Asia Pacific Laboratory Accreditation Cooperation

Plain Plug Gauges

INTERLABORATORY COMPARISON

APLAC M024 - June 2011

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1. INTRODUCTION

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

This program was the 24th APLAC interlaboratory comparison. The M024 was coordinated by Korea Laboratory Accreditation Scheme (KOLAS) and provided financial support by Ministry of Knowledge Economy. The circulation of the artifact began in February 2010 and finished in December 2010.

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(2008). 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.

4. ARTIFACTS

The artifacts used in this program are plain plug gauges. The artifacts to be circulated refer to the spec below:-

- Nominal diameter : 5 mm, 15 mm, 40 mm, 100 mm
- Material : steel (EN31)
- Manufacturer : YPG, UK
- Coefficient of thermal expansion: 11.6×10^{-6} /K
- Modulus of elasticity : 206 000 N/mm^2

5. PARTICIPANTS

Thirty two laboratories from thirteen accreditation bodies participated in the program. The results from thirty two 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, four calibrations were performed by the reference laboratory. The artifacts were calibrated by the reference laboratory at the beginning and end of the program. The maximum drift between two successive reference laboratory calibrations was 0.000 1 mm. According to the results of the regression analysis, there was no statistically significant association between time and measurement value at all point (refer Appendix C).

7. REFERENCE VALUES

Two artifacts with same ranges/values were used for this program. Two groups of reference values and uncertainties are derived from the mean of the beginning and end calibrations carried out by Korea Testing Laboratory (refer Appendix B).
According to APLAC PT001 chapter 3.9, the allowance for drift of the artifact is included in the uncertainty of the reference value.

TABLE 1: REFERENCE VALUE & UNCERTAINTY [mm]

No.	Loop A		Loop B	
	Reference Value	Uncertainty	Reference Value	Uncertainty
X-X’ 5	5.010 4	0.000 3	5.010 5	0.000 3
X-X’ 15	15.009 1	0.000 3	15.008 8	0.000 3
X-X’ 40	40.008 5	0.000 3	40.008 7	0.000 3
X-X’100	100.006 2	0.000 5	100.006 9	0.000 5
Y-Y’ 5	5.010 4	0.000 3	5.010 5	0.000 3
Y-Y’ 15	15.009 1	0.000 3	15.008 8	0.000 3
Y-Y’ 40	40.008 5	0.000 3	40.008 7	0.000 3
Y-Y’100	100.006 2	0.000 5	100.006 9	0.000 5

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.

Deviation (Lab-Ref), uncertainty and E_n score were expressed in table 2 ~ 4. The deviation between the laboratory's result and the reference value is plotted along with bars indicating their uncertainty of the measurement in figure 1 ~ 8. E_n scores are illustrated with bar chart in figure 9 ~ 16. The deviation of X is plotted along with the deviation of Y in figure 17 ~ 20.

TABLE 2: SUMMARY OF DEVIATION (LAB-REF) [mm]

No. \ Code	REF	1	2	3	4	5	6	7	8	9	10
X-X' 5	0	-0.001 9	-0.001 6	-0.000 8	-0.000 4	-0.000 4	-0.000 1	0.000 0	-0.000 3	-0.000 25	0.000 8
X-X' 15	0	-0.001 4	-0.000 1	-0.000 7	-0.000 5	-0.000 3	0.000 0	0.000 2	0.000 0	0.000 02	-0.000 5
X-X' 40	0	-0.000 3	-0.000 1	-0.001 0	-0.000 8	-0.000 3	-0.000 3	-0.000 2	-0.000 1	-0.000 21	-0.000 7
X-X'100	0	0.000 1	0.000 3	-0.000 3	0.000 7	0.000 7	-0.000 2	0.000 2	-0.000 6	0.000 06	-0.000 6
Y-Y' 5	0	-0.002 0	-0.001 5	-0.000 7	-0.000 4	-0.000 4	-0.000 1	0.000 1	-0.000 3	-0.000 24	0.000 2
Y-Y' 15	0	-0.001 2	0.000 2	-0.000 8	-0.000 7	-0.000 3	0.000 0	0.000 1	0.000 0	-0.000 07	-0.000 5
Y-Y' 40	0	-0.000 6	-0.000 5	-0.000 8	-0.000 9	-0.000 3	-0.000 2	-0.000 2	0.000 0	-0.000 30	-0.000 5
Y-Y'100	0	0.000 1	0.000 4	-0.000 2	0.000 6	0.000 8	-0.000 2	0.000 3	-0.000 7	-0.000 10	-0.000 6

No. \ Code	11	12	13	14	15	16	17	18	19	20	21
X-X' 5	-0.000 8	-0.000 17	0.000 0	-0.000 2	0.000 3	0.000 66	0.000 3	0.000 2	0.000 3	-0.001 5	0.000 03
X-X' 15	-0.000 7	0.000 02	-0.000 1	-0.000 1	0.000 7	0.001 28	0.000 0	-0.000 2	0.000 0	-0.001 7	0.000 51
X-X' 40	-0.000 7	-0.000 13	-0.000 1	-0.000 3	0.000 2	-0.000 06	0.000 0	0.000 3	0.000 3	-0.002 7	0.000 39
X-X'100	0.000 3	0.000 33	0.000 0	-0.000 1	0.000 0	-0.000 49	0.000 5	0.000 0	0.000 6	-0.000 3	-0.000 63
Y-Y' 5	-0.000 7	-0.000 09	0.000 0	-0.000 1	0.000 4	0.000 75	0.000 4	0.000 2	0.000 4	-0.000 9	0.000 10
Y-Y' 15	-0.000 6	-0.000 01	-0.000 1	-0.000 2	0.000 7	0.001 31	0.000 1	-0.000 2	0.000 0	-0.002 6	0.002 85
Y-Y' 40	-0.000 6	-0.000 13	-0.000 1	-0.000 3	0.000 3	-0.000 04	0.000 0	0.000 3	0.000 3	-0.002 4	-0.000 04
Y-Y'100	0.000 4	0.000 29	-0.000 2	0.000 0	0.000 2	-0.000 57	0.000 4	0.000 0	0.000 9	-0.000 3	-0.001 41

No. \ Code	22	23	24	25	26	27	28	29	30	31	32
X-X' 5	-0.000 3	-0.000 06	0.000 15	-0.000 11	-0.000 5	-0.000 39	-0.004 55	-0.000 05	0.000 16	0.000 02	-0.000 58
X-X' 15	-0.000 4	-0.000 01	0.000 11	0.000 09	-0.000 6	-0.000 89	-0.000 53	0.000 31	0.000 04	0.000 07	-0.000 33
X-X' 40	0.000 0	-0.000 08		-0.000 03	-0.001 3	-0.000 72	-0.012 37	-0.000 45	0.000 01	-0.000 07	-0.000 51
X-X'100	-0.000 8	0.000 18		0.000 49	0.000 2	-0.001 38	-0.000 03	0.001 79	0.000 24	0.000 23	-0.000 34
Y-Y' 5	-0.000 3	0.000 09	0.015 21	-0.000 06	-0.000 5	-0.000 44	-0.004 55	-0.000 09	0.000 15	-0.000 02	-0.000 54
Y-Y' 15	-0.000 4	-0.000 09	0.000 04	0.000 01	-0.000 5	-0.000 83	-0.000 52	0.000 31	-0.000 01	0.000 02	-0.000 38
Y-Y' 40	0.000 0	-0.000 14		-0.000 08	-0.001 5	-0.000 63	-0.012 33	-0.000 38	-0.000 03	-0.000 12	-0.000 48
Y-Y'100	-0.000 6	0.000 29		0.000 62	0.000 3	-0.001 49	-0.000 01	0.000 69	0.000 25	0.000 31	-0.000 23

TABLE 3: SUMMARY OF UNCERTAINTIES [mm]

Code / No.	REF	1	2	3	4	5	6	7	8	9	10
X-X’ 5	0.000 3	0.000 5	0.000 7	0.000 38	0.000 3	0.000 4	0.000 72	0.001 3	0.000 6	0.000 26	0.001 2
X-X’ 15	0.000 3	0.000 5	0.000 7	0.000 39	0.000 4	0.000 4	0.000 72	0.001 3	0.000 6	0.000 70	0.001 2
X-X’ 40	0.000 3	0.000 5	0.000 7	0.000 45	0.000 8	0.000 5	0.000 72	0.001 3	0.000 7	0.000 73	0.001 3
X-X’100	0.000 5	0.000 5	0.000 8	0.000 73	0.001 5	0.000 7	0.000 91	0.001 3	0.001 2	0.000 78	0.001 8
Y-Y’ 5	0.000 3	0.000 5	0.000 7	0.000 38	0.000 3	0.000 4	0.000 72	0.001 3	0.000 6	0.000 26	0.001 2
Y-Y’ 15	0.000 3	0.000 5	0.000 7	0.000 39	0.000 4	0.000 4	0.000 72	0.001 3	0.000 6	0.000 70	0.001 2
Y-Y’ 40	0.000 3	0.000 5	0.000 7	0.000 45	0.000 8	0.000 5	0.000 72	0.001 3	0.000 7	0.000 73	0.001 3
Y-Y’100	0.000 5	0.000 5	0.000 8	0.000 73	0.001 5	0.000 7	0.000 91	0.001 3	0.001 2	0.000 78	0.001 8

Code / No.	11	12	13	14	15	16	17	18	19	20	21
X-X’ 5	0.000 6	0.000 24	0.000 3	0.000 4	0.002 1	0.000 49	0.000 8	0.001 2	0.000 5	0.000 7	0.000 09
X-X’ 15	0.000 7	0.000 24	0.000 4	0.000 5	0.002 1	0.000 48	0.000 8	0.001 3	0.000 5	0.000 9	0.000 28
X-X’ 40	0.000 9	0.000 25	0.000 4	0.000 6	0.002 1	0.000 50	0.000 9	0.001 3	0.000 8	0.001 4	0.000 32
X-X’100	0.001 7	0.000 26	0.000 7	0.000 7	0.002 1	0.000 49	0.001 0	0.001 3	0.001 0	0.002 6	0.000 36
Y-Y’ 5	0.000 6	0.000 24	0.000 3	0.000 4	0.002 1	0.000 49	0.000 8	0.001 2	0.000 5	0.000 7	0.000 09
Y-Y’ 15	0.000 7	0.000 24	0.000 4	0.000 5	0.002 1	0.000 48	0.000 8	0.001 3	0.000 5	0.000 9	0.000 28
Y-Y’ 40	0.000 9	0.000 25	0.000 4	0.000 6	0.002 1	0.000 50	0.000 9	0.001 3	0.000 8	0.001 4	0.000 32
Y-Y’100	0.001 7	0.000 26	0.000 7	0.000 7	0.002 1	0.000 49	0.001 0	0.001 3	0.001 0	0.002 6	0.000 36

Code / No.	22	23	24	25	26	27	28	29	30	31	32
X-X’ 5	0.000 8	0.000 25	0.000 18	0.000 15	0.000 43	0.001 05	0.000 17	0.000 41	0.000 24	0.000 53	0.000 30
X-X’ 15	0.001 1	0.000 29	0.000 18	0.000 15	0.000 49	0.001 04	0.000 20	0.000 41	0.000 27	0.000 28	0.000 31
X-X’ 40	0.001 1	0.000 39		0.000 18	0.000 63	0.001 05	0.000 27	0.000 43	0.000 37	0.000 55	0.000 33
X-X’100	0.001 3	0.000 64		0.000 25	0.000 97	0.001 08	0.000 41	0.000 43	0.000 59	0.000 74	0.000 38
Y-Y’ 5	0.000 8	0.000 25	0.000 18	0.000 15	0.000 43	0.001 05	0.000 17	0.000 41	0.000 24	0.000 53	0.000 30
Y-Y’ 15	0.001 1	0.000 29	0.000 18	0.000 15	0.000 49	0.001 04	0.000 20	0.000 41	0.000 27	0.000 28	0.000 31
Y-Y’ 40	0.001 1	0.000 39		0.000 18	0.000 63	0.001 05	0.000 27	0.000 43	0.000 37	0.000 55	0.000 33
Y-Y’100	0.001 3	0.000 64		0.000 25	0.000 97	0.001 08	0.000 41	0.000 43	0.000 59	0.000 74	0.000 38

TABLE 4: SUMMARY OF E_n SCORE

Code / No.	REF	1	2	3	4	5	6	7	8	9	10
X-X’ 5	0	-3.26	-2.10	-1.65	-0.94	-0.80	-0.13	0.00	-0.45	-0.63	0.65
X-X’ 15	0	-2.40	-0.13	-1.42	-1.00	-0.60	0.00	0.15	0.00	0.03	-0.40
X-X’ 40	0	-0.51	-0.13	-1.85	-0.94	-0.51	-0.38	-0.15	-0.13	-0.27	-0.52
X-X’100	0	0.14	0.32	-0.34	0.44	0.81	-0.19	0.14	-0.46	0.06	-0.32
Y-Y’ 5	0	-3.43	-1.97	-1.45	-0.94	-0.80	-0.13	0.07	-0.45	-0.60	0.16
Y-Y’ 15	0	-2.06	0.26	-1.63	-1.40	-0.60	0.00	0.07	0.00	-0.09	-0.40
Y-Y’ 40	0	-1.03	-0.66	-1.48	-1.05	-0.51	-0.26	-0.15	0.00	-0.38	-0.37
Y-Y’100	0	0.14	0.42	-0.23	0.38	0.93	-0.19	0.22	-0.54	-0.11	-0.32

Code / No.	11	12	13	14	15	16	17	18	19	20	21
X-X’ 5	-1.19	-0.44	0.00	-0.40	0.14	1.15	0.35	0.16	0.51	-1.97	0.09
X-X’ 15	-0.92	0.05	-0.20	-0.17	0.33	2.26	0.00	-0.15	0.00	-1.79	1.25
X-X’ 40	-0.74	-0.33	-0.20	-0.45	0.09	-0.10	0.00	0.22	0.35	-1.89	0.89
X-X’100	0.17	0.59	0.00	-0.12	0.00	-0.70	0.45	0.00	0.54	-0.11	-1.02
Y-Y’ 5	-1.04	-0.23	0.00	-0.20	0.19	1.31	0.47	0.16	0.69	-1.18	0.33
Y-Y’ 15	-0.79	-0.03	-0.20	-0.34	0.33	2.31	0.12	-0.15	0.00	-2.74	6.96
Y-Y’ 40	-0.63	-0.33	-0.20	-0.45	0.14	-0.07	0.00	0.22	0.35	-1.68	-0.09
Y-Y’100	0.23	0.51	-0.23	0.00	0.09	-0.81	0.36	0.00	0.80	-0.11	-2.28

Code / No.	22	23	24	25	26	27	28	29	30	31	32
X-X’ 5	-0.35	-0.15	0.43	-0.33	-0.95	-0.36	-13.12	-0.10	0.42	0.03	-1.37
X-X’ 15	-0.35	-0.02	0.31	0.27	-1.05	-0.82	-1.48	0.61	0.10	0.17	-0.76
X-X’ 40	0.00	-0.16		-0.09	-1.87	-0.66	-30.70	-0.86	0.02	-0.11	-1.14
X-X’100	-0.57	0.22		0.87	0.18	-1.16	-0.05	2.71	0.31	0.26	-0.54
Y-Y’ 5	-0.35	0.23	43.47	-0.18	-0.95	-0.40	-13.15	-0.18	0.39	-0.03	-1.27
Y-Y’ 15	-0.35	-0.22	0.11	0.03	-0.87	-0.77	-1.45	0.61	-0.02	0.05	-0.88
Y-Y’ 40	0.00	-0.28		-0.23	-2.15	-0.58	-30.60	-0.72	-0.06	-0.19	-1.08
Y-Y’100	-0.43	0.36		1.11	0.28	-1.25	-0.02	1.05	0.32	0.35	-0.37

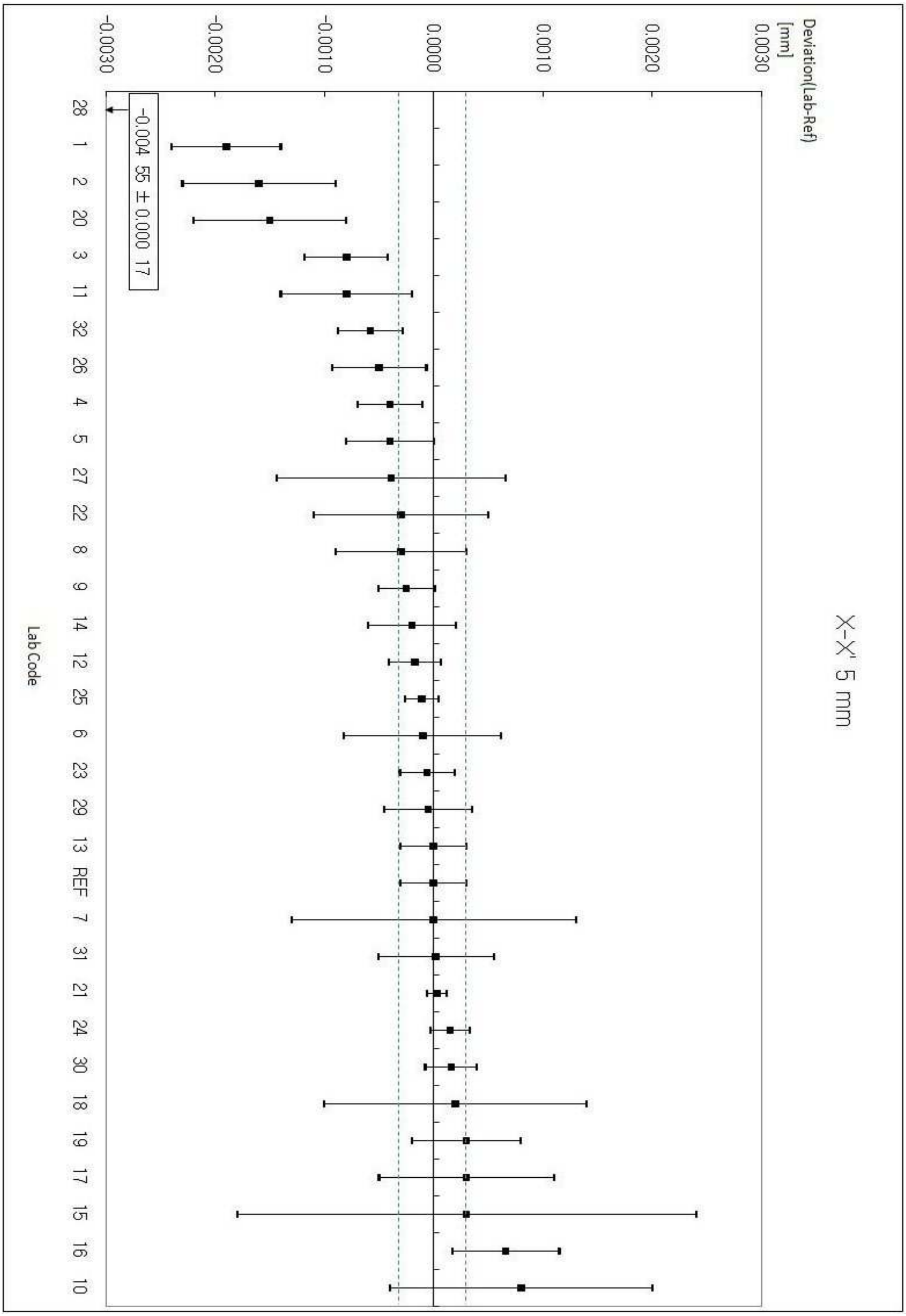


FIGURE 1: DEVIATION FOR X-X' 5 mm

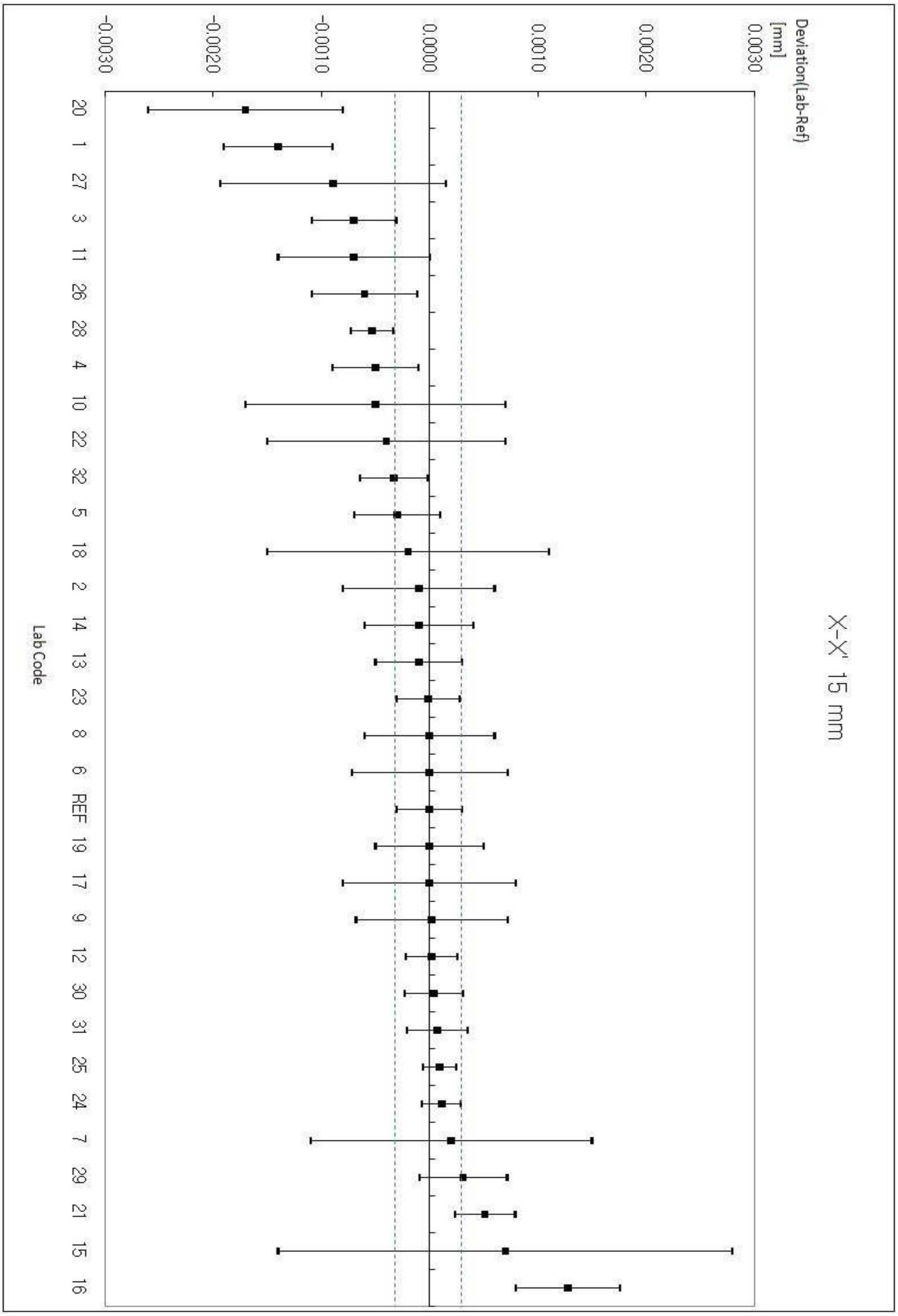


FIGURE 2: DEVIATION FOR X-X' 15 mm

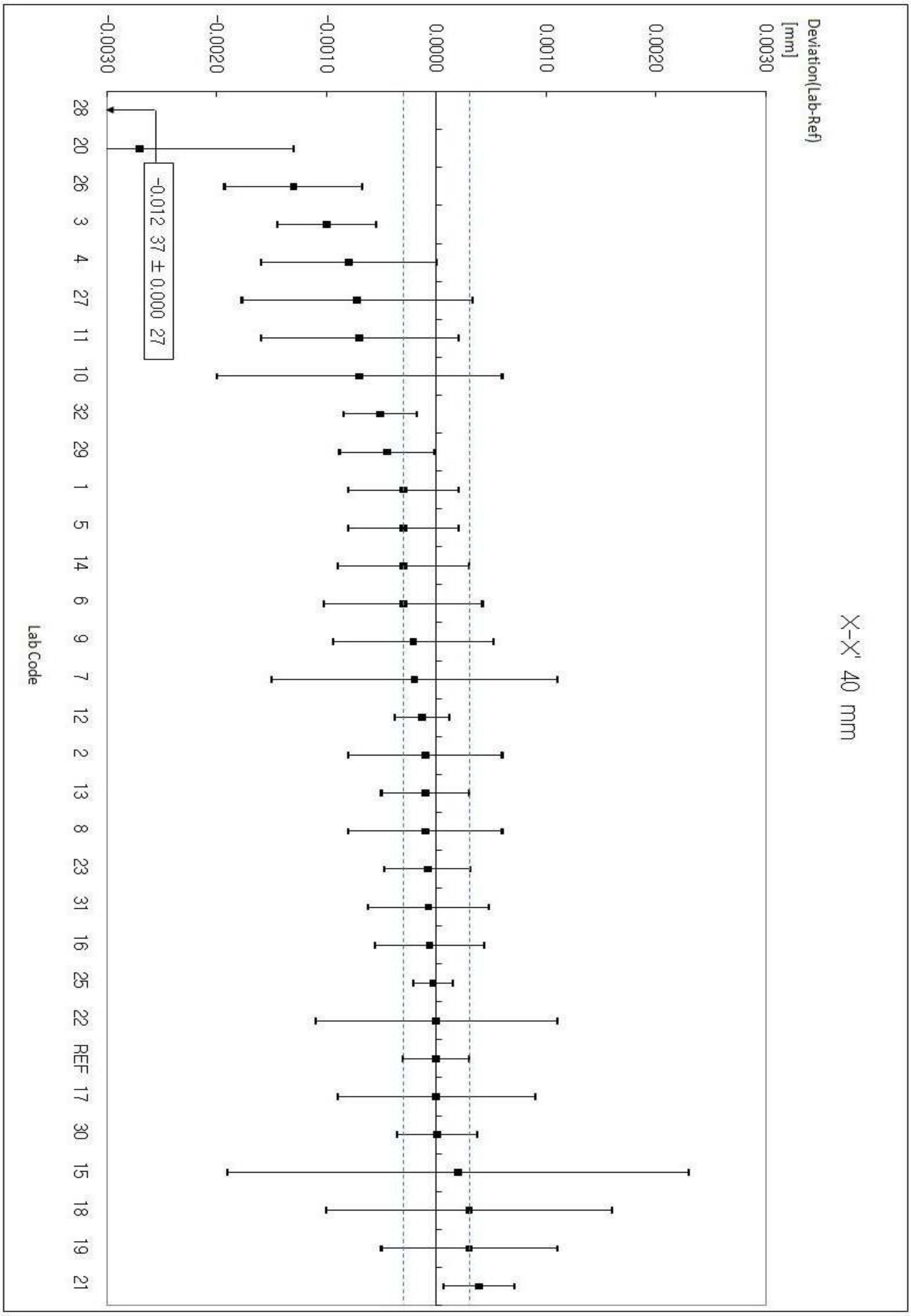


FIGURE 3: DEVIATION FOR X-X' 40 mm

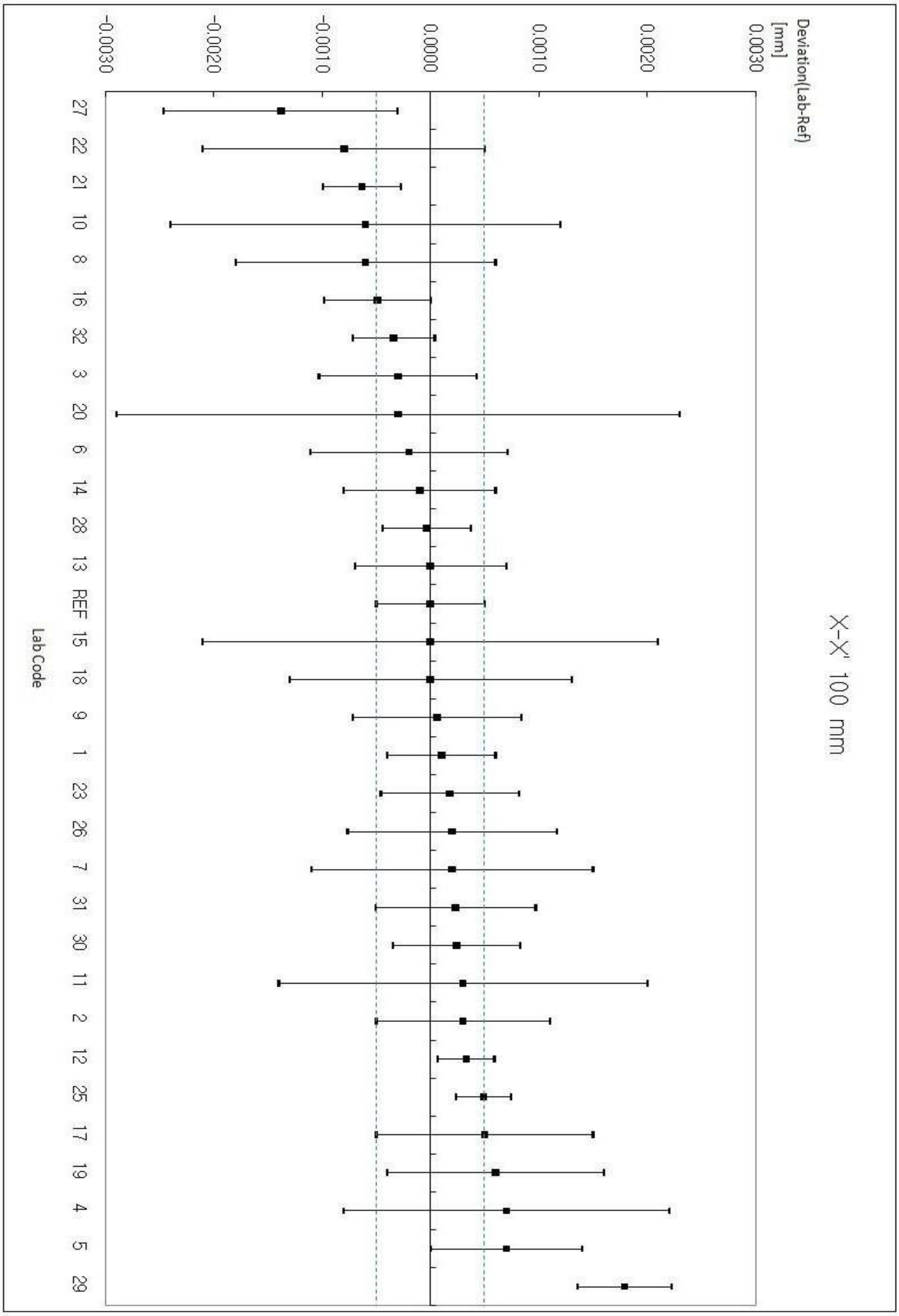


FIGURE 4: DEVIATION FOR X-X' 100 mm

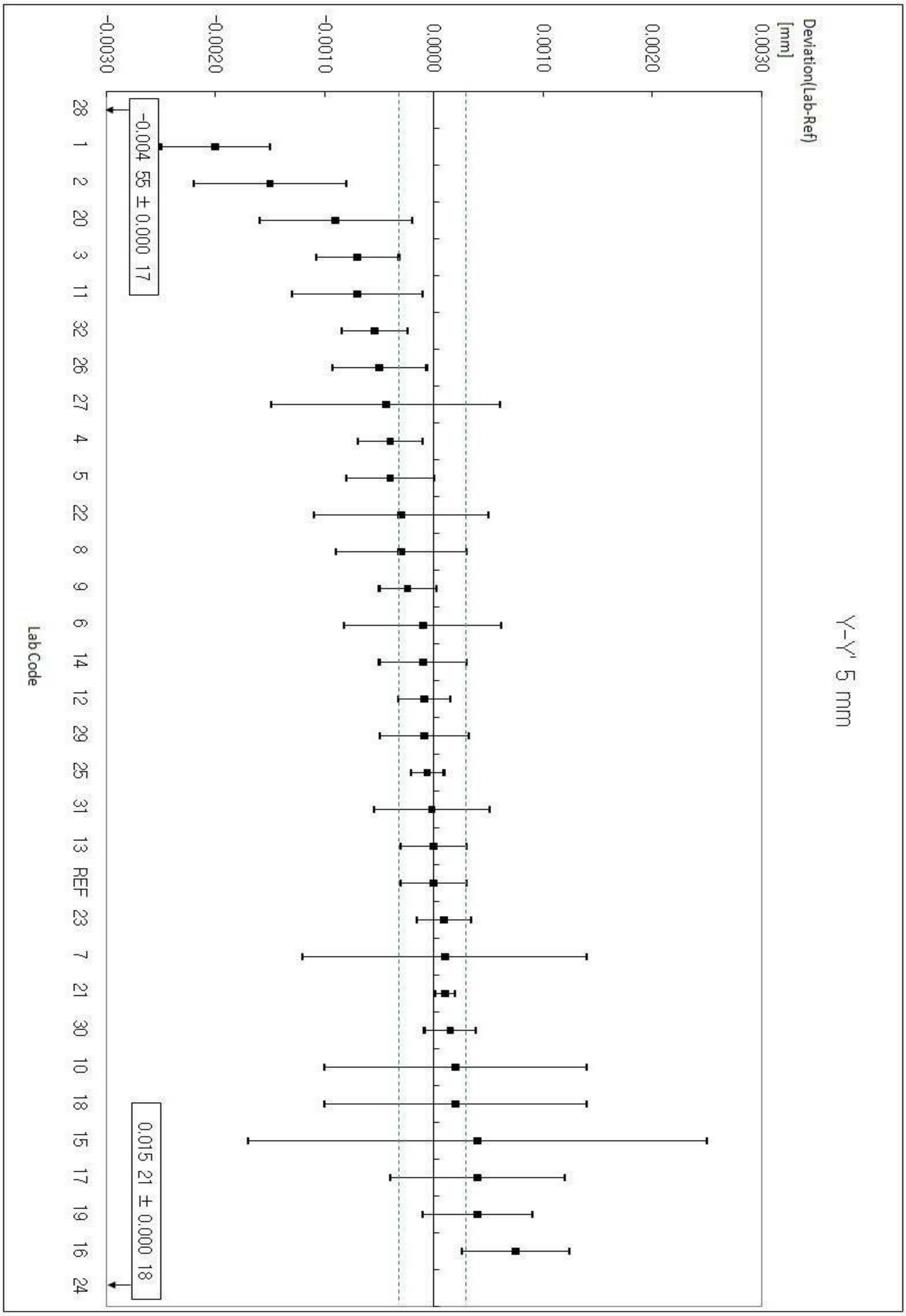


FIGURE 5: DEVIATION FOR Y-Y' 5 mm

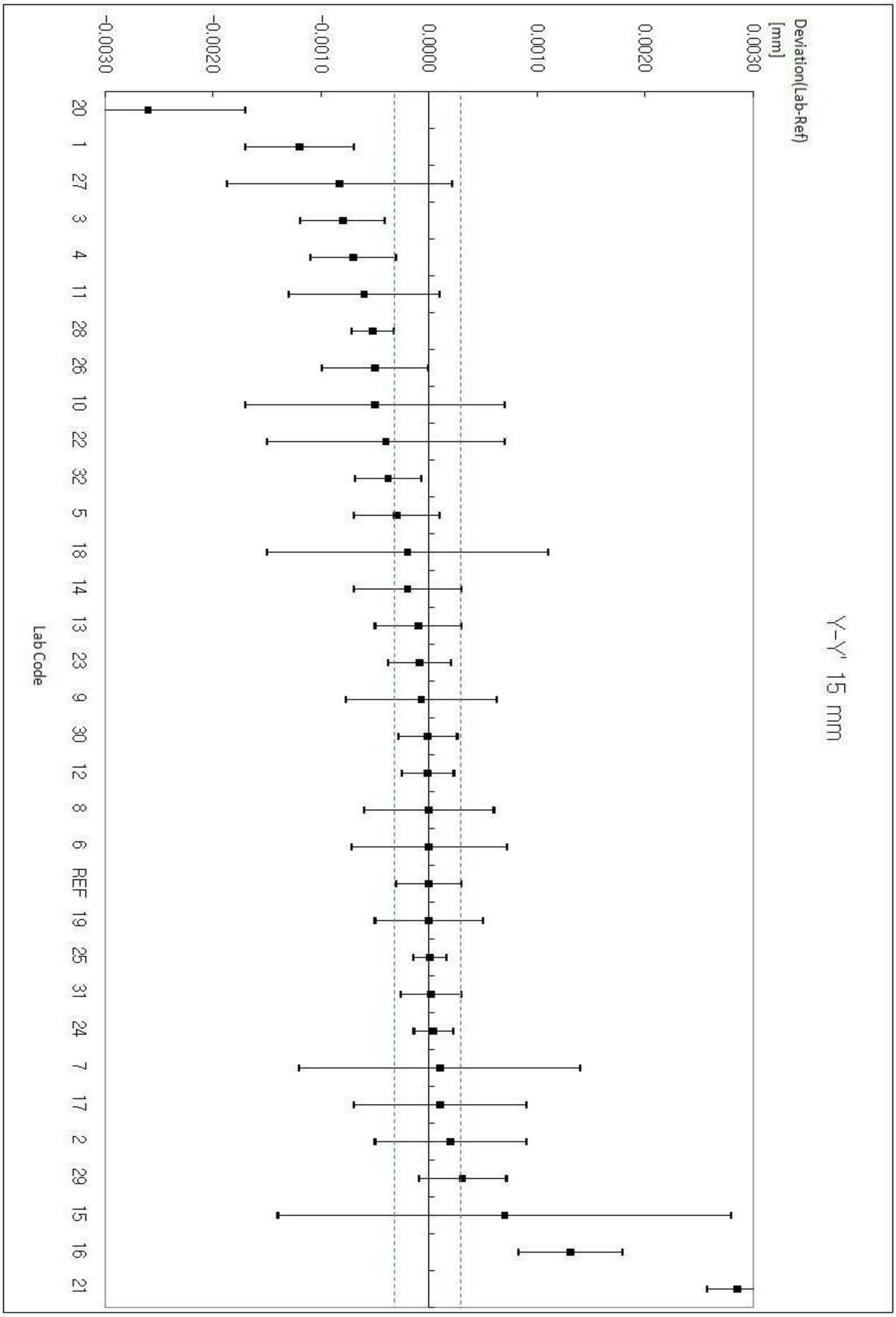


FIGURE 6: DEVIATION FOR Y-Y' 15 mm

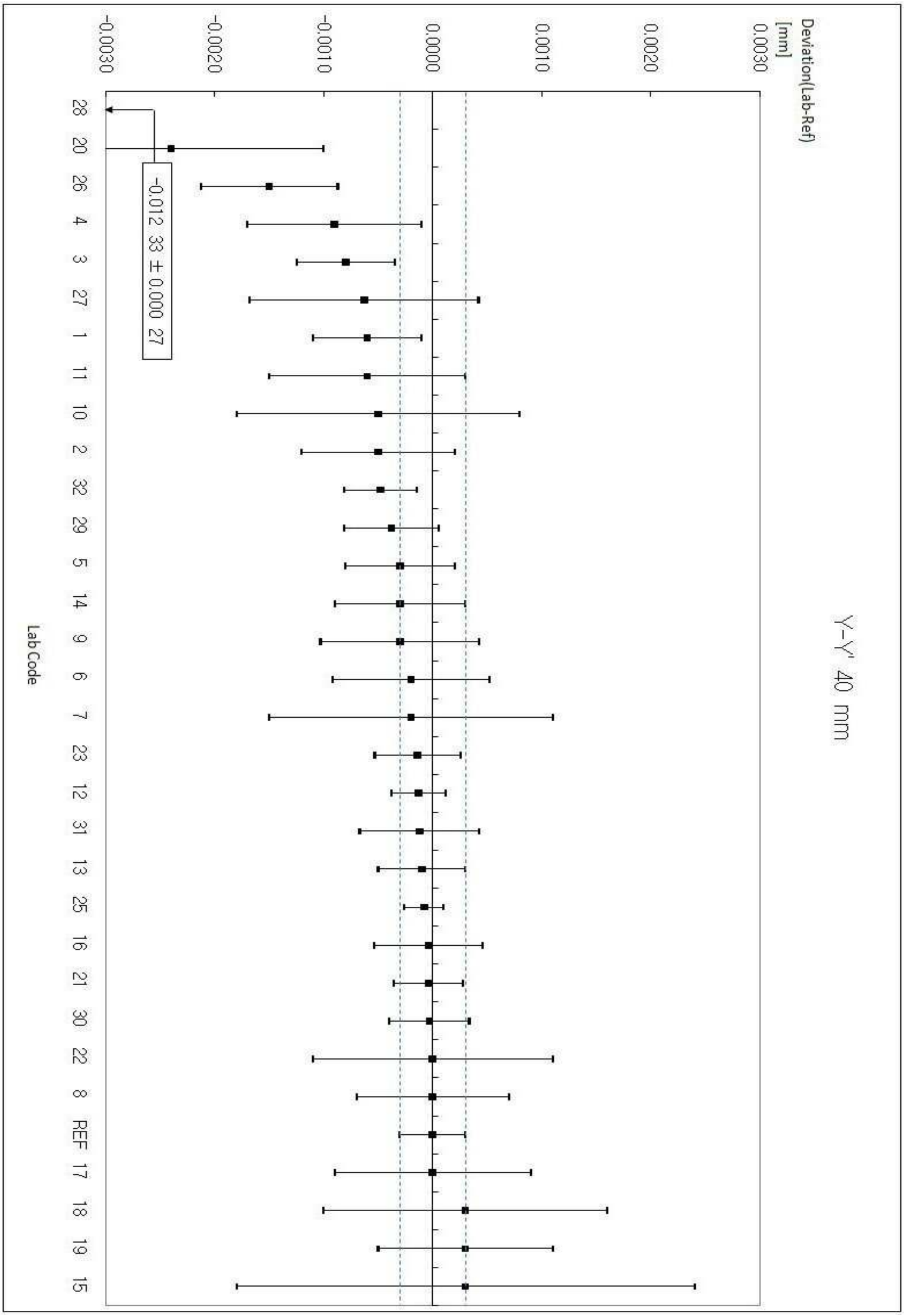


FIGURE 7: DEVIATION FOR Y-Y' 40 mm

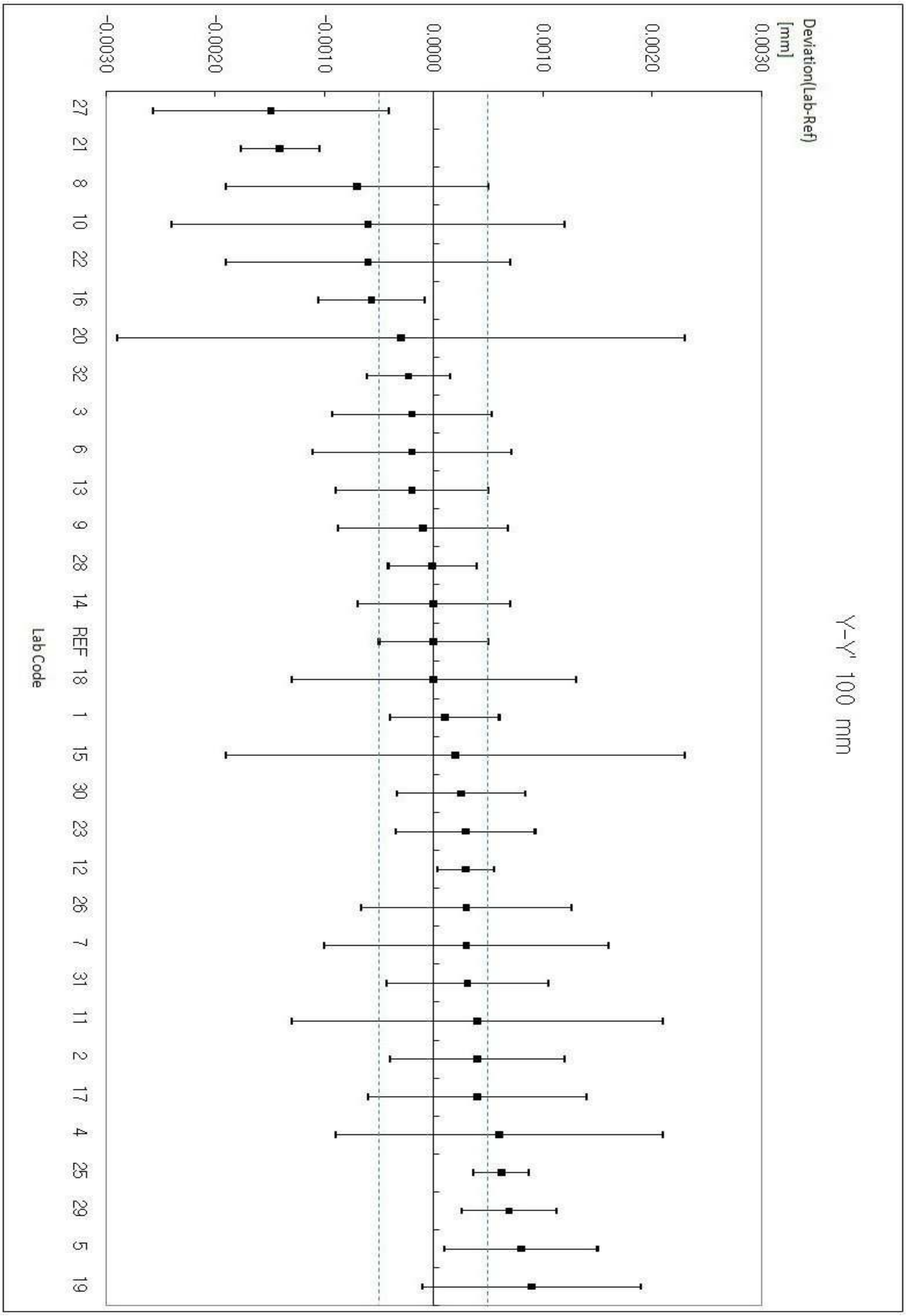


FIGURE 8: DEVIATION FOR Y-Y' 100 mm

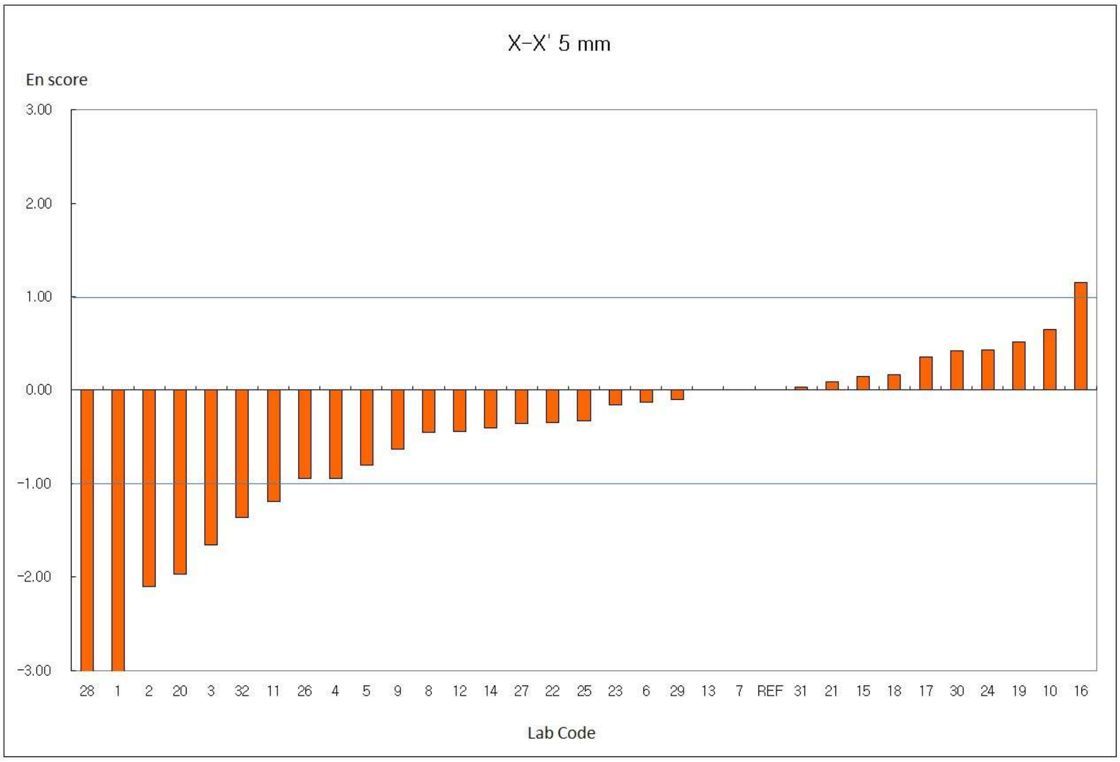


FIGURE 9: *En* SCORE FOR X-X' 5 mm

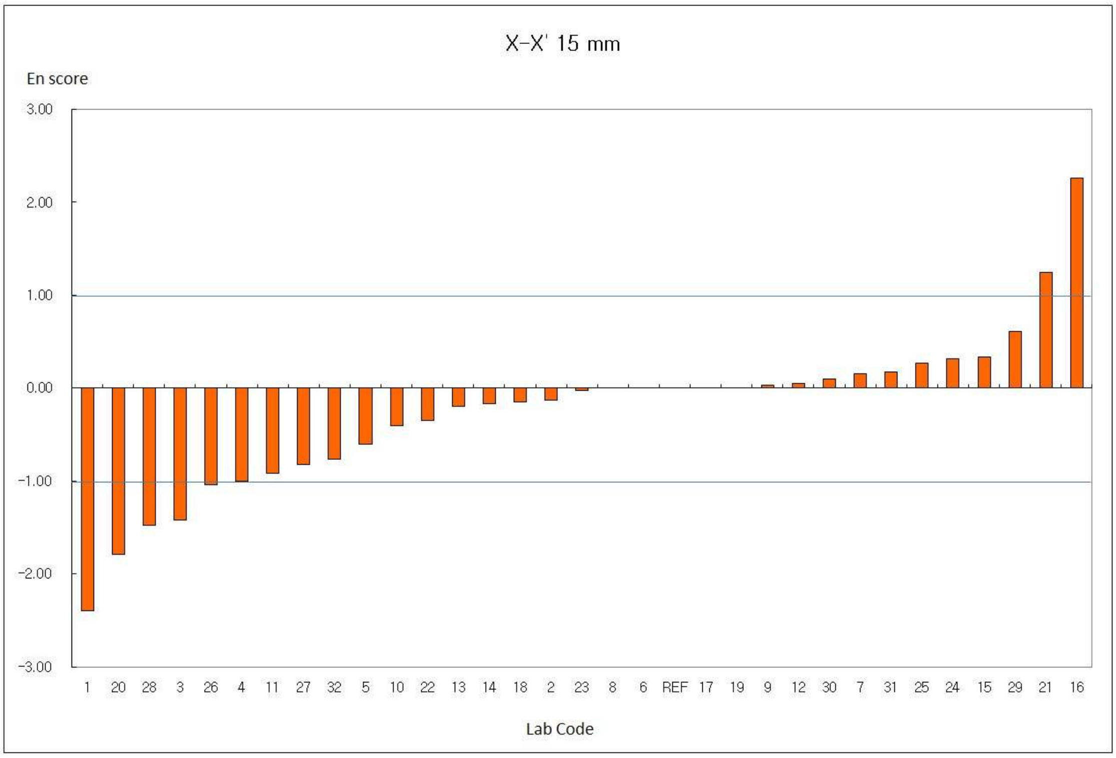


FIGURE 10: *En* SCORE FOR X-X' 15 mm

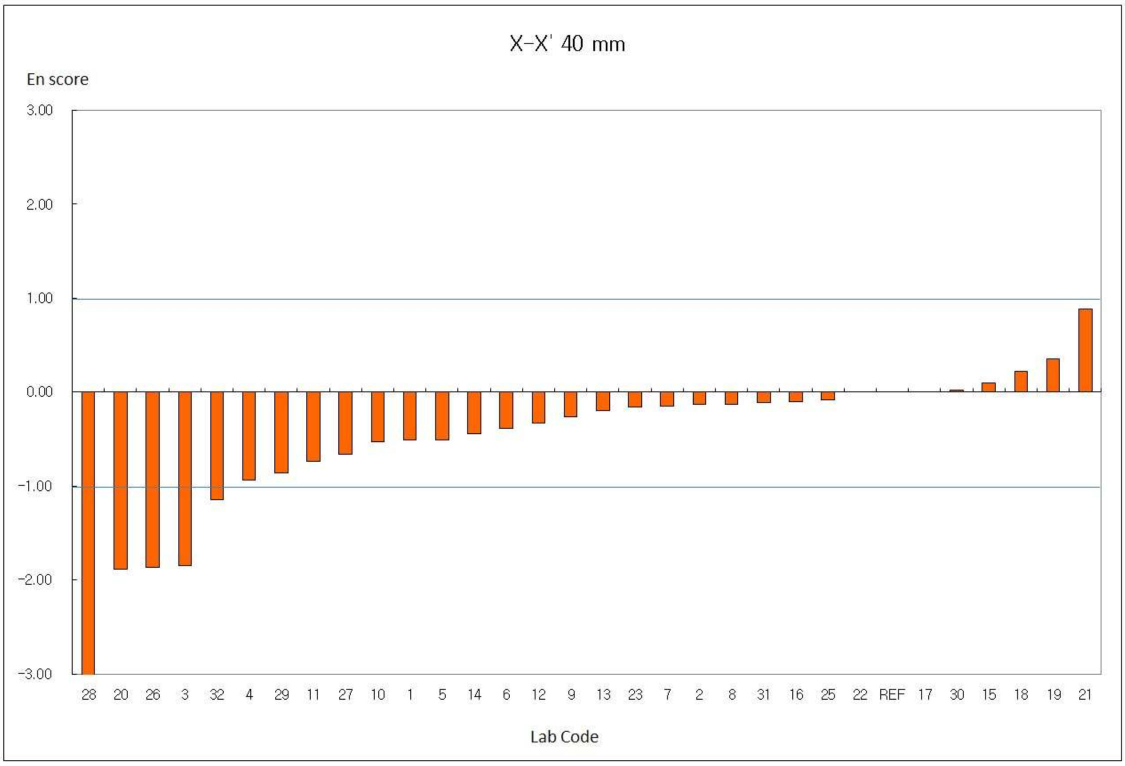


FIGURE 11: *En* SCORE FOR X-X' 40 mm

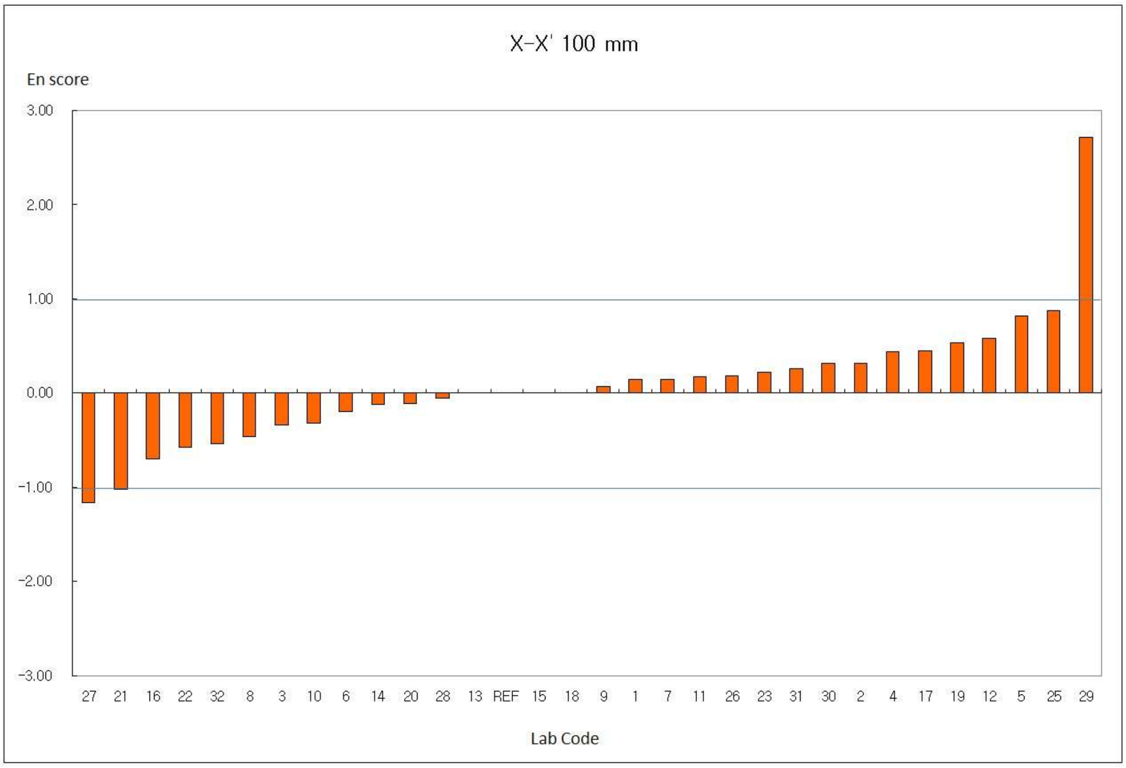


FIGURE 12: *En* SCORE FOR X-X' 10 mm

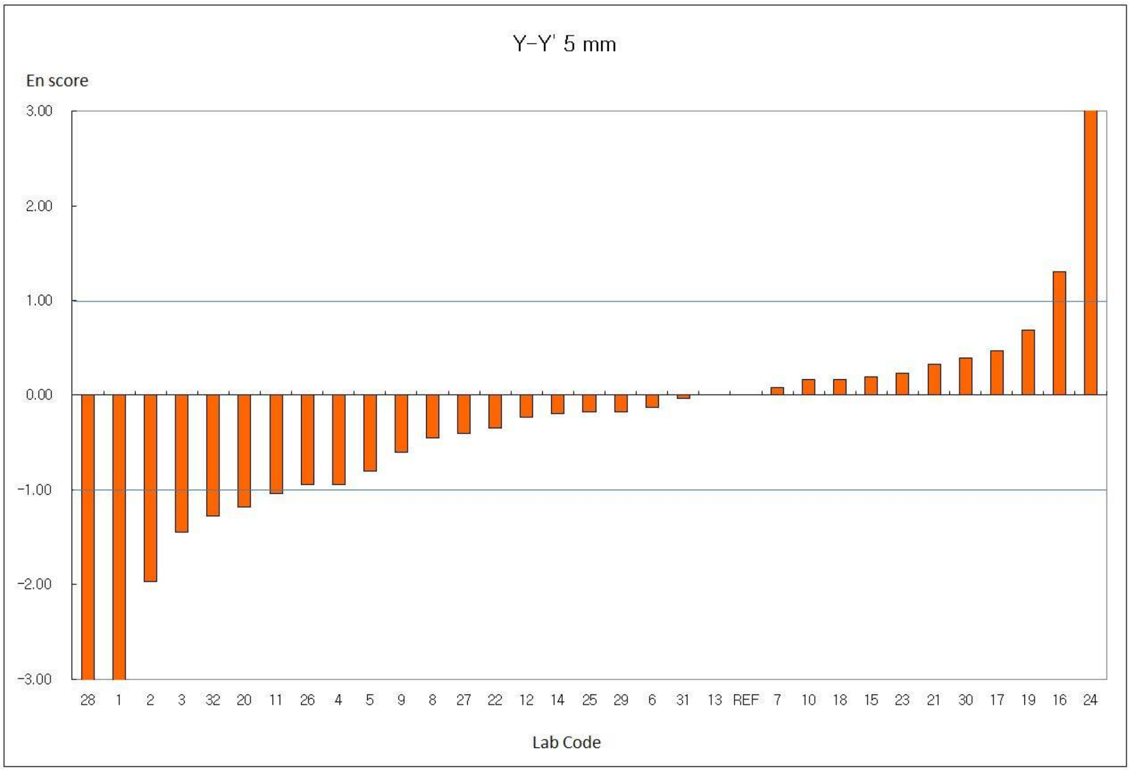


FIGURE 13: *En* SCORE FOR Y-Y' 5 mm

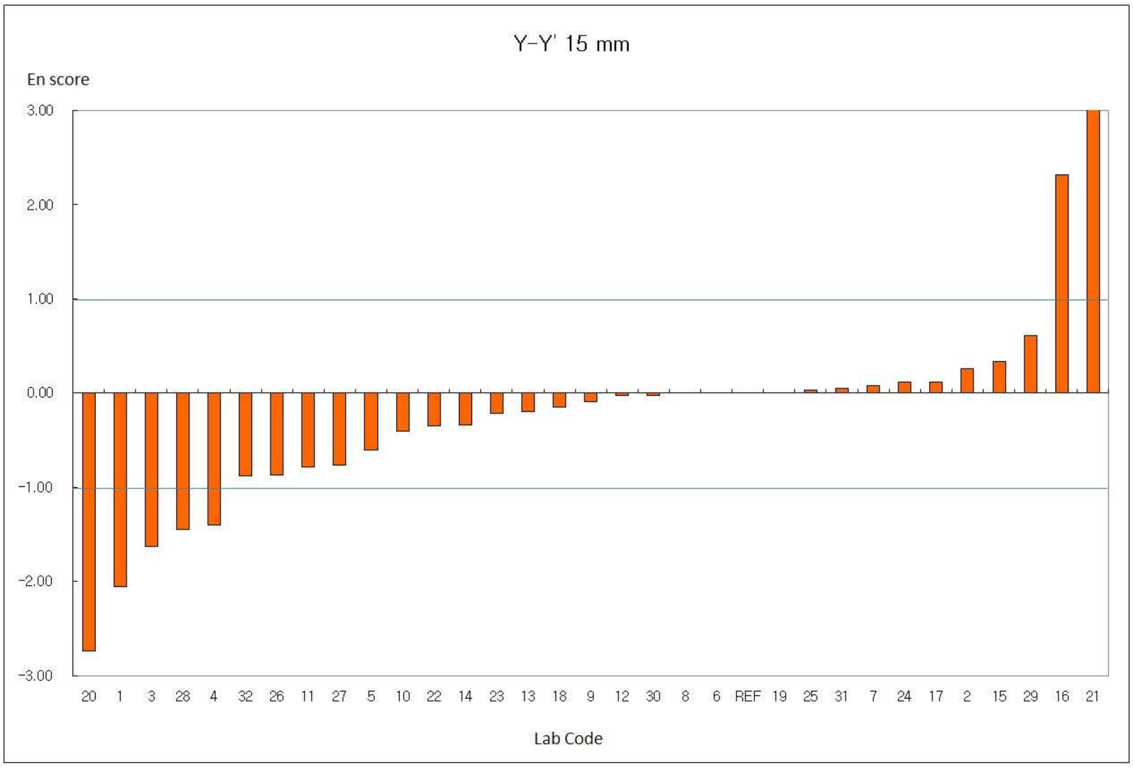


FIGURE 14: *En* SCORE FOR Y-Y' 15 mm

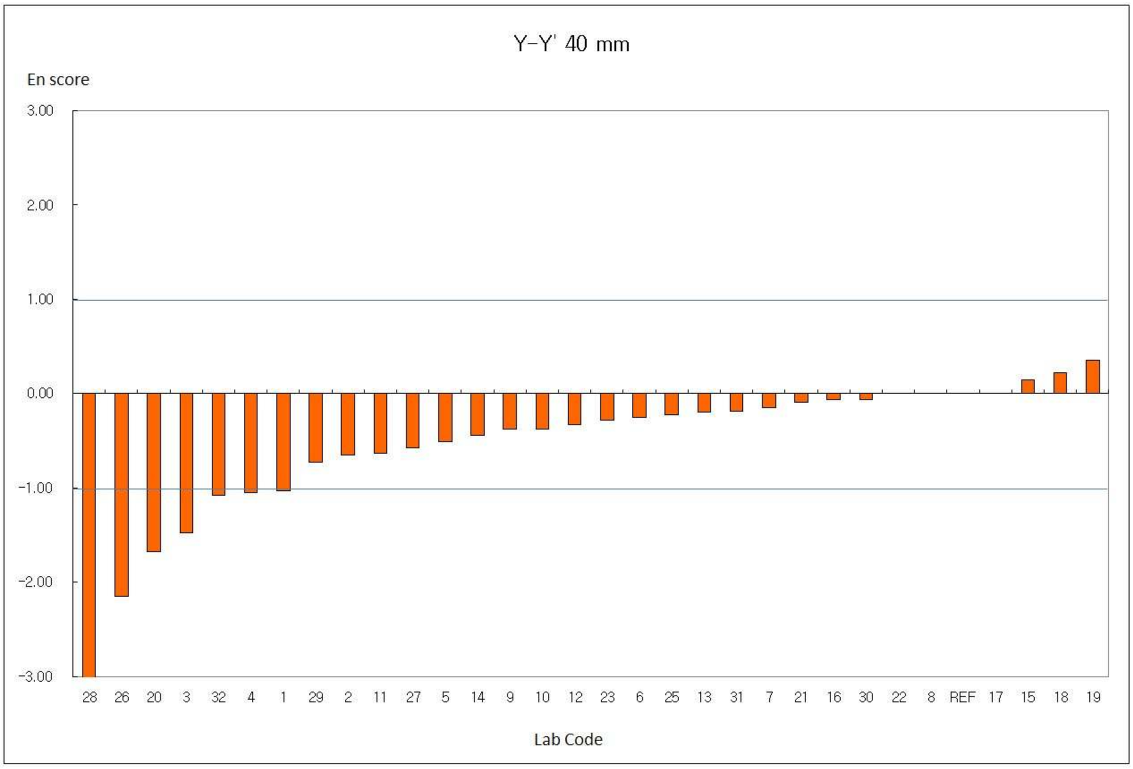


FIGURE 15: *En* SCORE FOR Y-Y' 40 mm

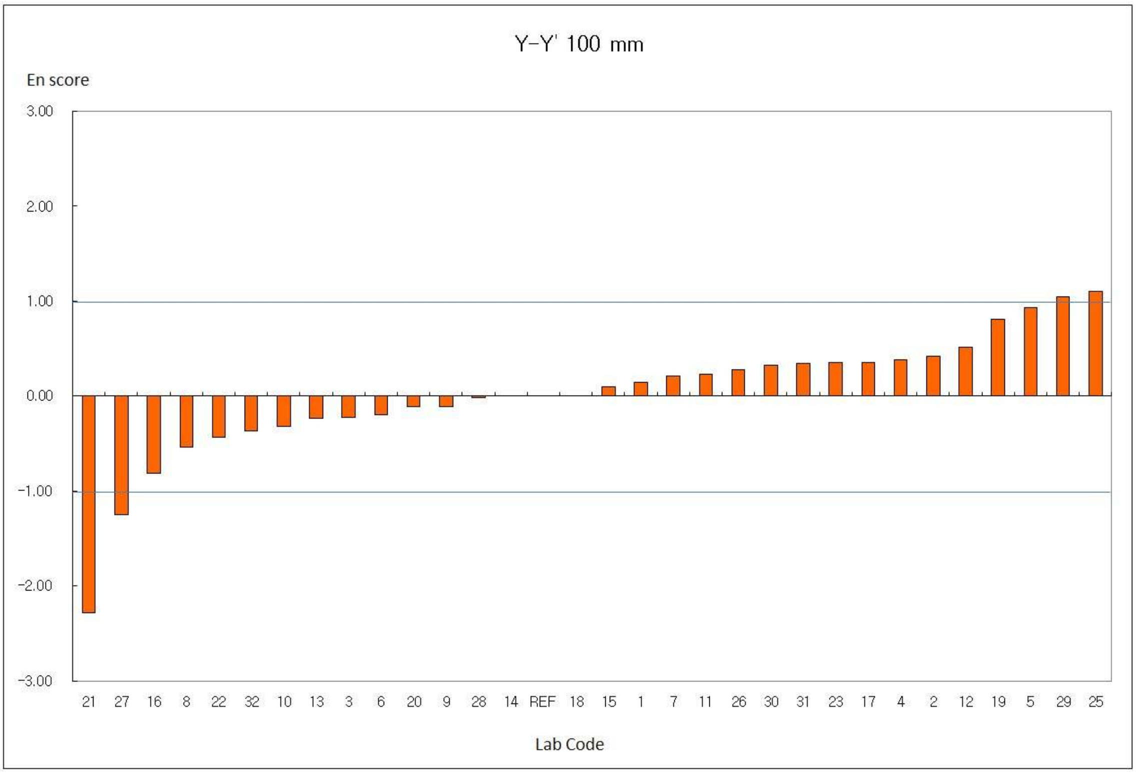


FIGURE 16: *En* SCORE FOR Y-Y' 100 mm

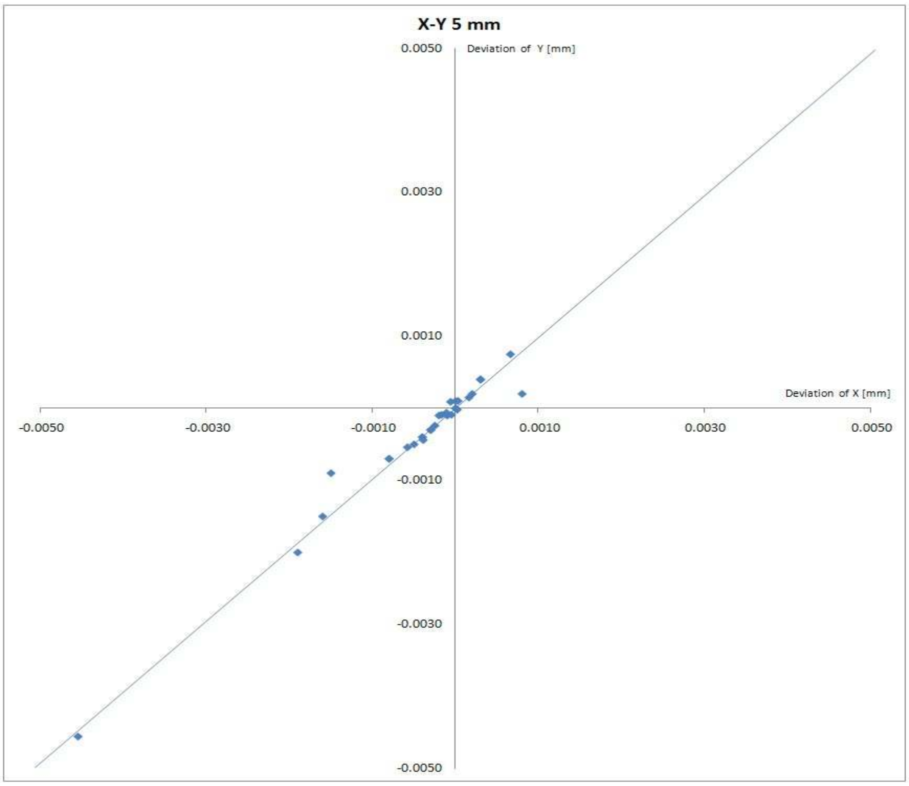


FIGURE 17: DEVIATION FOR X-Y 5 mm

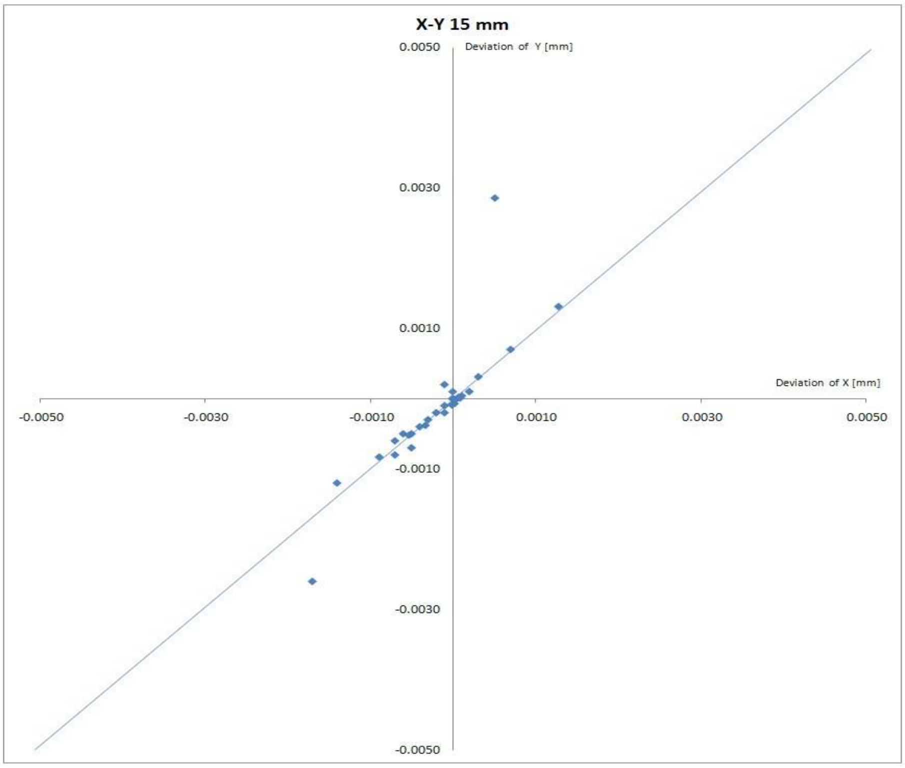


FIGURE 18: DEVIATION FOR X-Y 15 mm

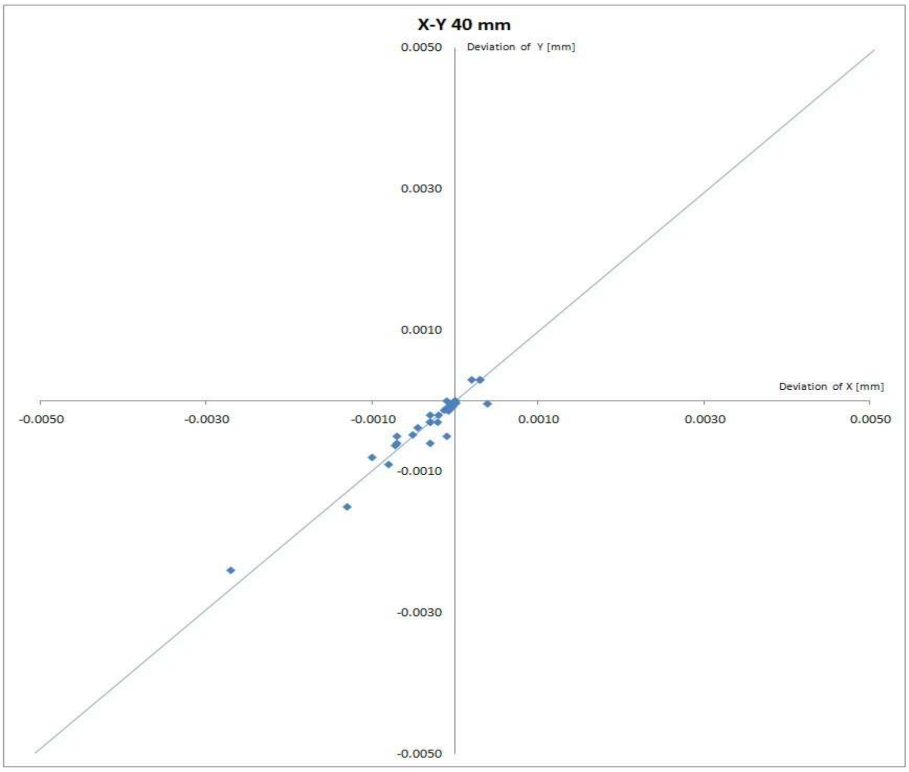


FIGURE 19: DEVIATION FOR X-Y 40 mm

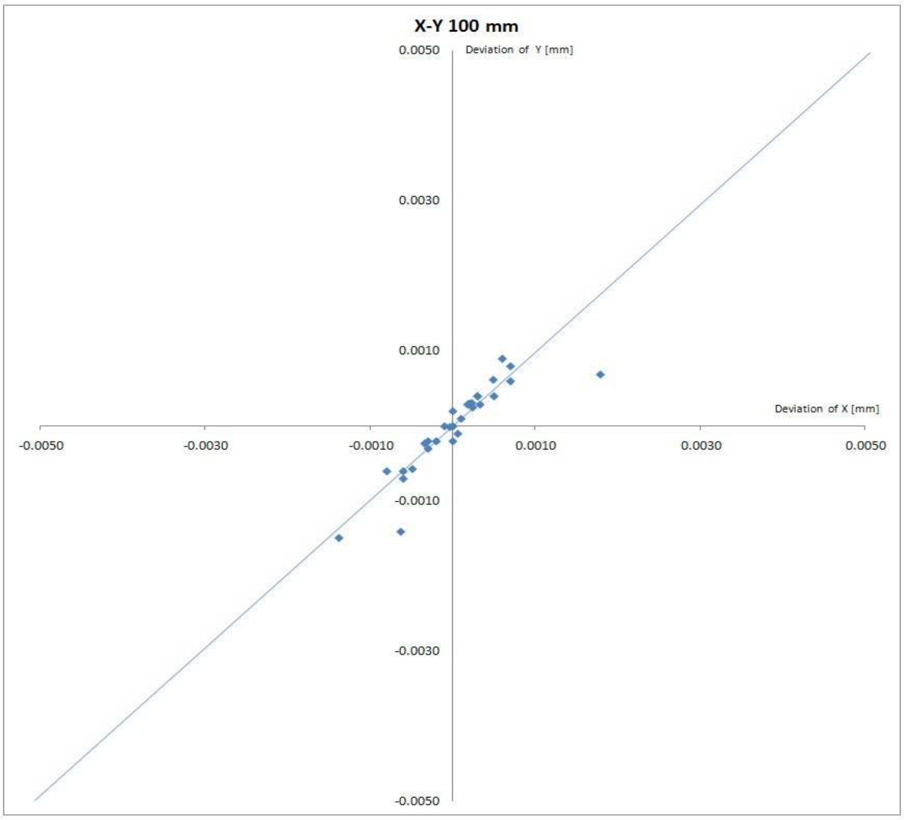


FIGURE 20: DEVIATION FOR X-Y 100 mm

9. PERFORMANCE OF PARTICIPANTS

The table of E_n scores shows the performance by the participating laboratories.

Lab code 12, 25, 28 and 32 reported smaller uncertainties than the reference laboratory. The lab code 12, 25 show good performance, but the lab code 25 have one $|E_n| > 1$ value at 100 mm.

Lab code 1, 2, 3, 4, 11, 16, 20, 21, 24, 26, 27, 28, 29 and 32 have one or more $|E_n| > 1$ values.

The labs with $|E_n| > 1$ may be able to overcome their problems by a review of their uncertainty calculation, incorrect calculation or correction factor.

The bias that laboratory results are smaller than the reference result is indentified. Although the bias had been reviewed by the technical committee of the organizing body, the cause restricted to M024 program was not found, excepting the general cause like elastic deformation correction, alignment error and self-weight deformation.

10. UNCERTAINTIES OF MEASUREMENT

An example of an uncertainty analysis for a plain plug gauge 100 mm 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 (2008) Calibration Interlaboratory Comparisons

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

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

(4) KTL Technical Memorandum No. CP801-10228-1 (2009) Standard Calibration Procedure of Plug Gauges, Cylindrical

A. INSTRUCTIONS TO LABORATORIES
for Circulation Group: A

1. EQUIPMENT

Equipment and Accessory Description:

Group	Content	Serial No.	Nominal diameter	Material	Manufacturer
A	Plain Plug Gauges	S-62/1	5 mm	Steel (EN31)	YPG, UK
		S-62/2	15 mm		
		S-62/3	40 mm		
		S-62/4	100 mm		
	Wooden Inner Box	S-62	-	Wood	YPG, UK
	Portable Transit Case	-	-	Aluminum	Daedo, Korea
	Material property of Plain Plug Gauges : Coefficient of Thermal expansion: 11.6×10^{-6} /K Modulus of Elasticity : 206 000 N/mm^2				

On receipt, unpack the artifacts and inspect them for any defects. Make sure to sketch surface condition of all the artifacts on the "*Surface Condition Report of Gauges*". Contact your accreditation body if there is any damage. Send "*Surface Condition Report of Gauges*" by fax and/or e-mail right away to your accreditation body.

2. MEASUREMENTS TO BE CARRIED OUT

The measurement items of interest are two diametrical distances between the nominal gauge points, defined as mid-elevation along the gauge cylinder and in the diameter direction specified by the engraved marks on the gauge (X-X' and Y-Y'. See Fig. 1).

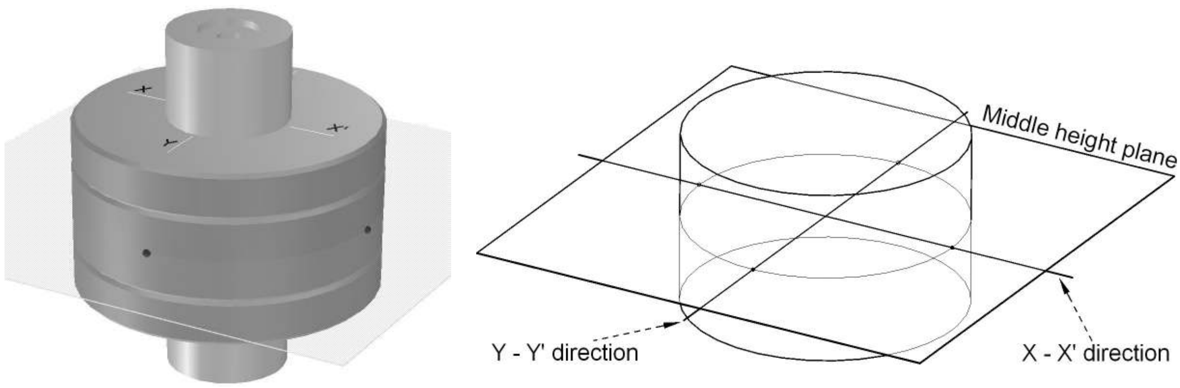


Fig. 1 Measurement positions of diameter

The measurement values must be appropriately corrected to the reference temperature of 20 °C using the thermal expansion coefficient given in this document. Additional corrections, if any, have to be applied according to the equipment and procedures used by each laboratory. And measurement uncertainty (*U*) shall be reported by using expanded measurement uncertainty. Coverage factor shall be a value which defines an interval having a level of confidence of approximately 95 %.

After the measurements, the artifacts must be cleaned, greased, and carefully re-packaged in the original container.

3. DOCUMENTS TO BE SUBMITTED

Within one week of the completion of the measurements, participating laboratories are required to send the attached "*Results Sheet*", "*Surface condition report of Gauges*", and their calibration report to their accreditation body. No other documents are required. Laboratories should make a copy of the *Results Sheet* for their own records.

Where possible, uncertainties should be calculated using the method in the ISO *Guide to the Expression of Uncertainty in Measurement.*

4. GENERAL INFORMATION

For general queries, please contact your accreditation body.
Additional information may be obtained from the program coordinator below:

Mr. YANG, Hee-Chan
KOLAS(Korea Laboratory Accreditation Scheme)
96 Kyoyookwon-gil, Gwacheon, Gyeonggi-do, 427-723, Republic of Korea
Phone No.: +82-2-509-7227
Fax No.: +82-2-507-6875
E-mail: kolas@kats.go.kr

B. SURFACE CONDITION REPORT OF GAUGES

Date:

Name of participant:

Circulation group:

Name of responsible person:

Name of accreditation body:

Please mark: ☐ on receipt ☐ after mesurement

Plain Plug Gauges of nominal diameter 5 mm:

S/N: ___________ Please sketch the damage (such as scratches or rusts) and describe it in detail.

< X >	< X' >	< Y >	< Y' >

____

____

____

____

____

____

Plain Plug Gauges of nominal diameter 15 mm:

S/N: ____________ Please sketch the damage (such as scratches or rusts) and describe it in detail.

< X > < X' > < Y > < Y' >

Plain Plug Gauges of nominal diameter 40 mm:

S/N: ____________ Please sketch the damage (such as scratches or rusts) and describe it in detail.

< X > < X' > < Y > < Y' >

Plain Plug Gauges of nominal diameter 100 mm:

S/N: ___________ Please sketch the damage (such as scratches or rusts) and describe it in detail.

< X >	< X' >	< Y >	< Y' >

NOTE: Photograph may be helpful to describe damages well.

C. RESULTS SHEET

Name of participant: ______________________________

Circulation group: ______________

Date of measurement: ______________

Environment: 1. Temperature ________ 2. Humidity ________

Reference standard (type, S/N, material): ______________________

Name of accreditation body: ______________________________

Results:

Nominal diameter (mm)	Gauge S/N	Diameter (mm)		Measurement uncertainty *U* (μm)	Coverage factor *k*	Remarks
		X – X'	Y – Y'			
5						
15						
40						
100						

NOTE:

1. Diameter must be reported as a value at the reference temperature of $t_o = 20\ ^{\circ}C$
2. Measurement uncertainty (*U*) shall be reported by using expanded uncertainty.
3. Coverage factor shall be a value which defines an interval having a level of confidence of approximately 95 %.
4. Thermal expansion coefficient: $(11.6 \pm 1.0) \times 10^{-6}$ /K (Level of confidence: approximately 95 %)
   Modulus of elasticity: 206 000 N/mm^2.
5. Use SI unit only.

Signature of responsible person: ______________________________

Date: _______ / _______ / _______
dd mm yyyy

CIRCULATION SCHEDULE

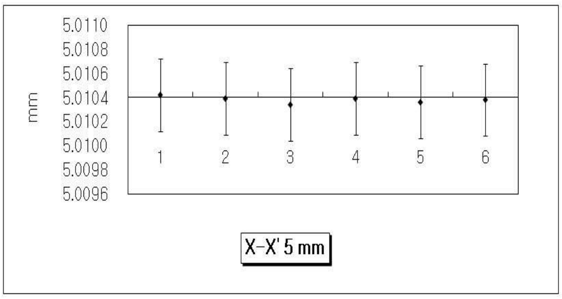
Loop A

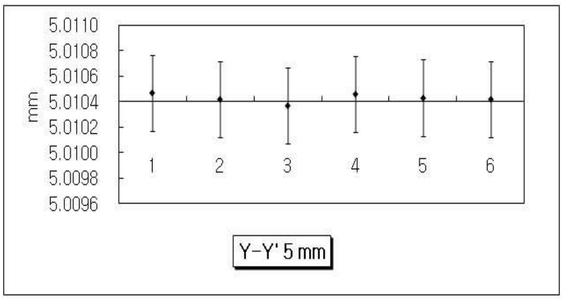
No.	Nation	Accreditation Body	Receipt	Dispatch
1	Korea (ref)	KOLAS (beginning)	-	2010-02-22
2	Japan	IAJapan	2010-03-08	2010-04-05
3	New Zealand	IANZ	2010-04-19	2010-05-10
4	Philippine	PAO	2010-05-24	2010-06-14
5	Taiwan	TAF	2010-06-28	2010-07-26
6	China	CNAS	2010-08-09	2010-09-06
7	Singapore	SAC	2010-09-20	2010-10-18
8	Korea	KOLAS	2010-11-01	2010-11-29
9	Korea (ref)	KOLAS (end)	2010-12-13	-

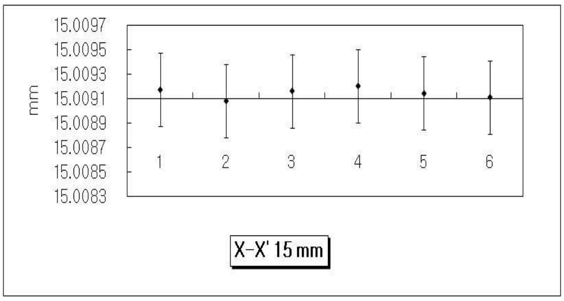
Loop B

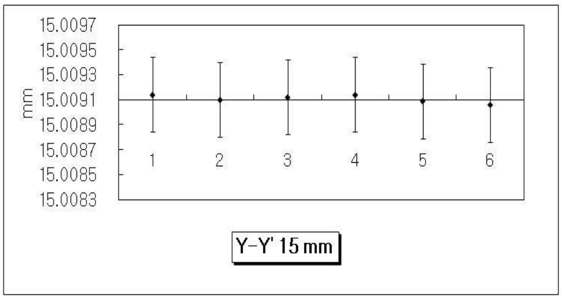
No.	Nation	Accreditation Body	Receipt	Dispatch
1	Korea (ref)	KOLAS (beginning)	-	2010-02-22
2	USA	IAS	2010-03-08	2010-03-29
3	USA	NVLAP	2010-04-12	2010-05-10
4	USA	L-A-B	2010-05-24	2010-06-21
5	USA	ACLASS	2010-07-05	2010-08-02
6	USA	PJLA	2010-08-16	2010-09-06
7	Australia	NATA	2010-09-20	2010-10-18
8	Korea (ref)	KOLAS (end)	2010-11-01	-

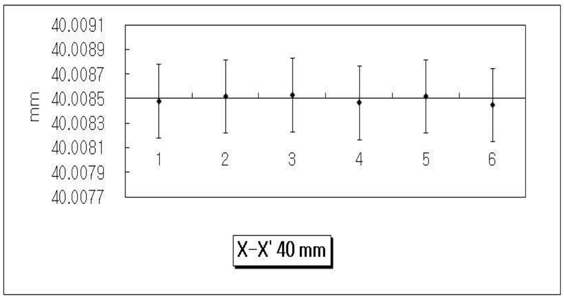
STABILITY OF ARTIFACTS – LOOP A
GRAPHS OF REFERENCE LABORATORY CALIBRATIONS

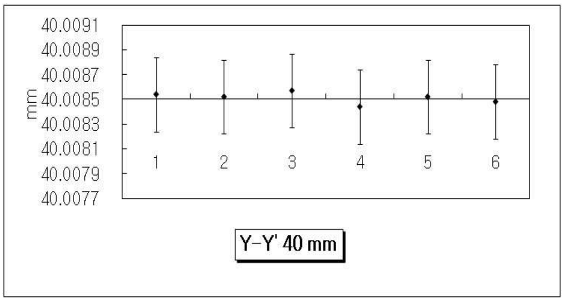


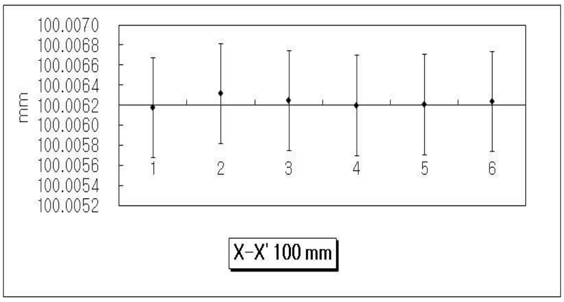


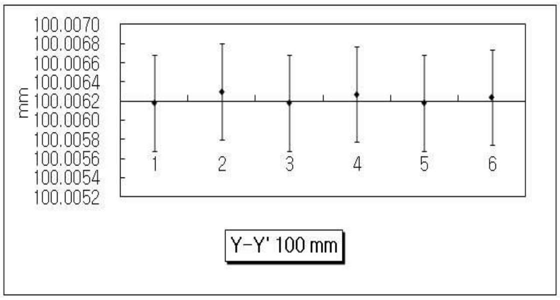












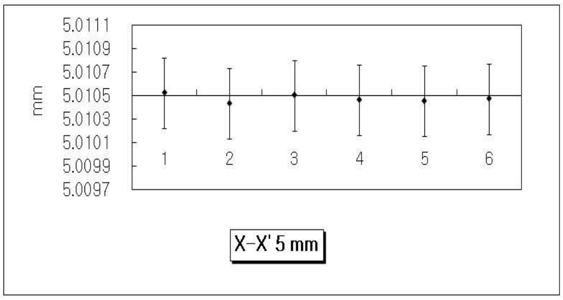
Before the program: 1 ~ 4

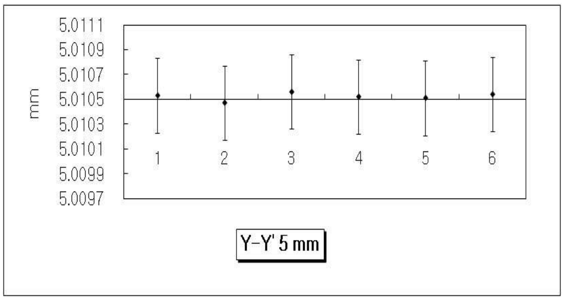
The beginning of the program: 5 / The end of the program: 6

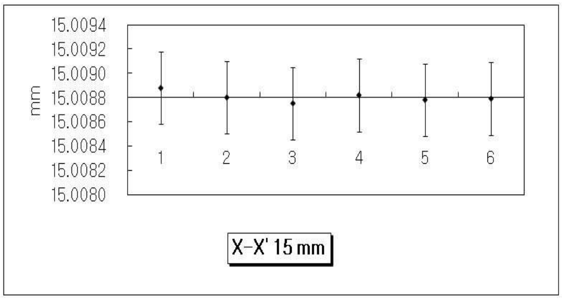
Drift between successive calibrations: Maximum 0.000 1 mm

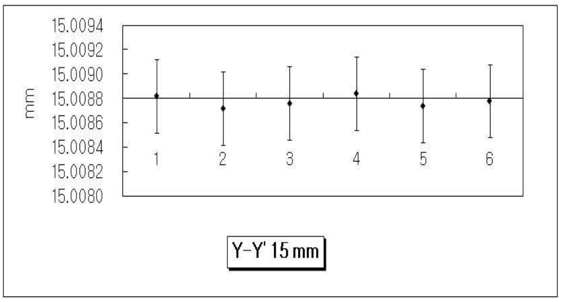
Regression analysis: there was no statistically significant association between time and measurement value at all point

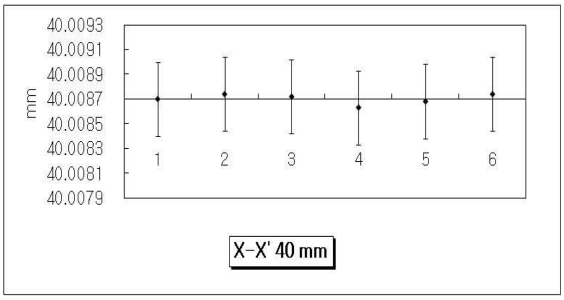
STABILITY OF ARTIFACTS – LOOP B
GRAPHS OF REFERENCE LABORATORY CALIBRATIONS

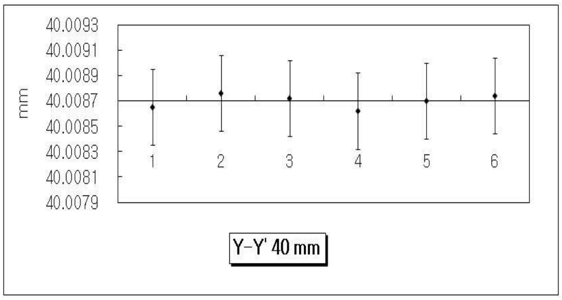


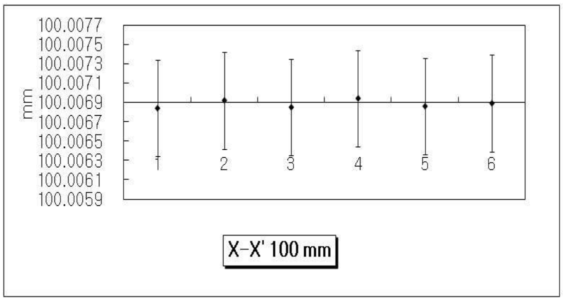


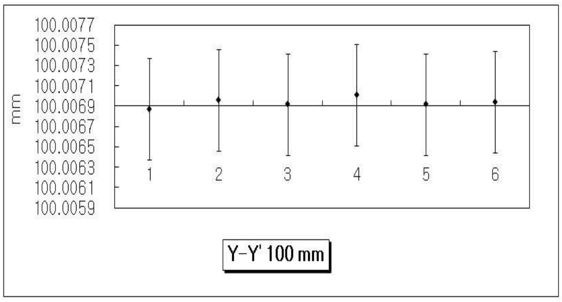












Before the program: 1 ~ 4

The beginning of the program: 5 / The end of the program: 6

Drift between successive calibrations: Maximum 0.000 1 mm

Regression analysis: there was no statistically significant association between time and measurement value at all point

EXAMPLE UNCERTAINTY OF MEASUREMENT ANALYSYS

The artifacts used in the APLAC interlaboratory comparison M024 were calibrated by standard measuring machine. This example only relates to the evaluation of the expanded uncertainty at plain plug gauge 100 mm.

1. Mathematical model

The external diameter d_x of the unknown plain plug gauge at the reference temperature $t_0 =$ 20 ℃ is obtained from the following expression:-

$$d_x = d_r - d(\overline{\alpha} \times \delta t + \delta\alpha \times \Delta t)$$

where:-

d_r	measured value of standard measuring machine (mm);
d	nominal diameter of the plain plug gauge considered (mm);
$\overline{\alpha} = (\alpha_x + \alpha_s)/2$	average of the thermal expansion coefficients of the plain plug gauge and standard measuring machine(/℃);
$\delta t = (t_x - t_s)$	temperature difference between the plain plug gauge and standard measuring machine (℃);
$\delta\alpha = (\alpha_x - \alpha_s)$	difference in the thermal expansion coefficients between the plain plug gauge and standard measuring machine (/℃);
$\Delta t = (t_x + t_s)/2 - t_0$	deviation of the average temperature of the plain plug gauge and standard measuring machine from the reference temperature (℃);

2. Uncertainty budget

Standard Uncertainty Component $u(x_i)$	Source of Uncertainty	Value of Standard Uncertainty $u(x_i)$	Probability Distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $u_i(y) = \|c_i\| u(x_i)$	Degree of Freedom
$u(d_r)$	Measured value	0.12 µm	normal	1	0.12 µm	233
$u(d_{rs})$	standard Measuring Machine	0.09 µm	normal			∞
$u(d_{rsd})$	drift of standard Measuring Machine	0.012 µm	rectangular			50
$u(d_{rx})$	repeated measurement	0.05 µm	t distribution			10
$u(d_{rA})$	abbe error correction	0.06 µm	rectangular			50
$u(d_{re})$	elastic deformation correction	0 µm	rectangular			50
$u(\overline{\alpha})$	Average of the thermal expansion coefficients	0.41 X 10^{-6}/℃	triangular	0 µm·℃	0.00 µm	100
$u(\delta t)$	Temperature difference	0.17 ℃	rectangular	-1.15 µm/℃	0.20 µm	50
$u(\delta\alpha)$	Difference in the thermal expansion coefficients	0.82 X 10^{-6}/℃	triangular	0 µm·℃	0.00 µm	100
$u(\Delta t)$	Deviation of the average temperature from the reference temperature	0.29 ℃	rectangular	0 µm/℃	0.00 µm	50
Combined Standard Uncertainty					0.23 µm	92

3. Sensitivity coefficient

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

$$c_{d_r} = \frac{\partial d_x}{\partial d_r} = 1$$

$$c_{\overline{\alpha}} = \frac{\partial d_x}{\partial \overline{\alpha}} = -d \cdot \delta t$$

$$c_{\delta t} = \frac{\partial d_x}{\partial \delta t} = -d \cdot \overline{\alpha}$$

$$c_{\delta\alpha} = \frac{\partial d_x}{\partial \delta\alpha} = -d \cdot \Delta t$$

$$c_{\Delta t} = \frac{\partial d_x}{\partial \Delta t} = -d \cdot \delta\alpha$$

4. List of the uncertainty components

- **Measured value of standard measuring machine** $u(d_r)$

The calibration certificate gives as the expanded uncertainty of the standard measuring machine 0.18 μm and states that it was obtained using a coverage factor of *k* = 2.
The standard uncertainty is:-

$$u(d_{rs}) = 0.18/2 = 0.09 \text{ μm}$$

The drift of the standard measuring machine is estimated from the changes in measured value over several calibrations. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The rectangular limit is assumed to be ± 0.02 μm. The probability of drift lying outside ± 0.02 μm is assumed to be 10 %. Therefore the degree of freedom is $v_{d_{rsd}} = 1/2 \times (100/10)^2 = 50$. The standard uncertainty is:-

$$u(d_{rsd}) = 0.02/\sqrt{3} = 0.012 \text{ μm}$$

In this example, eleven repeated observations were taken.

No.	Measured value
1	100.007 2
2	100.007 2
3	100.007 2
4	100.007 2
5	100.007 1
6	100.007 0
7	100.006 8
8	100.006 8
9	100.006 8
10	100.006 9
11	100.007 0

The degree of freedom is $v_{d_{rx}} = n-1 = 10$. The standard uncertainty associated with the mean of these reading is:-

$$u(d_{rx}) = \frac{1}{\sqrt{n}}\left(\sqrt{\frac{\sum_{i=1}^{11}(x_i - \bar{x})^2}{n-1}}\right) = 0.05 \text{ μm}$$

The actual values of the Abbe errors of the standard measuring machine are not determined during the current measurement. From experience and periodical verification data of the standard measuring machine, however, the maximum effect due to Abbe errors are estimated to be 0.2 µm. The rectangular limit is assumed to be (0.1 ± 0.1) µm. The probability of Abbe errors lying outside (0.1 ± 0.1) µm is assumed to be 10 %. The degree of freedom is $v_{d_{rA}} = 1/2 \times (100/10)^2 = 50$. The standard uncertainty is:-

$$u(d_{rA}) = 0.2/2/\sqrt{3} = 0.06 \ \mu\text{m}$$

The elastic deformation of the plain plug gauge to be calibrated is obtained from the following expression:-

$$d_{rE} = \frac{P(V_1 + V_2)}{a}\left[1 + \ln\left\{\frac{16a^3}{(V_1 + V_2)P \cdot d}\right\}\right] = 0.0013 \ \mu\text{m}$$

$$V_1 = V_2 = (1 - \sigma^2)/\pi E$$

where:-

P	applied force (0.2 N);
σ	poisson's ratio (0.28);
E	Modulus of Elasticity (2 x 10^5 N/mm^2);
a	length of contact (9.5 mm);
d	diameter of plain plug gauge (100 mm);

The change of the applied force is assumed to be within ± 0.05 N. The uncertainty due to elastic deformation is negligible.

The total contribution is obtained from the sum of the estimated variances:-

$$u(d_r) = \sqrt{u^2(d_{rs}) + u^2(d_{rsd}) + u^2(d_{rx}) + u^2(d_{rA})} = 0.12 \ \mu\text{m}$$

- **Average of the thermal expansion coefficients of the plain plug gauge and standard measuring machine** $u(\overline{\alpha})$

Based on the manufacturer's data of the standard measuring machine and the steel plain plug gauge to be calibrated, the linear thermal expansion coefficient is within the

(11.6 ± 1.0) x 10^{-6} /℃. The probability of thermal expansion coefficient lying outside ± 1.0 x 10^{-6} /℃ is assumed to be 10 %. Combining the two rectangular distributions is triangularly distributed $\overline{\alpha} = (\alpha_x + \alpha_s)/2$. Therefore the standard uncertainty of average of the thermal expansion coefficients and the degree of freedom are:-

$$u(\overline{\alpha}) = \sqrt{\frac{1}{4}u^2(\alpha_x) + \frac{1}{4}u^2(\alpha_s)} = \frac{1}{\sqrt{2}} \cdot \frac{1.0 \times 10^{-6}}{\sqrt{3}} = 0.41 \times 10^{-6} \ /℃$$

$$v_{\overline{\alpha}} = \frac{u^4(\overline{\alpha})}{\dfrac{\left(\frac{1}{2}u(\alpha_x)\right)^4}{\frac{1}{2}\cdot\left(\frac{100}{R}\right)^2} + \dfrac{\left(\frac{1}{2}u(\alpha_s)\right)^4}{\frac{1}{2}\cdot\left(\frac{100}{R}\right)^2}} = 100$$

- **Temperature difference between the plain plug gauge and standard measuring machine** $u(\delta t)$

From experience the effects due to difference between the plain plug gauge and standard measuring machine are estimated to be within ± 0.3 ℃. The probability of temperature difference lying outside ± 0.3 ℃ is assumed to be 10 %. Therefore the degree of freedom is $v_{\delta t} = 1/2 \times (100/10)^2 = 50$. The standard uncertainty is:-

$$u(\delta t) = 0.3/\sqrt{3} = 0.17 \ ℃$$

- **Difference in the thermal expansion coefficients between the plain plug gauge and standard measuring machine** $u(\delta\alpha)$

The best estimate of the difference in thermal expansion coefficients is zero. Based on the manufacturer's data of the standard measuring machine and the steel plain plug gauge to be calibrated the thermal expansion coefficient is assumed to be within the interval (11.6 ± 1.0) x 10^{-6} /℃. The probability of the difference in thermal expansion coefficients lying outside ± 1.0 x 10^{-6} /℃ is assumed to be 10 %. Combining the two rectangular distributions is triangularly distributed $\delta\alpha = \alpha_x - \alpha_s$. Therefore the standard uncertainty of difference of the thermal expansion coefficients and the degree of freedom are:-

$$u(\delta\alpha) = \sqrt{u^2(\alpha_x) + u^2(\alpha_s)} = \sqrt{2} \cdot \frac{1.0 \times 10^{-6}}{\sqrt{3}} = 0.82 \times 10^{-6} \ /℃$$

$$v_{\delta\alpha} = \frac{u^4(\delta\alpha)}{\dfrac{u^4(\alpha_x)}{\frac{1}{2}\cdot\left(\frac{100}{R}\right)^2} + \dfrac{u^4(\alpha_s)}{\frac{1}{2}\cdot\left(\frac{100}{R}\right)^2}} = 100$$

▪ **Deviation of the average temperature of the plain plug gauge and standard measuring machine from the reference temperature** $u(\Delta t)$

The best estimate of the deviations of the average temperature from the reference temperature is zero. The deviation of the average temperature of measurement from the reference temperature t_0 = 20 ℃ is estimated to be within ± 0.5 ℃. A rectangular distribution is assumed giving a divisor of $\sqrt{3}$. The probability of the deviations of the average temperature lying outside ± 0.5 ℃ is assumed to be 10 %. Therefore the degree of freedom is $v_{\Delta t} = 1/2 \times (100/10)^2 = 50$. The standard uncertainty is:-

$$u(\Delta t) = 0.5/\sqrt{3} = 0.29 \text{ ℃}$$

▪ **Second-order terms**

In this example the second-order terms is neglected.

▪ **Combined standard uncertainty of** d_x

The degrees of freedom are also combined via the Welch-Satterthwaite formula to give an effective degrees of freedom 92. A normal distribution is assumed.

$$v_{eff} = \frac{u_c^{\ 4}(y)}{\sum \dfrac{u_i^{\ 4}(y)}{v_i}} = 92$$

The combined standard uncertainty of external diameter is calculated from the following equation:-

$$u(d_x) = \sqrt{\sum u_i^{\ 2}(y)} = 0.23 \text{ µm}$$

5. 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:-

$$U(d_x) = ku(d_x) = 2 \times 0.23 = 0.46 \fallingdotseq 0.5 \text{ µm}$$