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FIRST INTERLABORATORY COMPARISON ON CALIBRATION OF DIAMETER STANDARTS IN TURKEY

O. GANİOGLU[1] *and I. MERAL*[1]

[1]TUBITAK-UME National Metrology Institute, Dimensional Lab., Kocaeli, Turkey,
okhan.ganioglu@tubitak.gov.tr, ilker.meral@tubitak.gov.tr

Abstract – Having successfully completed two EURAMMET Key Comparisons (EUROMET Project No. 384 and Project 812) with very good results led us as TUBİTAK UME Dimensional Laboratory to organize the first interlaboratory comparison on calibration of diameter standards in Turkey as a pilot laboratory during 2012 and 2013. Interlaboratory comparisons are one of the best ways to disseminate SI units within the country, thus assuring the reliability and quality of calibrations and their results for accredited/non-accredited laboratories. The main purpose of the comparison is to demonstrate the differences between the capability of the laboratories and their uncertainty declarations on accreditation scopes.

12 accredited laboratories which provide routine calibration services to the industry, participated in the comparison. The standards to be calibrated were one ring gauge of diameter 40 mm, one plug gauges of diameters 50 mm, one sphere of diameter 25 mm and a pin gauge of diameter 2.5 mm. The measurand is the diameter of transfer standards in a given measurement direction at different heights, determined for each standard. All measuring instruments used by the participating laboratories are commercially available universal measurement devices.
Determination of the statistical consistency of the results with the uncertainties given by the participants can be assessed by the method of "E_n" value assessment for each laboratory. "E_n" values for all measurement results between pilot and each participated laboratory is calculated.

In this paper the comparison method and results are explained and "E_n" values of the participants are presented.

Keywords: Diameter Standards, interlaboratory comparison.

1. INTRODUCTION

Accredited calibration laboratories should obey the rules of ISO 17025 for their recognition by the customer and increase the quality of their calibration services [1]. National Accreditation System controls the accredited laboratories in Turkey and TURKAK is the responsible organization for the accreditation system.

The organization of the interlaboratory comparison is one of the important and best activities at European (EA, EURAMET) and national level (TUBITAK UME, TURKAK), in order to verify the measurement capabilities of the calibration laboratories.

First interlaboratory comparison on calibration of diameter standards was organized by TUBİTAK UME to provide and demonstrate technical proficiency and quality of calibration results of accredited laboratories as a requirement of ISO 17025 item 5.9. The chosen type of the comparison was the circulation type. The gauges were measured 3 times by the pilot laboratory, before the circulation, middle and after the circulation in order to check the stability of the gauges.

A total of 12 accredited calibration laboratories are participated in the comparison which was piloted by TUBİTAK UME Dimensional Laboratory.

One ring gauge of diameter 40 mm, one plug gauge of diameters 50 mm, one sphere of diameter 25 mm and a pin gauge of diameter 2.5 mm were supplied newly and circulated by UME. After the pilot laboratory finished its first measurements, circulation of the standards, and thus the comparison starts. All participants were requested to measure the diameter of transfer standards in a given measurement direction at different heights, determined for each standards in their own laboratories.

2. COMPARISON

A technical protocol for Comparison was prepared and sent to all participant laboratories before comparison was started [2]. It includes the specifications of the gauges, time table for the calibration, calibration reports, a set of forms to allow unified reporting of the measurement results and calibration procedure.

2.1. Standards

Four cylindrical standards were circulated. The gauges that used in the comparison are listed in the table 1 below.

Table 1. Comparison Gauges

Type	Manufacturer	Dimension (mm)	Material
Ring Gauge	Mahr	40	Steel
Plug Gauge	Mahr	50	Steel
Pin Gauge	Mahr	2.5	Steel
Sphere	Saphirwerk	25	Ceramic

40 mm Ring Gauge

50 mm Plug Gauge

2.5 mm Pin Gauge

25 mm Sphere

Fig. 1. Picture of the Comparison Gauges

In order to characterize the quality of the ring gauge, plug gauge and sphere, form deviations were measured by the pilot laboratory. The roundness of the ring and plug gauges were measured at the same heights (three different heights) as the diameter measurements and one roundness measurement for the sphere on the equator were performed. The straightness of the ring and plug gauges were measured on the marked lines (0º and 180º). The parallelism of the two gauges was also evaluated by using two straightness profiles. Table 2 is used to show the measured form deviations.

Table 2. Form Deviations of the Gauges

Type	Diameter (mm)	Roundness (µm)	Straigthness (µm)	Paralellism (µm)
Ring Gauge	40	0,22	0,19	0,18
Plug Gauge	50	0,19	0,12	0,22
Sphere	25	0,08	--	--

Both roundness and straightness deviations were evaluated as peak-to valley differences from the least-squares best fits (the LS references). The parallelism was defined as the maximum distance over the evaluation length between the LS reference lines fitted through two opposite generating lines.

2.2. Measurand

The measurand was the diameter of each gauge at 20 ºC and corrected to zero force. The calibration had to be carried out as for a normal customer calibration. It means that there was no information about the form error of the artifacts. The measurements had to be reported for zero measuring force and at the reference temperature of 20 °C, using a thermal expansion coefficient of $11{,}5\cdot10^{-6}$ 1/K for the ring , plug and pin gauge and $8{,}1\cdot10^{-6}$ 1/K for the ceramic ball. Both thermal expansion coefficients were taken from literature and thus they have not been measured.

The diameter of the ring, plug and pin gauges was to be measured at the marked lines in 3 different heights. The diameter of the sphere had to be measured at the marked lines in different two positions at the equator. "...mm↑" and " .... mm↓" refer to the required measurement locations "..... mm" above and below the mid-height of the cylinder. The measurement locations for the cylindrical gauges are shown in table 3.

Table 3. Measurement location of the Gauges

Type	Diameter (mm)	Measurement Locations
Ring Gauge	40	5 mm↑ Midle 5 mm↓
Plug Gauge	50	3 mm↑ Midle 3 mm↓
Pin Gauge	2.5	5 mm↑ Midle 5 mm↓
Sphere	25	Equator (0º-180º) Equator (90º-270º)

2.3. Stability of the gauges

The gauges were measured 3 times by the pilot laboratory, before the circulation, middle and after the circulation in order to check the stability of the gauges. The following graphs shows the measured diameters with the stated expanded uncertainties (k=2).

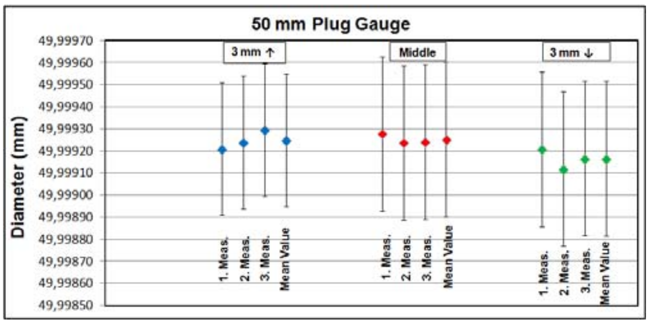

Fig. 2. Stability of 50 mm Plug Gauge

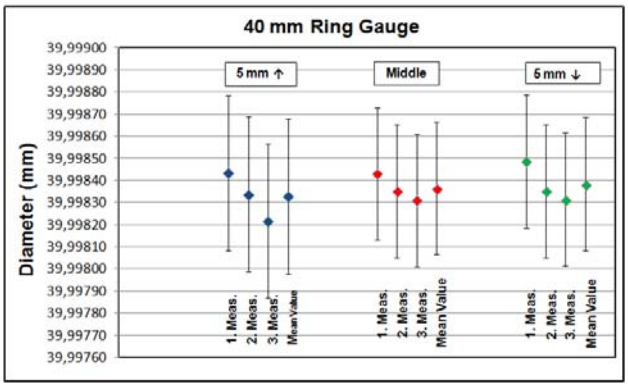

Fig. 3. Stability of 40 mm Ring Gauge

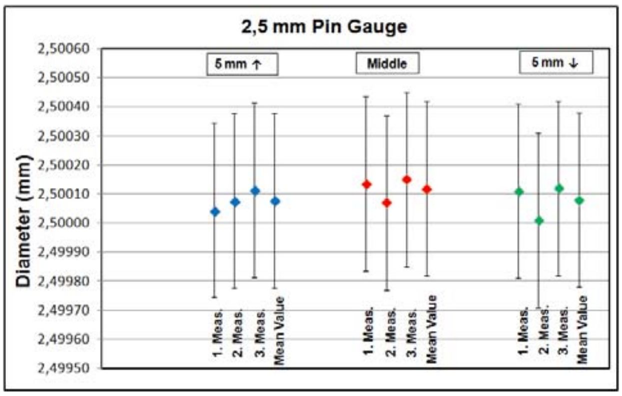

Fig. 4. Stability of 2.5 mm Pin Gauge

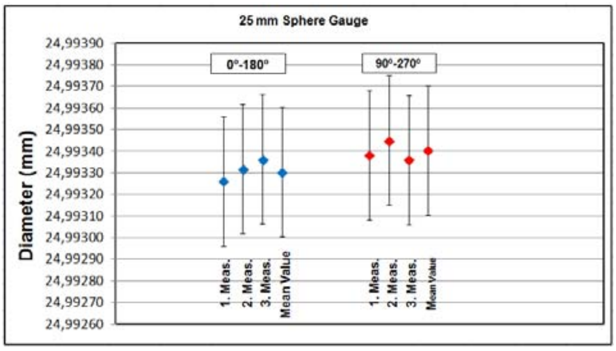

Fig. 5. Stability of 25 mm Sphere

No significant changes in diameter can be identified. The maximum deviation in diameter was found about 0.2 µm in the diameter value of 40 mm ring, but still it was insignificant variation. The comparison reference values obtained by the TUBITAK UME Dimensional Laboratory, mean value of the measured three results were taken as the "reference values". Pilot and the participated laboratories had to use the ISO Guide for the Expression of Uncertainty in Measurement for the estimation of uncertainty of measurement.

3. ANALYSIS OF THE RESULTS

The reference values were calculated by taking the mean value of the Pilot Laboratory's three measurements for each section (measurement location) of the standard. The deviation of each laboratory results from this value was evaluated in accordance with EN ISO/IEC 17043-2010: Conformity assessment – General requirements for proficiency testing [3]. Two parameters, (d) is the deviation from the reference value for a result of laboratory and E_n factor were calculated as given below in (1) and (2), respectively.

$$d = X_{LAB} - X_{UME} \tag{1}$$

$$E_n = \frac{X_{LAB} - X_{UME}}{\sqrt{U_{LAB}^2 + U_{UME}^2}} \tag{2}$$

Where,

X_{UME} is the measured value by UME

U_{UME} is the expanded uncertainty of UME

X_{LAB} is the measured value by each participant lab.

U_{LAB} is the expanded uncertainty of participant lab.

The statistical consistency of the results with the uncertainties given by the participants can be assessed by the "E_n" value for each laboratory. The calculated results with $E_n \leq 1$ are accepted as satisfactory while the ones with $E_n > 1$ are accepted as unsatisfactory for a coverage factor of k=2. This way of assessment was applied to every value of diameters.

4. COMPARISON RESULTS

Commercially available 1D Length Measuring Machines used by the participating laboratories.

Table 4,5,6 and 7 gives all the measurement results reported by the participating laboratories and pilot laboratories for the diameter of four gauges, together with their expanded measurement uncertainties. Fig.5 - 15 show these results graphically with error bars corresponding to the expanded uncertainties. Red line represents the reference value [4].

Table 4. Results of 50 mm Plug Gauge

Laboratories	50 mm Plug Gauge (mm)			
	3 mm↑	Middle	3 mm↓	U (k=2)
UME	49.99925	49.99925	49.99917	0.00030
LAB 01	49.9990	49.9992	49.9991	0.00097
LAB 02	49.99817	49.99890	49.99889	0.00125
LAB 03	49.99864	49.99891	49.99884	0.00085
LAB 04	49.9995	49.9998	49.9998	0.00072
LAB 05	49.99945	49.99952	49.99955	0.00100
LAB 06	49.9991	49.9993	49.9992	0.00100
LAB 07	49.99836	49.99845	49.99807	0.00181
LAB 08	50.00007	49.99986	49.99915	0.00093
LAB 09	49.99984	49.99987	49.99977	0.00203
LAB 10	49.99942	49.99959	49.99951	0.00064
LAB 11	49.99945	49.99965	49.99968	0.00105
LAB 12	49.99926	49.99909	49.99893	0.00159

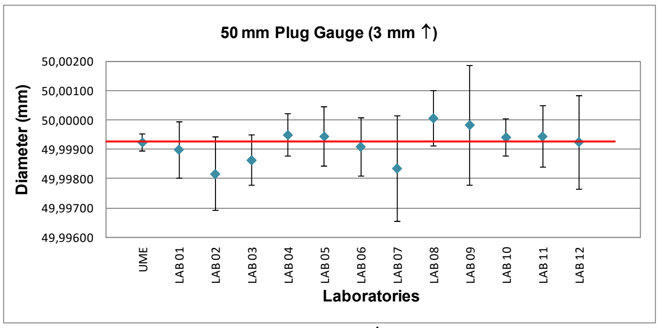

Fig. 5. Upper Results (3 mm↑) of 50 mm Plug Gauge

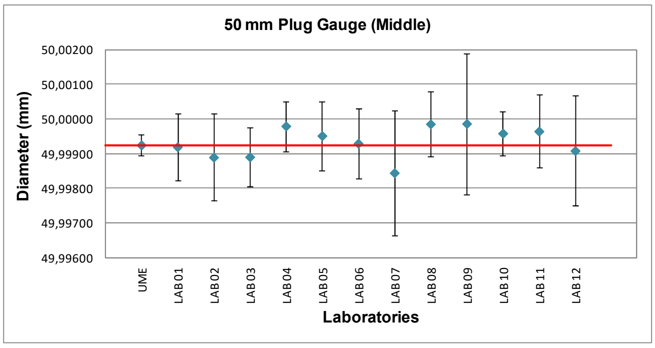

Fig. 6. Middle Results of 50 mm Plug Gauge

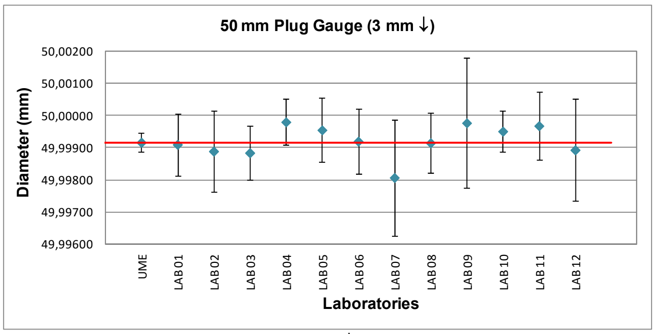

Fig. 7. Lover Results (3 mm↓) of 50 mm Plug Gauge

Table 5. Results of 40 mm Ring Gauge

Laboratories	40 mm Ring Gauge (mm)			
	5 mm↑	**Middle**	**5 mm↓**	**U (k=2)**
UME	39.99833	39.99836	39.99838	0.00035
LAB 01	39.9990	39.9992	39.9990	0.00121
LAB 02	39.99771	39.99815	39.99884	0.00117
LAB 03	39.99977	39.99982	39.99979	0.00075
LAB 04	39.9980	39.9980	39.9980	0.00063
LAB 05	39.99849	39.99864	39.99879	0.00094
LAB 06	39.9991	39.9990	39.9992	0.00130
LAB 07	39.99868	39.99877	39.99876	0.00180
LAB 08	39.99842	39.99861	39.99859	0.00078
LAB 09	39.99642	39.99662	39.99654	0.00204
LAB 10	39.99838	39.99850	39.99848	0.00072
LAB 11	39.99854	39.99814	39.99848	0.00125
LAB 12	39.99847	39.99850	39.99860	0.00174

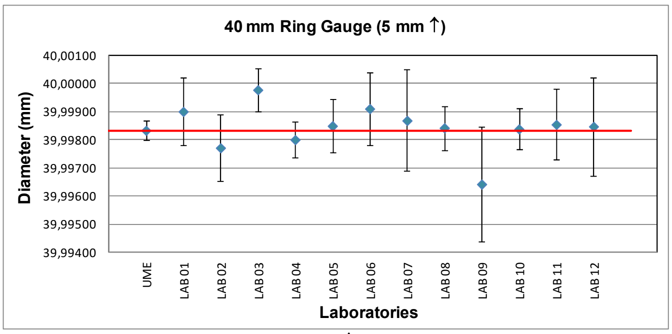

Fig. 8. Upper Results (5 mm↑) of 40 mm Ring Gauge

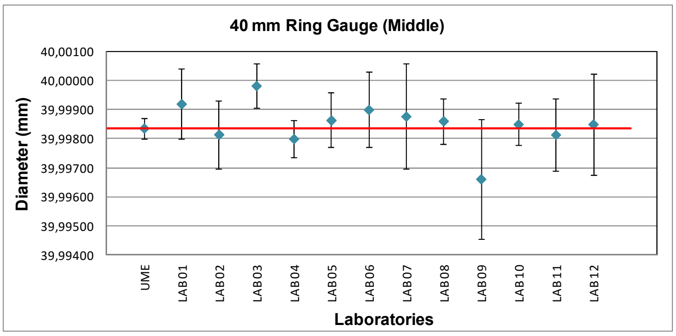

Fig. 9. Middle Results of 40 mm Ring Gauge

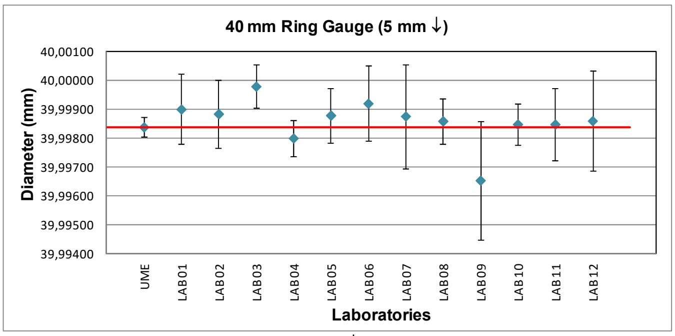

Fig. 10. Lover Results (5 mm↓) of 40 mm Ring Gauge

Table 6. Results of 2.5 mm Pin Gauge

Laboratories	2.5 mm Pin Gauge (mm)			
	5 mm↑	**Middle**	**5 mm↓**	**U (k=2)**
UME	2.50008	2.50012	2.50008	0.00030
LAB 01	2.4995	2.4993	2.4993	0.00080
LAB 02	2.49958	2.49954	2.49961	0.00101
LAB 03	--	--	--	--
LAB 04	2.5001	2.5001	2.5001	0.00072
LAB 05	2.50005	2.50001	2.50002	0.00060
LAB 06	2.4999	2.4999	2.4993	0.00080
LAB 07	2.49867	2.49873	2.49864	0.00056
LAB 08	2.50045	2.50044	2.50039	0.00070
LAB 09	2.49993	2.49995	2.49998	0.00180
LAB 10	2.50043	2.50040	2.50039	0.00053
LAB 11	2.50006	2.50003	2.50005	0.00082
LAB 12	2.50037	2.50044	2.50058	0.00150

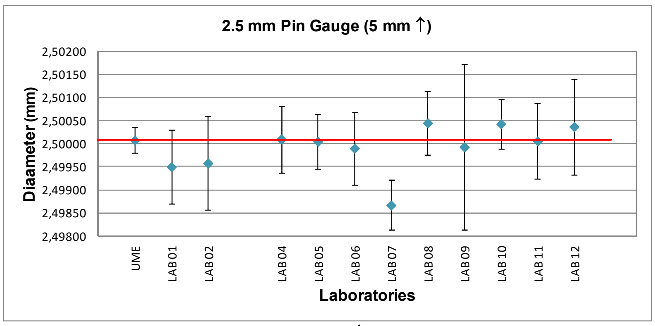

Fig. 11. Upper Results (5 mm↑) of 2.5 mm Pin Gauge

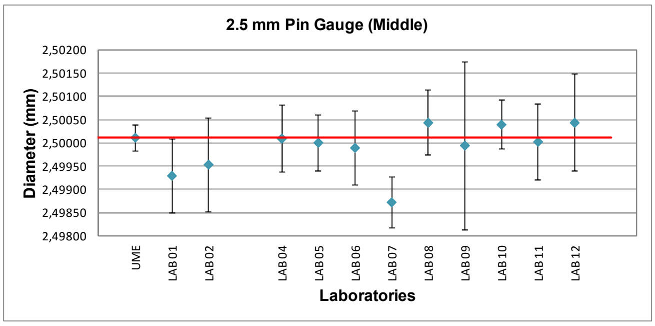

Fig. 12. Middle Results of 2.5 mm Pin Gauge

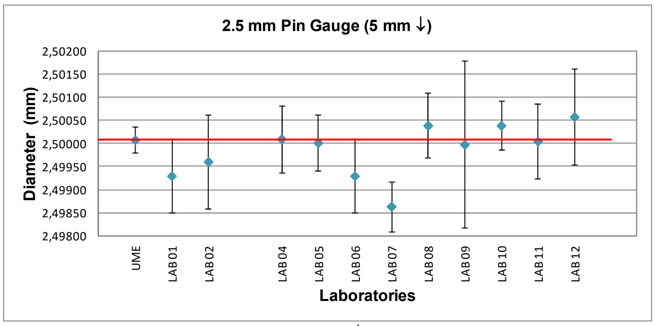

Fig. 13. Lover Results (5 mm↓) of 2.5 mm Pin Gauge

Table 7. Results of 2.5 mm Pin Gauge

Laboratories	25 mm Sphere (mm)		
	0º-180º	90º-270º	U (k=2)
UME	24.99331	24.99340	0.00030
LAB 01	24.9900	24.9902	0.00083
LAB 02	24.99227	24.99173	0.00112
LAB 03	--	--	--
LAB 04	24.9930	24.9930	0.00048
LAB 05	24.99231	24.99228	0.00072
LAB 06	24.9923	24.9923	0.00090
LAB 07	24.98651	2.,98648	0.00059
LAB 08	--	--	--
LAB 09	24.99485	24.99499	0.00224
LAB 10	24.99340	24.99352	0.00056
LAB 11	--	--	--
LAB 12	24.99255	24.99238	0.00120

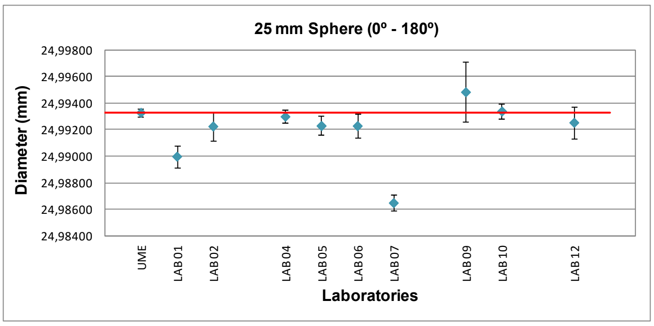

Fig. 14. Results (0º-180º) of 25 mm Sphere

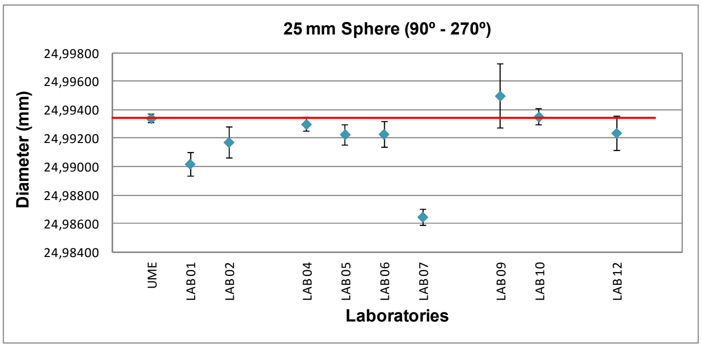

Fig. 15. Results (90º-270º) of 25 mm Sphere

Calibration results of the participating laboratories were compared with the pilot laboratory and E_n number for each participant and for each value was calculated. The E_n calculations are performed with the expanded uncertainties (k=2). E_n values are given in the tables Table 8-11.

Table 8. E_n Values Between Participants and Pilot for 50 mm Plug Gauge

Laboratories	50 mm Plug Gauge (mm)		
	3 mm↑	Middle	3 mm↓
LAB 01	-0.25	-0.05	-0.06
LAB 02	-0.84	-0.27	-0.21
LAB 03	-0.67	-0.38	-0.36
LAB 04	0.32	0.70	0.81
LAB 05	0.19	0.26	0.37
LAB 06	-0.14	0.05	0.03
LAB 07	-0.48	-0.44	-0.60
LAB 08	0.84	0.62	-0.02
LAB 09	0.29	0.30	0.29
LAB 10	0.24	0.48	0.49
LAB 11	0.18	0.36	0.47
LAB 12	0.01	-0.10	-0.14

Table 9. E_n Values Between Participants and Pilot for 40 mm Ring Gauge

Laboratories	40 mm Ring Gauge (mm)		
	5 mm↑	Middle	5 mm↓
LAB 01	0.53	0.66	0.49
LAB 02	-0.51	-0.17	0.37
LAB 03	1.74	1.76	1.70
LAB 04	-0.46	-0.50	-0.53
LAB 05	0.16	0.28	0.40
LAB 06	0.57	0.47	0.61
LAB 07	0.19	0.22	0.20
LAB 08	0.11	0.29	0.24
LAB 09	-0.92	-0.84	-0.89
LAB 10	0.06	0.17	0.12
LAB 11	0.16	-0.17	0.07
LAB 12	0.08	0.08	0.12

Table 10. E_n Values Between Participants and Pilot for 2.5 mm Pin Gauge

Laboratories	2.5 mm Pin Gauge (mm)		
	5 mm↑	Middle	5 mm↓
LAB 01	-0.68	-0.96	-0.91
LAB 02	-0.47	-0.55	-0.45
LAB 03	--	--	--
LAB 04	0.03	-0.02	0.03
LAB 05	-0.04	-0.16	-0.09
LAB 06	-0.21	-0.26	-0.91
LAB 07	-2.28	-2.25	-2.33
LAB 08	0.49	0.42	0.41
LAB 09	-0.08	-0.09	-0.05
LAB 10	0.58	0.46	0.51
LAB 11	-0.02	-0.10	-0.03
LAB 12	0.28	0.28	0.48

Table 11. E_n Values Between Participants and Pilot for 25 mm Sphere

	25 mm Sphere (mm)	
	0°-180°	90°-270°
LAB 01	-3.74	-3.62
LAB 02	-0.89	-1.44
LAB 03	--	--
LAB 04	-0.54	-0.72
LAB 05	-1.28	-1.44
LAB 06	-1.06	-1.16
LAB 07	-10.27	-10.46
LAB 08	--	--
LAB 09	0.68	0.70
LAB 10	0.15	0.18
LAB 11	--	--
LAB 12	-0.61	-0.83

5. COCNLUSION

A total of 12 accredited laboratories joined the comparison. All of them have the accreditation scope on calibration of plug and ring gauges but they haven't got any accreditation scope on sphere and pin gauges. Newly purchased gauges were used in the comparison. The pilot laboratory measured the gauges three times (with form parameters) to monitor the stability of the gauges during the measurements and transport. The results show good stability for every gauge so that it was decided all of them were suitable to accept as an artifact of this comparison.

The cylindrical gauges suffered small visible scratches but they did not affect the diameter measurements. No scratches on the sphere.

All participants were measured and reported the results of the plug and ring gauges, one laboratory did not measure the pin gauges (LAB 03) and three laboratory did not measure the sphere (LAB 03,LAB 08 and LAB 11).

Generally, all the participating laboratories demonstrated the compatible diameter measurements with the reference laboratory. However, six laboratories having unsatisfactory measurement results, probably due to the alignment error, wrong fixturing and operator mistakes. The results show interesting situation because the results of all laboratories is consistent at the plug measurements, but results of one laboratory for pin and ring measurements, also five laboratories for sphere measurements is inconsistent. Therefore the comparison can be considered as successful with the consistencies and inconsistencies all together with their reasonable assessment .

This interlaboratory comparison was also a very good practice for accredited laboratories to compare and correct themselves for some errors.

Acknowledgements. The pilot laboratory would like to thank all the participating laboratories for the measurements they contributed, Gökçen Bozkurt and Emre Sonoluk from the TUBİTAK-UME for performing part of the measurements of the pilot laboratory.

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