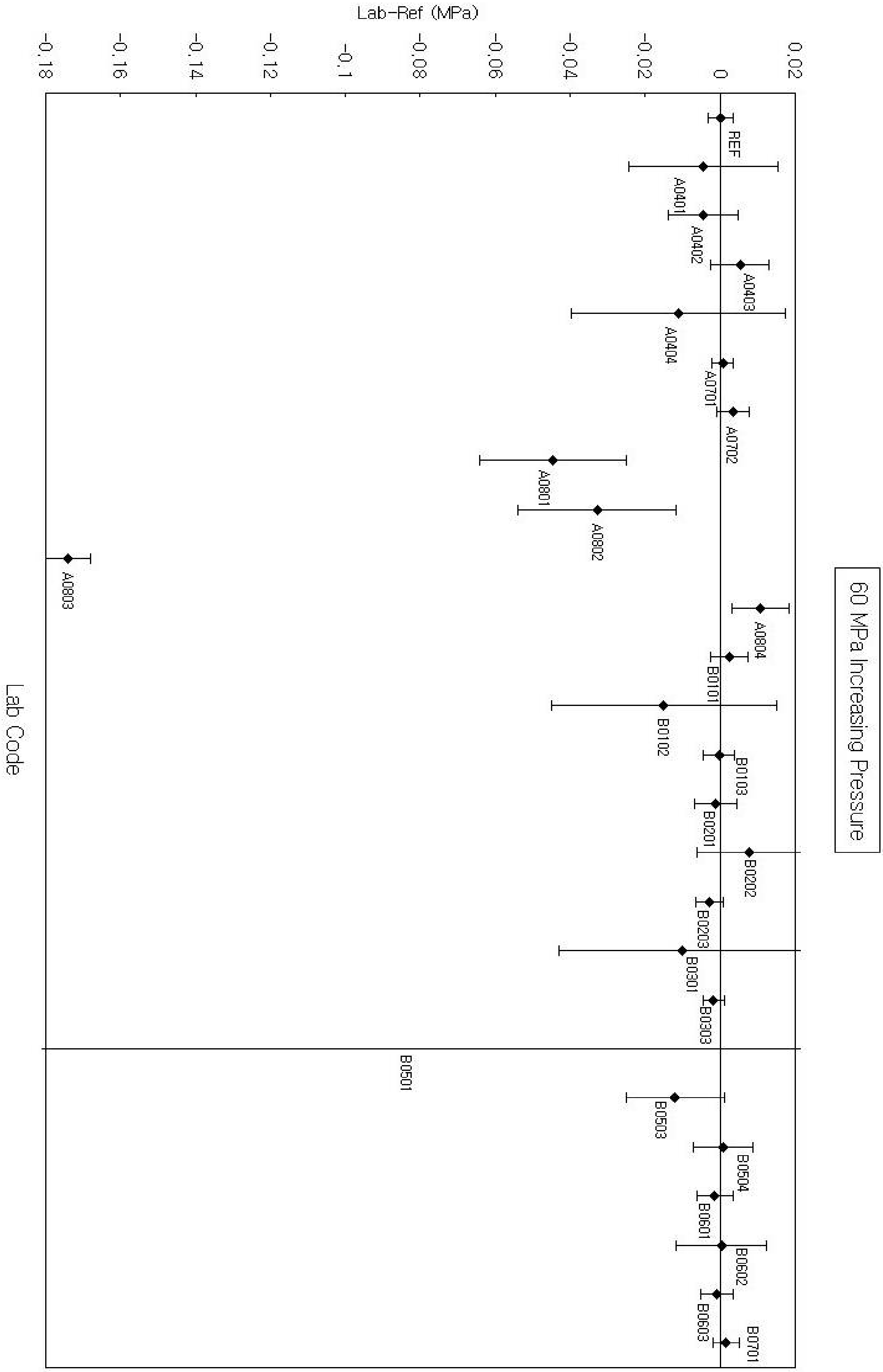
No. \ Code	REF	A0401	A0402	A0403	A0404	A0701	A0702	A0801	A0802	A0803
20		-0.84	-0.16	1.25	-0.02	0.94	-0.27	-4.29	-0.84	-21.75
40		-0.60	-0.33	0.65	-0.47	0.54	-0.22	-3.28	-1.24	-25.09
60		-0.22	-0.46	0.63	-0.39	0.16	0.65	-2.26	-1.55	-25.59
80		-0.40	-0.60	0.64	-0.57	-0.08	0.10			-26.23
100		-0.31	-0.27	0.66	-0.78	-0.03	0.30			-26.68
80		-0.39	-0.63	0.67	-0.39	-0.54	0.10			-26.15
60		0.11	-0.41	0.58	-0.25	-0.83	-0.16	-2.26		-25.22
40		-0.51	-0.31	0.48	-0.26	-0.86	-0.33	-3.46	-0.35	-24.54
20		-0.89	-0.24	0.83	-0.04	-0.85	-0.35	-4.51	0.16	-23.42

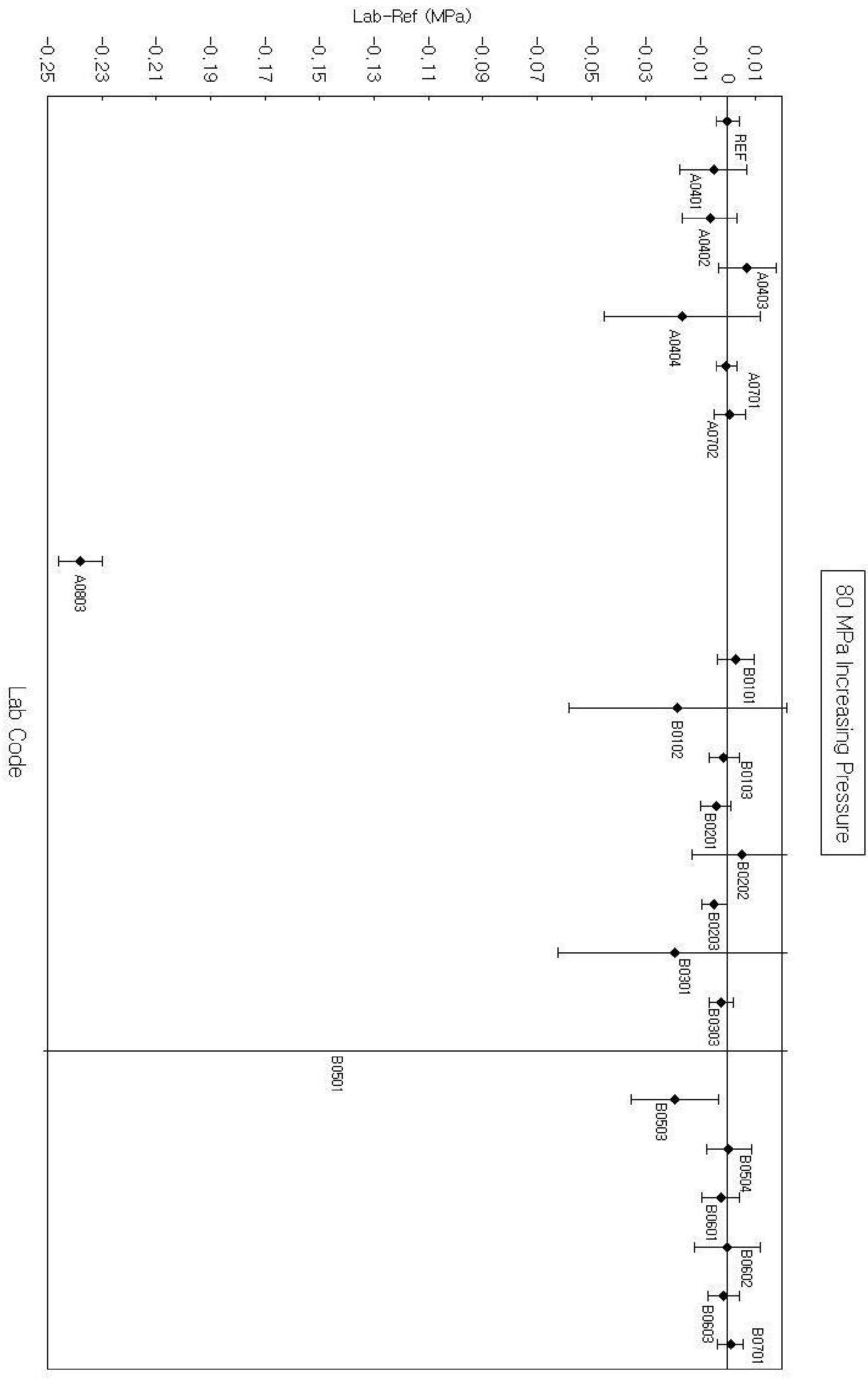
No. \ Code	A0804	B0101	B0102	B0103	B0201	B0202	B0203	B0301	B0303	B0501
20	3.43	0.11	0.26	-0.20	0.94	1.34	-0.68	0.00	-1.22	-0.92
40	1.88	0.30	-0.07	-0.10	0.53	0.63	-0.69	-0.15	-0.62	-0.74
60	1.28	0.42	-0.50	-0.07	-0.21	0.54	-0.60	-0.30	-0.41	-0.73
80		0.37	-0.45	-0.19	-0.59	0.28	-0.77	-0.45	-0.39	-0.64
100			-0.79	-0.16	-0.66	0.05	-0.69	-0.56	-0.34	
80		0.38	-0.37	-0.15	-0.62	0.30	-0.76	-0.46	-0.35	
60		0.38	-0.19	-0.03	-0.27	0.55	-0.65	-0.31	-0.40	-0.61
40	1.17	0.28	0.09	-0.04	0.42	0.62	-0.91	-0.22	-0.60	-0.54
20	2.52	0.09	0.36	-0.16	0.93	1.42	-1.33	-0.03	-0.97	-0.54

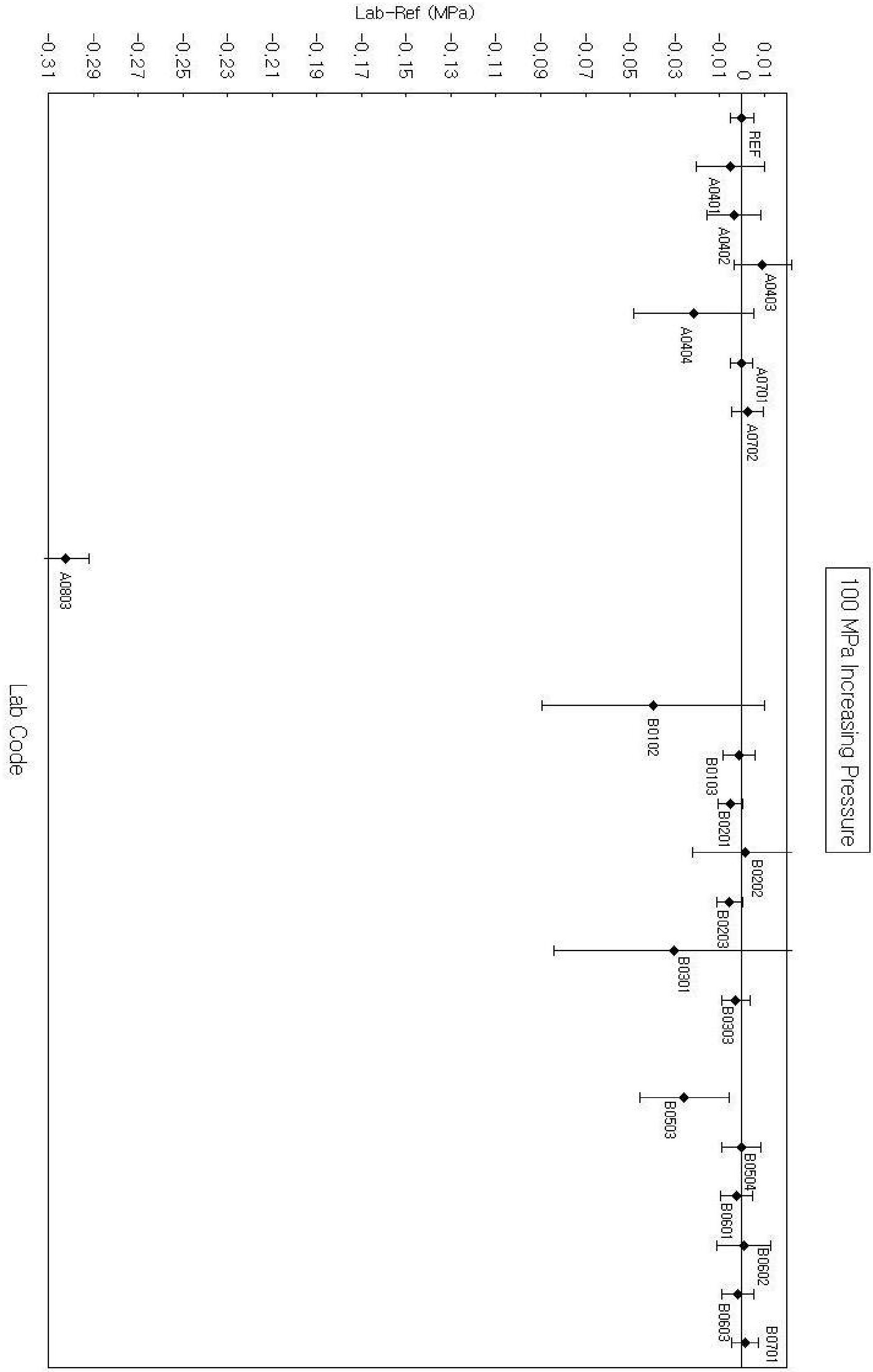
No. \ Code	B0503	B0504	B0601	B0602	B0603	B0701
20	-0.30	0.08	-0.46	-0.04	-0.33	0.64
40	-0.54	0.14	-0.45	-0.05	-0.24	0.29
60	-0.90	0.10	-0.24	0.02	-0.16	0.32
80	-1.17	0.04	-0.30	-0.02	-0.23	0.16
100	-1.25	-0.02	-0.29	0.05	-0.21	0.17
80	-1.26	0.02	-0.30	0.00	-0.24	0.16
60	-1.11	0.08	-0.24	0.01	-0.15	0.30
40	-0.88	0.08	-0.44	-0.06	-0.26	0.28
20	-0.74	-0.02	-0.40	-0.06	-0.33	0.63

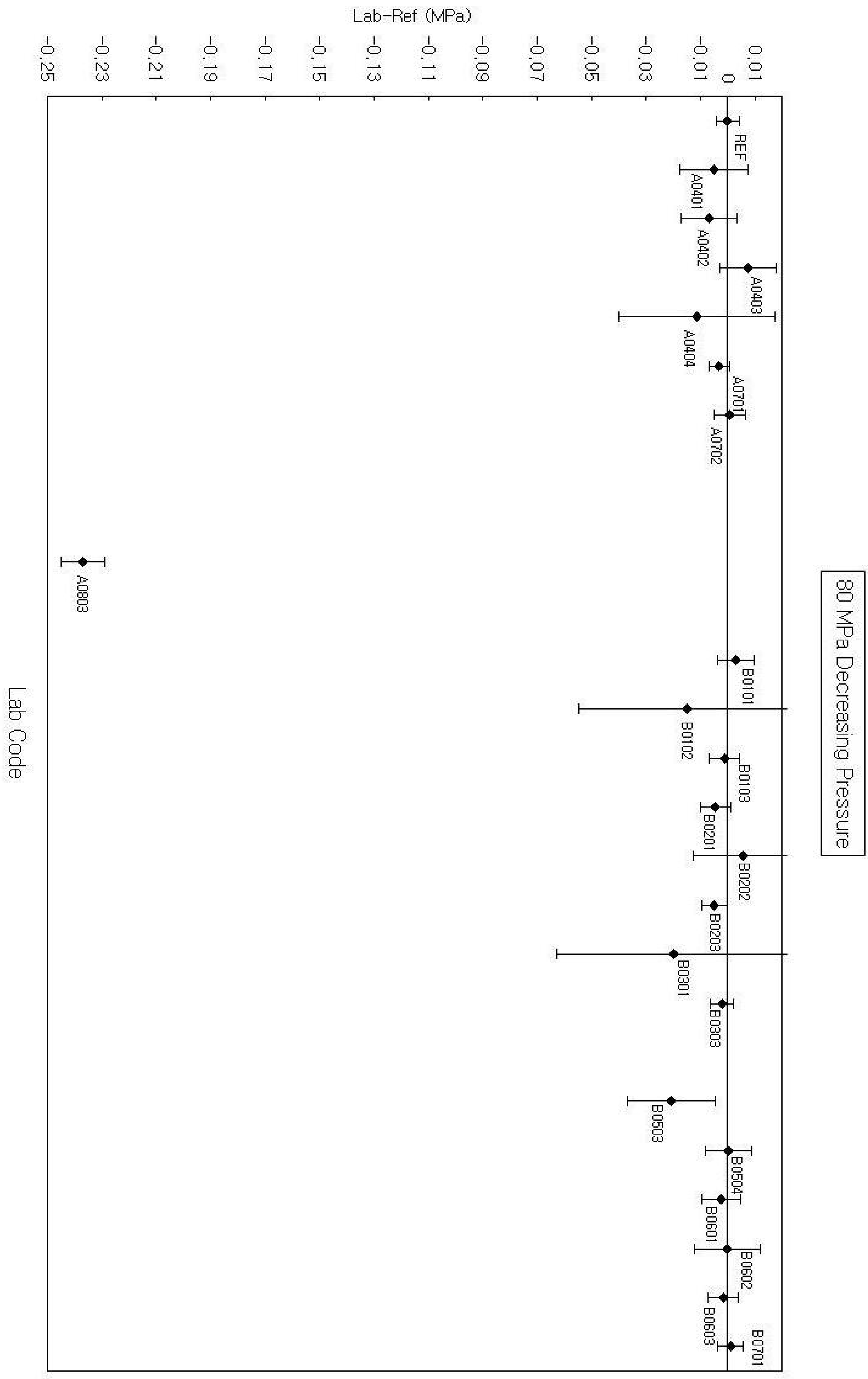

Lab-Ref (MPa)
-0.06
-0.04
-0.02
0
0.02
Lab Code
20 MPa Increasing Pressure
REF
A0401
A0402
A0403
A0404
A0701
A0702
A0801
A0802
A0803
A0804
B0101
B0102
B0103
B0201
B0202
B0203
B0301
B0303
B0501
B0503
B0504
B0601
B0602
B0603
B0701

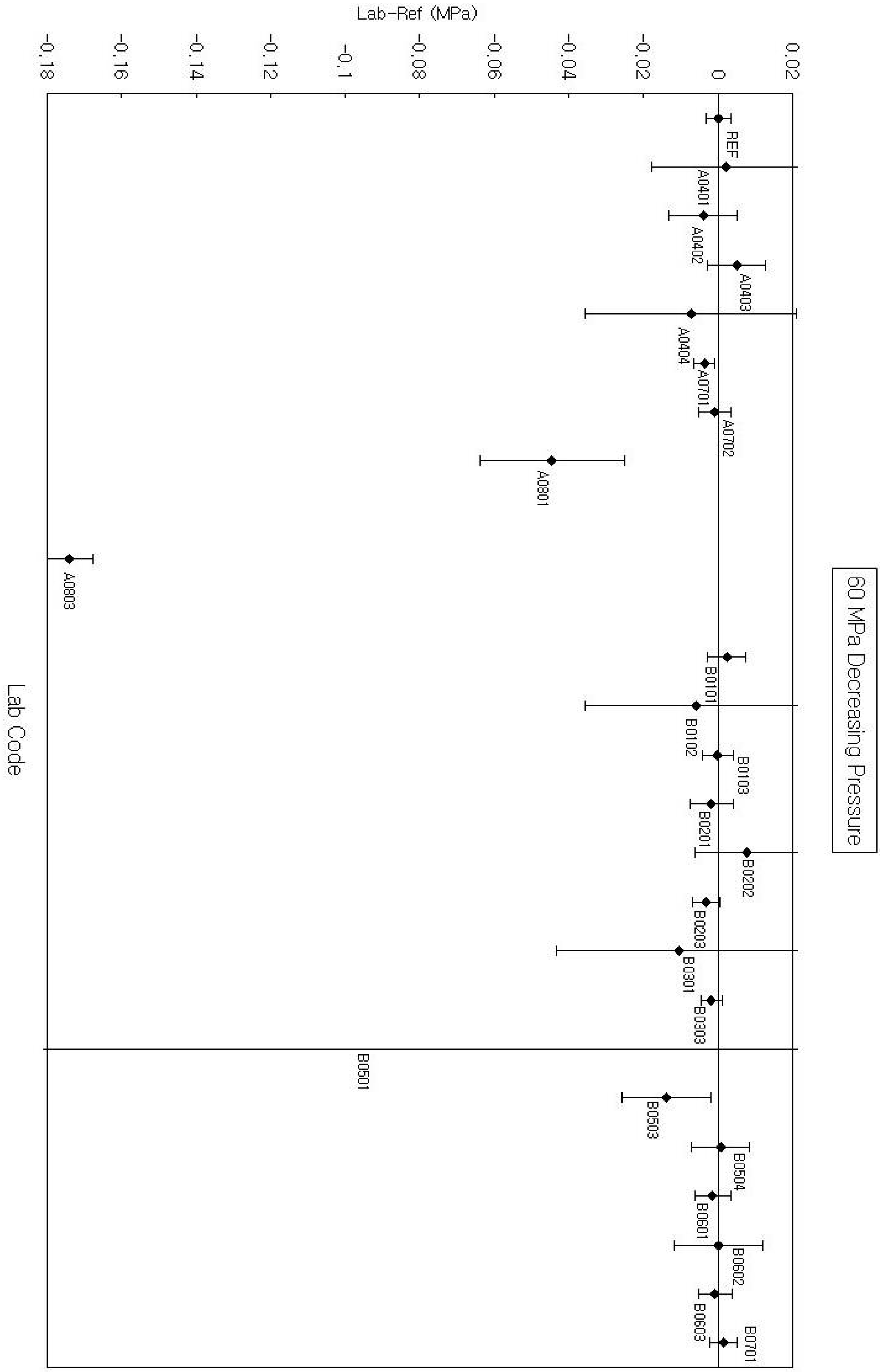

40 MPa Increasing Pressure
Lab-Ref (MPa)
-0.12
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
Lab Code
REF
A0401
A0402
A0403
A0404
A0701
A0702
A0801
A0802
A0803
A0804
B0101
B0102
B0103
B0201
B0202
B0203
B0301
B0303
B0501
B0503
B0504
B0601
B0602
B0603
B0701

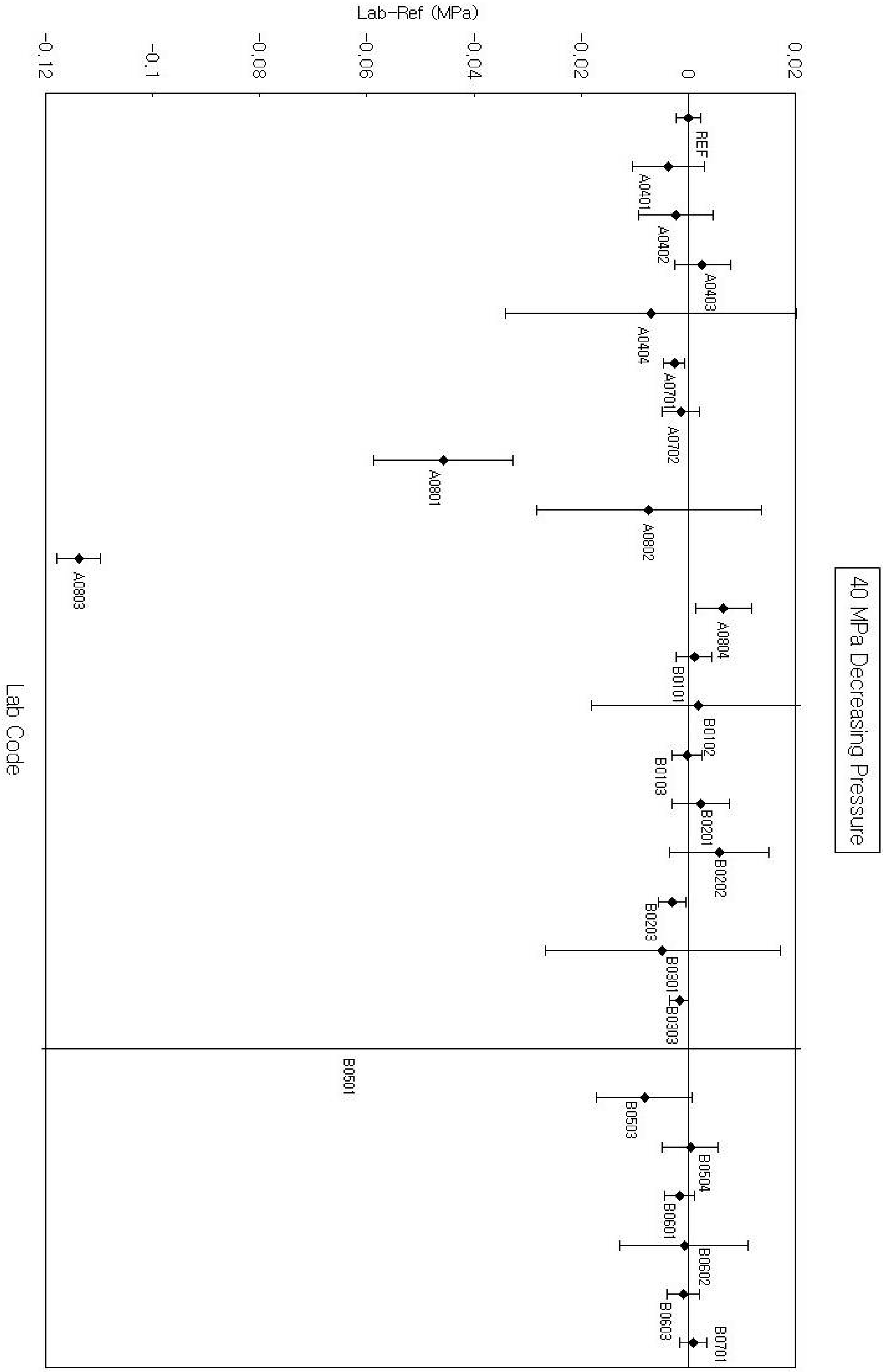

60 MPa Increasing Pressure
Lab-Ref (MPa)
Lab Code
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
REF
A0401
A0402
A0403
A0404
A0701
A0702
A0801
A0802
A0803
A0804
B0101
B0102
B0103
B0201
B0202
B0203
B0301
B0303
B0501
B0503
B0504
B0601
B0602
B0603
B0701

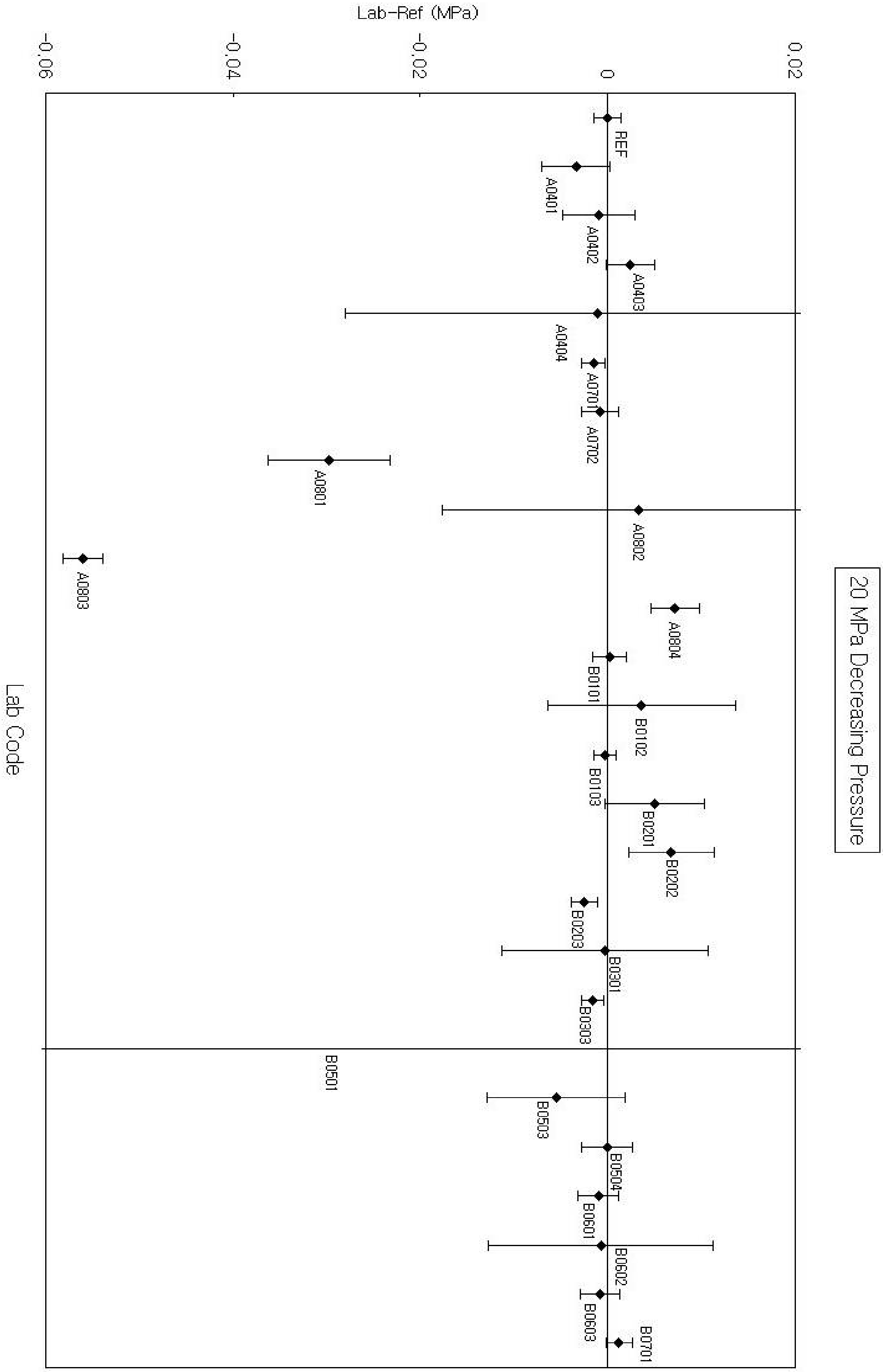

80 MPa Increasing Pressure
Lab-Ref (MPa)
0.01
0
-0.01
-0.03
-0.05
-0.07
-0.09
-0.11
-0.13
-0.15
-0.17
-0.19
-0.21
-0.23
-0.25
Lab Code
REF
A0401
A0402
A0403
A0404
A0701
A0702
A0803
B0101
B0102
B0103
B0201
B0202
B0203
B0301
B0303
B0501
B0503
B0504
B0601
B0602
B0603
B0701


100 MPa Increasing Pressure
Lab-Ref (MPa)
0.01
0
-0.01
-0.03
-0.05
-0.07
-0.09
-0.11
-0.13
-0.15
-0.17
-0.19
-0.21
-0.23
-0.25
-0.27
-0.29
-0.31
Lab Code
REF
A0401
A0402
A0403
A0404
A0701
A0702
A0803
B0102
B0103
B0201
B0202
B0203
B0301
B0303
B0503
B0504
B0601
B0602
B0603
B0701


80 MPa Decreasing Pressure
Lab-Ref (MPa)
Lab Code
0.01
0
-0.01
-0.03
-0.05
-0.07
-0.09
-0.11
-0.13
-0.15
-0.17
-0.19
-0.21
-0.23
-0.25
REF
A0401
A0402
A0403
A0404
A0701
A0702
A0803
B0101
B0102
B0103
B0201
B0202
B0203
B0301
B0303
B0503
B0504T
B0601
B0602
B0603
B0701


60 MPa Decreasing Pressure
Lab-Ref (MPa)
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
Lab Code
REF
A0401
A0402
A0403
A0404
A0701
A0702
A0801
A0803
B0101
B0102
B0103
B0201
B0202
B0203
B0301
B0303
B0501
B0503
B0504
B0601
B0602
B0603
B0701


40 MPa Decreasing Pressure
Lab-Ref (MPa)
Lab Code
-0.12
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
REF
A0401
A0402
A0403
A0404
A0701
A0702
A0801
A0802
A0803
A0804
B0101
B0102
B0103
B0201
B0202
B0203
B0301
B0303
B0501
B0503
B0504
B0601
B0602
B0603
B0701


20 MPa Decreasing Pressure
Lab-Ref (MPa)
-0.06
-0.04
-0.02
0
0.02
Lab Code
REF
A0401
A0402
A0403
A0404
A0701
A0702
A0801
A0802
A0803
A0804
B0101
B0102
B0103
B0201
B0202
B0203
B0301
B0303
B0501
B0503
B0504
B0601
B0602
B0603
B0701

9. PERFORMANCE OF PARTICIPANTS

The table of E_n ratios shows an overall good performance by the majority of participating laboratories.

Lab codes A0801, A0803, A0804, B0503 have problems at all points with a positive or negative bias. Their problem may be due to an incorrect calculation or correction factor in the determination of actual pressure applied.

Lab codes A0403, B0202, B0203, B0303 have one or more pressure result with an $|E_n| > 1$. They may be able to overcome their problems by a review of their uncertainty calculations.

Lab code A0802 may be able to get a good result, if the laboratory uses a dead weight piston gauge as reference gauge.

Lab code B0501 have pressure result with an $|E_n| < 1$, but the uncertainty is too large.

10. UNCERTAINTIES OF MEASUREMENT

An example of an uncertainty analysis for a 100 ㎫ measurement is given in Appendix D of this report.

11. CORRECTIVE ACTION

In general, details of corrective action were not requested for this interlaboratory comparison. Values of $|E_n| > 1$ require investigation and corrective action by the participating laboratory. The Laboratory's accreditation body needs to ensure that the problem has been rectified and procedures have been put in place to prevent a recurrence.

12. REFERENCES

(1) APLAC PT001 (2006) *Calibration Interlaboratory Comparisons*

(2) APLAC (1999) *Interlaboratory Comparison* APM006

(3) EA 4/02 (1999) *Expression of the Uncertainty of Measurement in Calibration*

(4) ISO (1995) *Guide to the Expression of Uncertainty in Measurement*

(4) KTL Technical Memorandum No. CP201-20413-1 (2006) *Standard Calibration Procedure of Pressure gauges*

APLAC INTERLABORATORY COMPARISON APLAC M019 INSTRUCTIONS TO LABORATORIES

1. EQUIPMENT

Item	Maker	Model	Serial No.
Pressure Gauge	DHI	RPM4	186

On receipt, unpack the artifacts and inspect them for any defects. Contact your accreditation body if there is any damage.

2. MEASUREMENTS TO BE CARRIED OUT

Prior to the calibration itself, the good working condition of the instrument shall be visually checked, especially good quality of the electrical contacts, operation of the artifacts.

Place the pressure gauge as closely as possible to the reference gauge in order to reach the thermal equilibrium. Connect the tube to connector in the rear of the pressure gauge and your dead weight piston gauge (pressure balance). Ensure that the reference levels of both instruments are as closely as possible. And account for the difference in the reference level when calculating corrections and uncertainties. And Di-2-Ethylhexyl Sebacate Oil is recommended for measurement.

Sufficient time should be allowed for the artifacts to reach ambient temperature after mounting. Switch on the pressure gauge for at least 4 hours before starting measurements.
Don’t switch off before complete the whole measurement.

The pressure gauge has a full-scale range of 100 ㎫. It is an absolute pressure gauge set up to read gauge pressure and to activate DISPLAY AVERAGE function. The pressure gauge should display mean pressure and standard deviation for 20 seconds. The 0 ㎫ gauge pressure reading may not be near zero due to differences in atmospheric pressure. Do not attempt to zero.

The pressure gauge will not be reading exactly 100.0000 when 100 ㎫ is applied. It should be within ± 1%.

IMPORTANT: The instrument should provide very repeatable results provided the environment is stable and the following measurement sequence is adhered to:-

① Exercise the pressure gauge by applying 100 ㎫ for 10 minutes then release the pressure.
② Vent the pressure line to atmosphere by turning the valve in the rear of the pressure gauge. Some oil should appear at the drain outlet just beside the vent valve. If no oil is present, wind the dead weight piston gauge handle in slowly until it does. Make sure that the Air is not trapped in the oil. This ensures the correct reference level (i.e. the reference level is in line with the drain pipe).
③ wait 60 minute.
④ Record the 0 ㎫ (gauge) pressure reading.
⑤ Close the vent and apply 20 ㎫, wait 10 minute and take a reading
⑥ Increase the pressure to 40 ㎫, wait 10 minute and take a reading
⑦ Do the same at 60, 80 and 100 ㎫.
⑧ Reduce the pressure to 80 ㎫, wait 10 minute and take a reading.
⑨ Do the same at 60, 40, 20 ㎫.
⑩ Reduce the pressure to 0 ㎫, vent the line and take a reading after 10 minute.
⑪ wait 50 minute and repeat steps ④ to ⑩
⑫ Repeat steps ⑪.

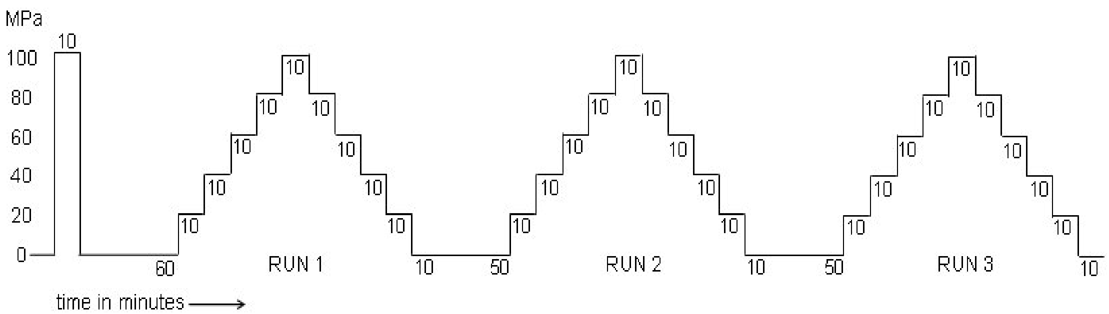


Diagram of measurement sequence

3. DOCUMENTS TO BE SUBMITTED

Within one week of the completion of the measurements, participating laboratories are required to fax or send the attached Result Sheet (1) and (2) to their accreditation body. No other documents are required. Laboratories should make a copy of the Result Sheet for their own records.

Where possible, uncertainties should be calculated using the method in the EA-4/02 Expression the Uncertainty of Measurement in Calibration or the ISO Guide to the Expression of Uncertainty in Measurement.

A final report will be issued at the end of the program with each laboratory only identified by a confidential code number.

4. GENERAL INFORMATION

For general queries, please contact your accreditation body. Additional information may be obtained from

Lee Sung Wook, KOLAS
Tel: +82-2-509-7226
Fax: +82-2-507-6875
E-mail: lee532@ats.go.kr
Address: 2 JOONGANG-DONG KWACHON KYUNGGI-DO,
KOREA 427-716

APLAC INTERLABORATORY COMPARISON, APLAC M019
RESULT SHEET (1)

Laboratory Name:

Code Number (to be assigned by the KOLAS):

Date of Calibration:

Testing Officer:

Local Gravity Value: m/s^2

Height Difference (between reference level of DWG and pressure gauge): mm

The Name of the Oil Used for Measurement

Environment of Laboratory

Temperature: ± ℃

Relative Humidity: ± % R.H.

APLAC INTERLABORATORY COMPARISON, APM019

RESULT SHEET (2)

Nominal Pressure	Actual Pressure	RUN 1		RUN 2		RUN 3		Reported Uncertainty	Best Measurement Capability
		Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation		
MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
0	0								
20									
40									
60									
80									
100									
80									
60									
40									
20									
0	0								

NOTES: The ***Actual Pressure*** is the exact pressure developed by the laboratory's reference equipment (after any corrections have been applied).

The ***Average*** is the mean pressure that is read from the pressure gauge.

The ***Standard Deviation*** can be read in the display of the pressure gauge.

Reported Uncertainty is the uncertainty that you would state on your calibration certificate for these results (95% confidence level).

Best Measurement Capability is the uncertainty for which you are accredited.

CIRCULATION SCHEDULE

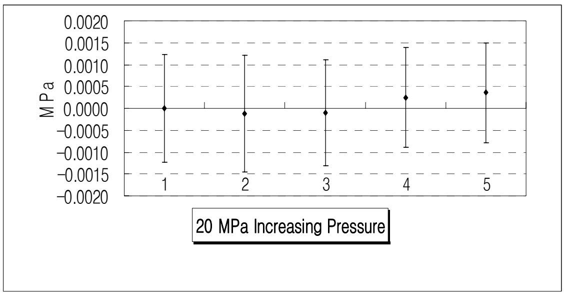
Loop A

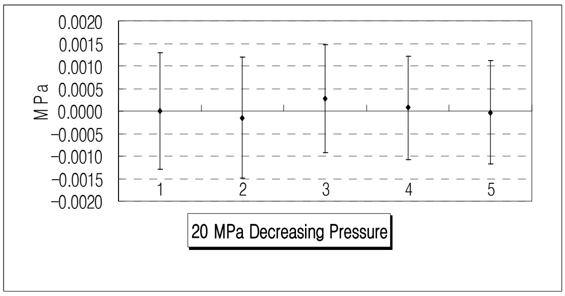
No.	Nation	Accreditation Body	Receipt	Dispatch
1	Korea (ref)	KOLAS 1	2007-02-13	2007-03-23
2	Korea (ref)	KOLAS 2	2007-05-30	2007-06-25
3	Korea	KOLAS	2007-06-25	2007-07-09
4	Korea (ref)	KOLAS 3	2007-07-09	2007-08-10
5	India	NABL	2007-08-25	2007-10-11
6	Korea (ref)	KOLAS 4	2007-10-25	2007-11-02
7	Malaysia	DSM	2007-11-20	2007-12-24
8	Korea (ref)	KOLAS 5	2008-01-08	2008-01-15

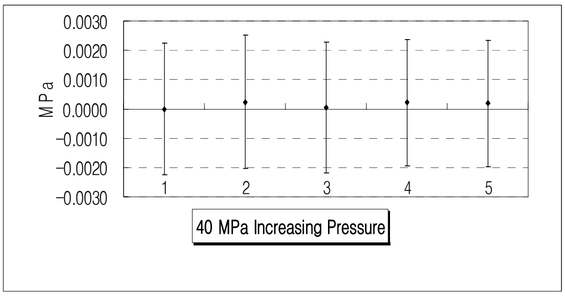
Loop B

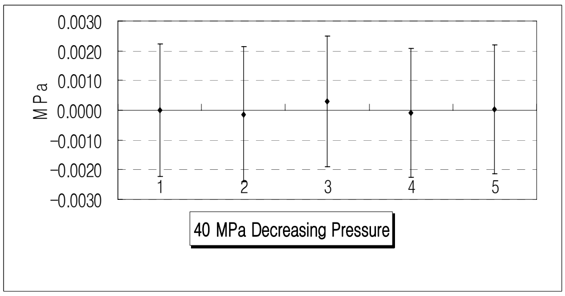
No.	Nation	Accreditation Body	Receipt	Dispatch
1	Korea (ref)	KOLAS 1	2007-02-13	2007-03-03
2	Korea	KOLAS	2007-03-03	2007-03-10
3	Korea (ref)	KOLAS 2	2007-03-10	2007-03-23
4	Australia	NATA	2007-04-07	2007-05-02
5	Japan	IA-JAPAN	2007-05-21	2007-06-15
6	Korea (ref)	KOLAS 3	2007-06-25	2007-07-11
7	China	CNAS	2007-07-25	2007-09-16
8	Korea (ref)	KOLAS 4	2007-10-02	2007-10-25
9	China (Hong Kong)	HKAS	2007-11-11	2007-12-06
10	Indonesia	KAN	2007-12-25	2008-01-28
11	Korea (ref)	KOLAS 5	2008-02-12	2008-02-19

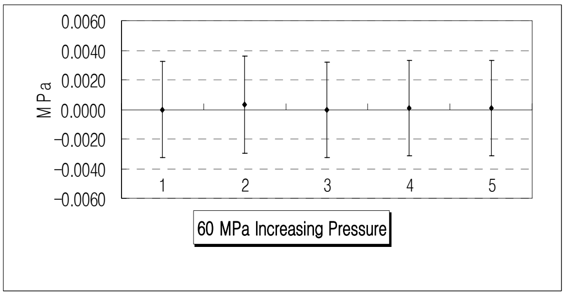
STABILITY OF ARTIFACTS – LOOP A
GRAPHS OF REFERENCE LABORATORY CALIBRATIONS

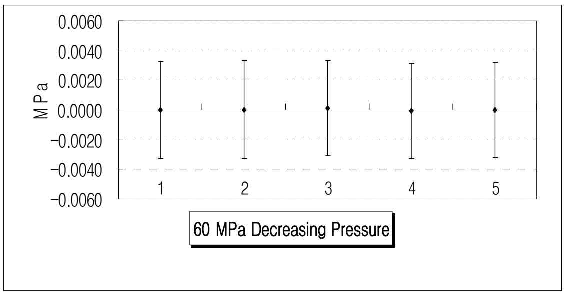


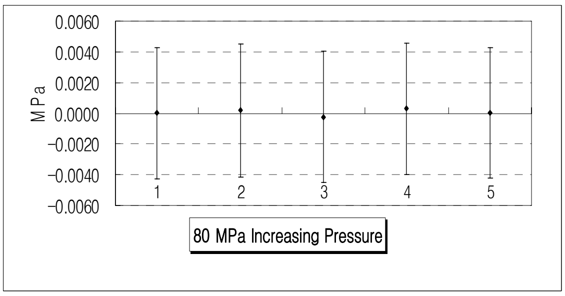


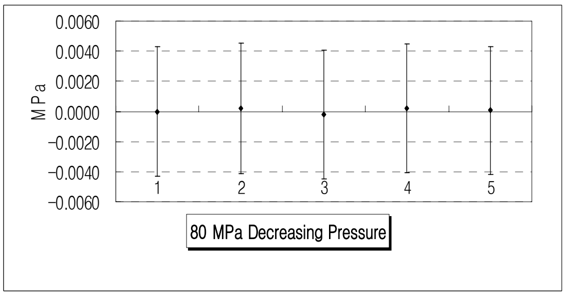


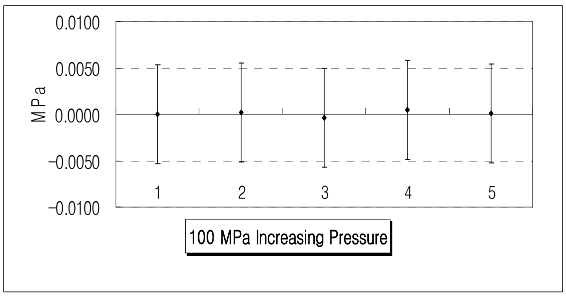










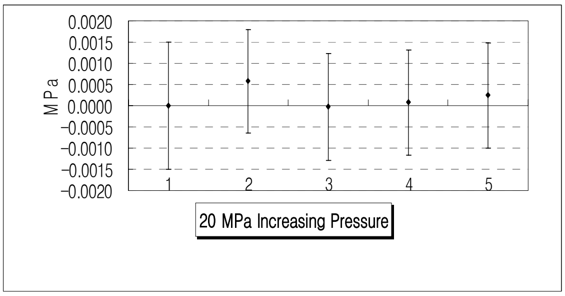


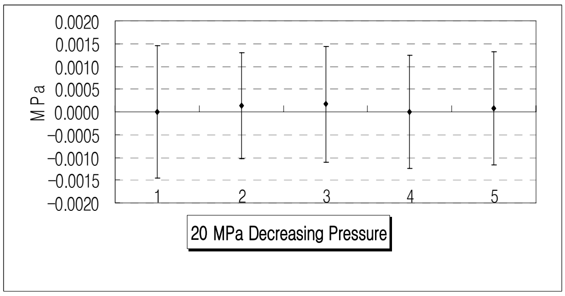
Drift between successive calibrations:

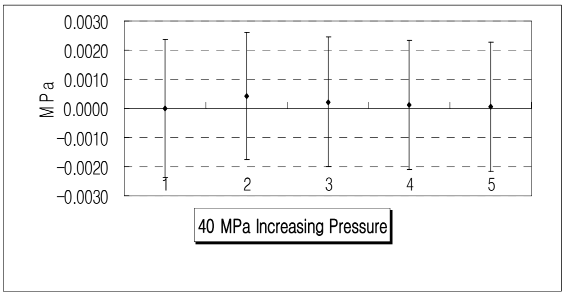
Maximum: 0.0005 MPa

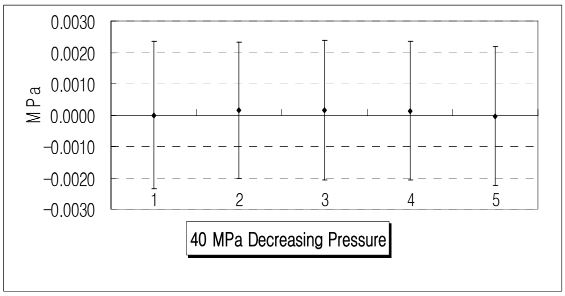
Average: 0.0003 MPa

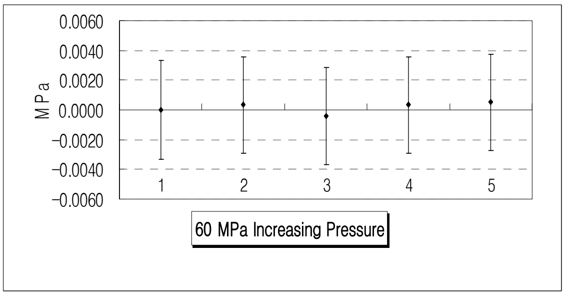
STABILITY OF ARTIFACTS – LOOP B
GRAPHS OF REFERENCE LABORATORY CALIBRATIONS

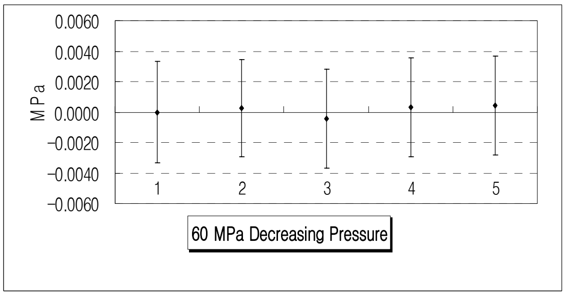


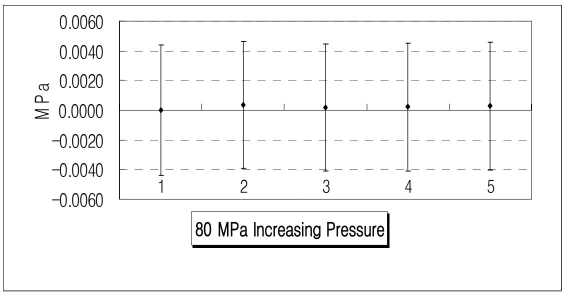


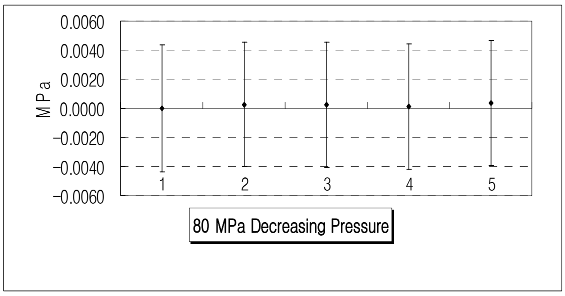


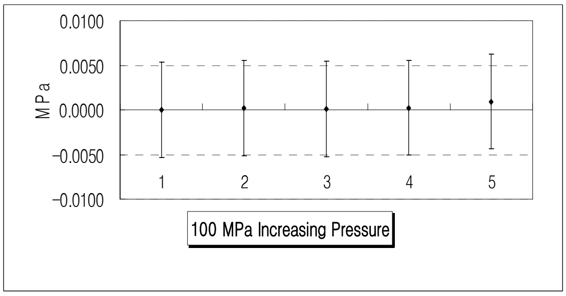












Drift between successive calibrations:

Maximum: 0.0009 MPa

Average: 0.0004 MPa

EXAMPLE UNCERTAINTY OF MEASUREMENT ANALYSYS

The instrument used in the APLAC interlaboratory comparison APLAC M019 was calibrated by dead weight piston gauge. This example only relates to the evaluation of the expanded uncertainty at 100 ㎫.

1. The combined standard uncertainty of pressure generated by reference standard

The definition of the pressure at the reference level of the instrument to be calibrated by reference standard is obtained from the following expression:-

$$p_{standard} = \frac{\sum_i m_i g \left(1 - \frac{\rho_a}{\rho_m}\right) \cos\theta + \gamma C}{A_0 (1 + \lambda p_n)(1 + (\alpha_p + \alpha_c)(t - t_r))} + (\rho_f - \rho_a) g \Delta h \qquad \text{(D.1)}$$

where:-

$p_{standard}$ is the pressure measured (㎩),

m_i is the individual mass value of each weight applied on the piston (㎏), $(M = \sum m_i)$

g is the local gravity (㎨),

ρ_a is the density of air (㎏/㎥),

ρ_m is the density of each weight (㎏/㎥),

$\cos\theta$ is the verticality of piston-cylinder assembly,

γ is the surface tension of the liquid (N/m),

C is the circumference of the piston (m),

A_0 is the effective area of the piston-cylinder assembly at reference temperature and at null pressure (㎡),

λ is the pressure distortion coefficient of the piston-cylinder assembly (/㎩),

p_n is the nominal pressure (㎩),

α_p is the thermal expansion coefficient of the piston (/℃),

α_c is the thermal expansion coefficient of the cylinder (/℃),

t is the measured temperature of the piston-cylinder assembly during its use (℃),

t_r is the reference temperature at which it was calibrated (℃),

ρ_f is the density of the measuring fluid (㎏/㎥),

Δh is the difference between the altitude h_1 of the reference level of the dead weight piston gauge and the altitude h_2 of the reference level of the instrument: $\Delta h = h_1 - h_2$ (m).

Uncertainty budget ($p_{standard}$)

Standard Uncertainty Component $u(x_i)$	Source of Uncertainty	Value of Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(y) = \lvert c_i \rvert u(x_i)$	Degree of Freedom
$u(M)$	Mass	2.3X10^{-4} ㎏	normal	2.0X10^{6} ㎩/㎏	4.5X10^{2} ㎩	30
$u(g)$	Local gravity	2.5X10^{-6} ㎨	normal	1.0X10^{7} ㎩/㎨	25 ㎩	30
$u(\rho_a)$	Density of air	3.5X10^{-2} ㎏/㎥	rectangular	1.2X10^{4} ㎩/㎏/㎥	4.3X10^{2} ㎩	12.5
$u(\rho_m)$	Density of weight	4.6X10^{2} ㎏/㎥	rectangular	1.9 ㎩/㎏/㎥	8.7X10^{2} ㎩	50
$u(\theta)$	Verticality	8.7X10^{-4}	rectangular	1.5X10^{5} ㎩	1.3X10^{2} ㎩	6
$u(\gamma)$	Surface tension	1.8X10^{-3} N/m	rectangular	1.6X10^{3} ㎩/N/m	2.9 ㎩	50
$u(C)$	Circumference	4.5X10^{-4} m	rectangular	6.3X10^{3} ㎩/m	2.9 ㎩	50
$u(\lambda)$	Effective area	1.3X10^{-10} ㎡	normal	2.0X10^{13} ㎩/㎡	2.7X10^{3} ㎩	30
$u(A_0)$	Pressure distortion coefficient	1.4X10^{-13}/㎩	rectangular	1.0X10^{16} ㎩²	1.4X10^{3} ㎩	50
$u(p_n)$	Nominal pressure	2.9X10^{3} ㎩	rectangular	1.2X10^{-4}	3.5X10^{-1} ㎩	50
$u(\alpha_p + \alpha_C)$	Thermal expansion coefficient	5.2X10^{-7}/℃	rectangular	2.1X10^{8} ㎩℃	1.1X10^{2} ㎩	12.5
$u(t - t_r)$	temperature difference	5.8X10^{-1} ℃	rectangular	9.0X10^{2} ㎩/℃	5.2X10^{2} ㎩	50
$u(\rho_f)$	Density of the measuring fluid	2.8X10^{1} ㎏/㎥	rectangular	1.5 ㎩/㎏/㎥	4.2X10^{1} ㎩	12.5
$u(\Delta h)$	Level difference	5.8X10^{-4} m	rectangular	9.5X10^{3} ㎩/ m	5.5 ㎩	6
$u(reproducibility)$	Reproducibility	1.0X10^{-5}	normal	1.0X10^{8} ㎩	1.0X10^{3} ㎩	30
				Combined Standard Uncertainty	3.5X10^{3} ㎩	70

Sensitivity coefficient

The sensitivity coefficient c_i is calculated as the partial derivative of the function (D.1) with respect to the quantity x_i

$$c_M = \frac{\partial p_{standard}}{\partial M} = \frac{p_{standard}}{M}$$

$$c_g = \frac{\partial p_{standard}}{\partial g} = \frac{p_{standard}}{g}$$

$$c_{\rho_a} = \frac{\partial p_{standard}}{\partial \rho_a} = -\frac{p_{standard}}{\rho_m}$$

$$c_{\rho_m} = \frac{\partial p_{standard}}{\partial \rho_m} = \frac{p_{standard}\,\rho_a}{\rho_m{}^2}$$

$$c_\theta = \frac{\partial p_{standard}}{\partial \theta} = -p_{standard} \sin\theta$$

$$c_\gamma = \frac{\partial p_{standard}}{\partial \gamma} = \frac{p_{standard} C}{Mg}$$

$$c_C = \frac{\partial p_{standard}}{\partial C} = \frac{p_{standard} \gamma}{Mg}$$

$$c_{A_0} = \frac{\partial p_{standard}}{\partial A_0} = -\frac{p_{standard}}{A_0}$$

$$c_\lambda = \frac{\partial p_{standard}}{\partial \lambda} = -p_{standard}\, p_n$$

$$c_{p_n} = \frac{\partial p_{standard}}{\partial p_n} = -p_{standard}\, \lambda$$

$$c_{\alpha_p+\alpha_c} = \frac{\partial p_{standard}}{\partial(\alpha_p + \alpha_c)} = -p_{standard}\,(t - t_r)$$

$$c_{t-t_r} = \frac{\partial p_{standard}}{\partial(t - t_r)} = -p_{standard}\,(\alpha_p + \alpha_c)$$

$$c_{\rho_f} = \frac{\partial p_{standard}}{\partial \rho_f} = \frac{p_{standard} A_0 h}{M}$$

$$c_{\Delta h} = \frac{\partial p_{standard}}{\partial \Delta h} = \frac{p_{standard} A_0 \rho_f}{M}$$

$$c_{reproducibility} = \frac{\partial p_{standard}}{\partial reproducibility} = p_{standard}$$

List of the uncertainty components

- Mass

The calibration certificate on the weights gives the mass value 50.000 4 kg, the expanded uncertainty 4.5 x 10^{-4} kg at a 95% confidence level, an effective degrees of freedom of 30 and a coverage factor of 2. The standard uncertainty is:-

$$u(M) = \frac{4.5\times10^{-4}}{2} = 2.3\times10^{-4} \text{ kg}$$

- Local gravity

The calibration certificate on the gravity gives the local gravity value 9.799 413 ㎨, the expanded uncertainty 5 x 10^{-6} ㎨ at a 95% confidence level, an effective degrees of freedom of 30 and a coverage factor of 2. The standard uncertainty is:-

$$u(g) = \frac{5 \times 10^{-6}}{2} = 2.5 \times 10^{-6} \text{ ㎨}$$

- Density of air

The NIST air density formula was used:-

$$\rho_a = \frac{(0.348444 \times P - H(0.00252t - 0.020582))}{(273.15 + t)} = 1.202 \text{ kg/m}^3$$

where:-

P is air pressure (h㎩)

H is relative humidity of the air (% R.H.)

t is air temperature (℃)

A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 5 % (± 0.06 kg/m³). And it's also estimated that rectangular limit could be out by 20%. Therefore degree of freedom is $v_{\rho_a} = 1/2 \times (100/20)^2 = 12.5$.

The standard uncertainty is:-

$$u(\rho_a) = \frac{0.06}{\sqrt{3}} = 3.5 \times 10^{-2} \text{ kg/m}^3$$

- Density of weight

The Material of weight is 304L non-magnetic stainless steel. The weight's density is 8000 kg/m³ provided from manufacturer's manual. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 10 % (± 800 kg/m³). And it's also estimated that rectangular limit could be out by 10%. Therefore degree of freedom is $v_{\rho_m} = 1/2 \times (100/10)^2 = 50$. The standard uncertainty is:-

$$u(\rho_m) = \frac{800}{\sqrt{3}} = 4.6 \times 10^2 \text{ kg/m}^3$$

▪ Verticality

The deviation from the vertical is checked by using a spirit level put on the top of the piston. The possible deviation is considered 0.0015 rad. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 0.0015 rad. And it's also estimated that rectangular limit could be out by 10 %. Therefore degree of freedom is $v_{\cos\theta} = 1/2 \times (100/10)^2 = 50$. The standard uncertainty is:-

$$u(\theta) = \frac{0.0015}{\sqrt{3}} = 8.7 \times 10^{-4}$$

▪ Surface tension

Di-2-Ethylhexyl Sebacate Oil is used for calibration. The surface tension of the oil is 0.031 N/m provided from manufacturer's manual. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 10 % (± 0.0031 N/m). And it's also estimated that rectangular limit could be out by 10%. Therefore degree of freedom is $v_{\gamma} = 1/2 \times (100/10)^2 = 50$. The standard uncertainty is:-

$$u(\gamma) = \frac{0.0031}{\sqrt{3}} = 1.8 \times 10^{-3} \ \mathrm{N/m}$$

▪ Circumference

The circumference is calculated from the diameter of piston. The circumference of piston is 0.0078 m. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 10 % (± 0.00078 m). And it's also estimated that rectangular limit could be out by 10%. Therefore degree of freedom is $v_C = 1/2 \times (100/10)^2 = 50$. The standard uncertainty is:-

$$u(C) = \frac{0.00078}{\sqrt{3}} = 4.5 \times 10^{-4} \ \mathrm{m}$$

▪ Effective area

The calibration certificate on the dead weight piston gauge gives the effective area value 4.902 26 x 10^{-6} m², the expanded uncertainty 2.7 x 10^{-10} m² at a 95% confidence level, an effective degrees of freedom of 30 and a coverage factor of 2. The standard uncertainty is:-

$$u(A_0) = \frac{2.7 \times 10^{-10}}{2} = 1.3 \times 10^{-10} \ \mathrm{m^2}$$

▪ Pressure distortion coefficient

The calibration certificate on the dead weight piston gauge gives the pressure distortion coefficient value 1.2 x 10^{-12} ㎡. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 20 % (± 2.4 x 10^{-13} /Pa). And it's also estimated that rectangular limit could be out by 10%. Therefore degree of freedom is $v_{\lambda} = 1/2 \cdot (100/10)^2 = 50$. The standard uncertainty is:-

$$u(\lambda) = \frac{2.4 \times 10^{-13}}{\sqrt{3}} = 1.4 \times 10^{-13} \ /\mathrm{Pa}$$

▪ Nominal pressure

The nominal pressure can be calculated from $p_n = Mg / A_0$ (1.0 x 10^8 Pa). A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 50 ppm (± 5000 Pa). And it's also estimated that rectangular limit could be out by 10%. Therefore degree of freedom is $v_{p_n} = 1/2 \cdot (100/10)^2 = 50$.

The standard uncertainty is:-

$$u(p_n) = \frac{5000}{\sqrt{3}} = 2.9 \times 10^3 \ \mathrm{Pa}$$

▪ Thermal expansion coefficient

The Material of piston and cylinder is tungsten carbide. The thermal expansion coefficient of piston and cylinder is 9.0 x 10^{-6} /℃. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 10 % (± 9.0 x 10^{-7} /℃). And it's also estimated that rectangular limit could be out by 20%. Therefore degree of freedom is $v_{\alpha_p + \alpha_c} = 1/2 \cdot (100/20)^2 = 12.5$. The standard uncertainty is:-

$$u(\alpha_p + \alpha_c) = \frac{9.0 \times 10^{-7}}{\sqrt{3}} = 5.2 \times 10^{-7} \ /℃$$

▪ Difference between the measured and reference temperature

The difference between the measured and reference temperature is derived from the measurement. The measurement value is -2.1 ℃. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 1.0 ℃. And it's also estimated that rectangular limit could be out by 10%. Therefore degree of freedom is $v_{t-t_r} = 1/2 \cdot (100/10)^2 = 50$. The standard uncertainty is:-

$$u(t - t_r) = \frac{1.0}{\sqrt{3}} = 0.58 \ ℃$$

▪ Density of the measuring fluid

The following equation was used to calculate the density of the measuring fluid:-

$\rho_f = 912.7 + 0.752 \times p_n - 0.001645 \times p_n{}^2 + 0.000001456 \times p_n{}^3 = 973$ kg/m³

A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 5 % (± 48.6 kg/m³). And it's also estimated that rectangular limit could be out by 20%. Therefore degree of freedom is $v_{\rho_f} = 1/2 \cdot (100/20)^2 = 12.5$.

The standard uncertainty is:-

$$u(\rho_f) = \frac{48.6}{\sqrt{3}} = 28 \text{ kg/m}^3$$

▪ Difference between two reference levels

The difference is derived from the measurement of the reference level h_1 and h_2. The measurement value is 0.001 m. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 0.001 m. And it's also estimated that rectangular limit could be out by 30%. Therefore degree of freedom is $v_{\Delta h} = 1/2 \cdot (100/30)^2 = 5.6$. The standard uncertainty is:-

$$u(\Delta h) = \frac{0.001}{\sqrt{3}} = 5.8 \times 10^{-4} \text{ m}$$

▪ Reproducibility

The reproducibility is estimated from the measurement environment, friction, repeatability, and the long term stability provided by manufacturer. It is assumed that reproducibility = 0. The uncertainty of reproducibility is assumed to be 20 ppm. A normal distribution is assumed using a coverage factor *k* = 2. The standard uncertainty is:-

$$u(reproducibility) = \frac{20 \times 10^{-6}}{2} = 1.0 \times 10^{-5}$$

▪ Combined standard uncertainty of $p_{standard}$

The degrees of freedom are also combined via the Welch-Satterthwaite formula to give an effective degrees of freedom 70. A normal distribution is assumed. The combined standard uncertainty of pressure is calculated from the following equation:-

$$u(p_{standard}) = \sqrt{\sum u_i{}^2(y)} = 3.5 \times 10^3 \text{ Pa}$$

2. The expanded uncertainty of deviation

The expanded uncertainty of deviation is obtained from:-

$$\Delta p = p_{indication} - p_{standard} + \delta p_{zero\,error} + \delta p_{repeatability} \qquad \text{(D.2)}$$

where:-

Δp is the deviation of the instrument,

$p_{indication}$ is the indication of the instrument,

$p_{standard}$ is the pressure generated by reference standard,

$\delta p_{zero\,error}$ is the uncorrected measurement error due to zero error,

$\delta p_{repeatability}$ is the measurement error due to repeatability.

Uncertainty budget (Δp)

Standard Uncertainty Component $u(x_i)$	Source of Uncertainty	Value of Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient $\lvert c_i \rvert$	Uncertainty Contribution $u_i(y) = \lvert c_i \rvert u(x_i)$	Degree of Freedom
$u(p_{indicaion})$	Resolution	29 Pa	normal	1	29 Pa	30
$u(p_{standard})$	Reference standard	3.5X10^3 Pa	normal	1	3.5X10^3 Pa	30
$u(\delta p_{zero\,error})$	Zero error	1.7X10^2 Pa	rectangular	1	1.7X10^2 Pa	12.5
$u(\delta p_{repeatability})$	Repeatability	58 Pa	rectangular	1	58 Pa	50
			Combined Standard Uncertainty		3.5X10^3 Pa	30
			Coverage Factor "*k*"		2	
			Expanded Uncertainty U_{95}		7.0 X10^3 Pa	

Sensitivity coefficient

The sensitivity coefficient c_i is calculated as the partial derivative of the function (D.2) with respect to the quantity x_i

$$c_{p_{indication}} = \frac{\partial \Delta p}{\partial p_{indication}} = 1$$

$$c_{p_{standard}} = \frac{\partial \Delta p}{\partial p_{standard}} = -1$$

$$c_{\delta p_{zero\,error}} = \frac{\partial \Delta p}{\partial \delta p_{zero\,error}} = 1$$

$$c_{\delta p_{repeatability}} = \frac{\partial \Delta p}{\partial \delta p_{repeatability}} = 1$$

List of the uncertainty components

- Resolution

The indication value is 9.992 73 x 10^7 Pa at nominal pressure 100 MPa. The resolution corresponds to the digit step. The indication does not vary more than one digit step. The resolution of the instrument is 100 Pa. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 50 Pa. The standard uncertainty is:-

$$u(p_{indication}) = \frac{50}{\sqrt{3}} = 29 \text{ Pa}$$

- Reference standard

The standard value is 9.992 50 x 10^7 Pa at nominal pressure 100 MPa. According to page 35, the combined standard uncertainty of pressure generated by the reference standard is:-

$$u(p_{standard}) = 3.5 \times 10^3 \text{ Pa}$$

- Zero error

It is assumed that $\delta p_{zero error} = 0$. The uncertainty of zero error is determined from the greatest difference among the first zero value and the last zero value in each measurement cycle. The maximum difference value is 600 Pa. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 300 Pa. And it's also estimated that rectangular limit could be out by 10%. Therefore degree of freedom is $v_3 = 1/2 \cdot (100/10)^2 = 50$. The standard uncertainty is:-

$$u(\delta p_{zero error}) = \frac{300}{\sqrt{3}} = 1.7 \times 10^2 \quad \text{Pa}$$

- Repeatability

It is assumed that $\delta p_{repeatability} = 0$. The uncertainty of repeatability is determined from the greatest difference among the values measured at the same point, corrected by the zero value. The maximum difference value is 200 Pa. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 100 Pa. And it's also estimated that rectangular limit could be out by 10%. Therefore degree of freedom is $v_4 = 1/2 \cdot (100/10)^2 = 50$. The standard uncertainty is:-

$$u(\delta p_{repeatability}) = \frac{100}{\sqrt{3}} = 58 \ \ \mathrm{Pa}$$

▪ Combined standard uncertainty of Δp

The degrees of freedom are also combined via the Welch-Satterthwaite formula to give an effective degrees of freedom 30. A normal distribution is assumed. The combined standard uncertainty of deviation is calculated from the following equation:-

$$u(\Delta p) = \sqrt{\sum u_i^{\ 2}(y)} = 3.5 \times 10^3 \ \ \mathrm{Pa}$$

3. Determination of the expanded uncertainty

At a 95% confidence level, the expanded uncertainty is directly derived from the combined standard uncertainty by multiplying it by a coverage factor *k* = 2:-

$$U(\Delta p) = ku(\Delta p) = 2 \times 3.5 \times 10^3 = 7.0 \times 10^3 \ \ \mathrm{Pa}$$

4. Standard uncertainty components of pressure generated by reference standard at nominal pressure 100 MPa