NSC “Institute of Metrology”

COOMET Supplementary bilateral comparison

COOMET.L- S22

COOMET No. 765/UA/18

The bilateral comparison of length standards for measuring end measures in the range up from 0.5 mm to 100 mm

FINAL REPORT

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Contents

1. Description of the project

This supplementary comparison is a bilateral one. The purpose of the comparison is to determine the equivalence of the measurement standards being compared.

The participants of this comparison should have the possibility to measure the end measures of length from steel (gauge blocks) with a nominal size of 1.28 mm; 70 mm; 100 mm by the mechanical method. Whatever measuring instruments are used by the participants of comparisons, they should be traceable to the definition of the SI unit for the meter.

The CMC number by KCDB classifier, for support of which this project is aimed: L.2.2.1.

2. Participants of the comparison

2.1 The list of participants is drawn up by COOMET Technical Committee 1.5 "Length and angle" and is presented in Table 1.

2.1.1 Having declared the intention to participate in this comparison, the participants of the comparison agree with the general instructions and technical requirements specified in the Technical Protocol, and to strictly observe them.

Table 1. Participants of the comparisons

No.	COUNTRY	CONTACT PERSON / ADDRESS
1	Ukraine NSC "Institute of Metrology" – laboratory-coordinator	Kostrikov Alexander Leonidovich Laboratory of geometric measurements NSC "Institute of Metrology", St. Mironositskaya, 42, Kharkov, 61002, Ukraine, tel. +38 (057) 700-34-09 fax +38 (057) 700-34-47 alex_kost@ukr.net
2	Georgia YuLOP "Georgian National Agency for Standards and Metrology" (GEOSTM) Institute of Metrology	Sikharulidze Vazha Mikhailovich Department of geometric measurements Institute of Metrology GEOSTM, St. Chargalskaya 67, Tbilisi, 0178, Georgia tel.: (99532) 261 25 30 fax: (99532) 261 35 00 vazhasikharulidze@yahoo.com

3. Schedule of the comparison

Measurement of transfer standards is carried out by:

From December 3 to December 17, 2018 – NSC "Institute of Metrology;

from December 20 to December 21, 2018 – YuLOP "Georgian National Agency for Standards and Metrology" (GEOSTM) Institute of Metrology.

4. The transfer standards

4.1 As transfer standards, flat-parallel end measures of length (measure) were used with a nominal size of 1.28 mm; 70 mm; 100 mm shown in Fig. 1, 2, 3. The measures are made of steel (unknown manufacturer), the temperature coefficient of linear expansion was previously measured by NPL to be $(11.31\times10^{-6} \pm 0.1\times10^{-6})$ K^{-1}.

The measures are packaged in an original box with the gross weight 0.663 kg.

The transfer measures are provided by Ukraine, NSC "Institute of Metrology".

Fig.1 Transfer standard end measure 1.28 mm

Fig.2 Transfer standard end measure 70 mm

Fig.3 Transfer standard end measure 100 mm

5 Transportation of the transfer standards

The transfer standards shall be preserved, packaged in a box and delivered to YuLOP “Georgian National Agency for Standards and Metrology” (GEOSTM), Institute of Metrology, by an employee of NSC “Institute of Metrology”.

After delivery of the transfer measures, the employees of YuLOP “Georgian National Agency for Standards and Metrology” (GEOSTM) Institute of Metrology and NSC “Institute of Metrology” shall jointly examine them for any defects on the measuring surfaces.

6 Financial aspects

The costs for a business trip for an employee of NSC “Institute of Metrology” to YULOP YuLOP “Georgian National Agency for Standards and Metrology” (GEOSTM) Institute of Metrology shall undertake the British Standardization Institute (BSI) under the Contract 2/3953-18.

7 Measurement procedure

The central length of the transfer standard shall be measured. The central length of the transfer standard is the length from the center point of the measuring surface of the transfer standard to its opposite measuring surface. Determination of the central length is carried out in accordance with the requirements of the International Standard DSTU ISO 3650:2009 [1].

8 Measurement conditions

The applied measuring instruments should have traceability to the measurement standard of length – meter.

Ukraine's reference gauge is calibrated using a set of flat-parallel measures of length No. 074, which was calibrated with a secondary reference standard of a unit of length WETU 01-03-05-98, calibrated using the State Primary Reference unit of length DETU 01-03-98.

Georgian's reference gauge is calibration was carried out using a set of terminal measures of length No. 88808, which were calibrated using Koesters interferometers No. 21252, No. 21246, No. 21247 that are part of the Belarusian National Standard of the unit of length of meter No. NE RB 31-18.

Before measurement, the transfer standards were cleaned of contamination. The working surfaces of the transfer standards were washed with alcohol and wiped with a clean cotton tissue.

Before measurements, the transfer standards were kept on the instrument table for at least 3 hours.

Temperature measurements were carried out using the 1990 International Temperature Scale (ITS-90).

Each laboratory measured the transfer standards at a temperature of (20.0 ± 1.0) °C. The permissible temperature deviation during the measurement not exceeded 0.5 °C per hour.

Relative air humidity was within (58 ± 20) %.

Before measurement, the transfer standards were examined for any damages on the measuring surfaces.

The laboratory was indicating in the protocol the temperature at which the measurement of the central length of the transfer standards was taken.

When installing the transfer standards into the device, cotton gloves was used.

9 Methods for assessing and drawing up measurement results

The measurement results shall be drawn up in the form of protocol, where the following is indicated:

- General information about the reference installation being compared;
- Conditions under which measurements were carried out;
- Experimental data obtained from measurements;

The measurement result is recorded as follows:

$$L = l_{rm} + \Delta l, \text{ where}$$

L – measurement result for the transfer standard of each laboratory;

l_{rm} – nominal value of the reference standard of each laboratory;

Δl – correction to the measurement result;

The participants shall submit a description of their measurement procedure.

The participants shall submit an uncertainty budget of the measurement result with a list of the main uncertainty components.

ISO/IEC Guide 98-3:2008 – Measurement Uncertainty – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995) [2] was used in the calculation of measurement uncertainty.

To achieve optimal comparability, a mathematical model including the main parameters of influence when calibrating end measures of length is indicated below:

$$L = l_{rm} + d + l_{nom}(\bar{\alpha} \cdot \Delta t + \Delta\alpha \cdot \delta t) \text{ where,}$$

L – length of the transfer standard;

l_{rm} – length of the reference standard of each laboratory;

l_{nom} – nominal length of the reference standard;

d – measured difference between the length of the reference standard and the transfer standard;

$\bar{\alpha} = \frac{a_{rm} + a_{ts}}{2}$ – the arithmetic average of the temperature coefficient of linear expansion of the reference standard and the transfer standard;

$\Delta\alpha = \alpha_{rm} - \alpha_{ts}$ – the difference between the temperature coefficients of the linear expansion of the reference standard and the transfer standard;

$\Delta t = t_{rm} - t_{ts}$ – the difference between the temperatures of the reference standard and the transfer standard;

$\delta t = \left(20 - \frac{t_{rm} + t_{ts}}{2}\right)°C$ – deviation from 20 °C of the average temperature of the reference standard and the transfer standard.

The results of measurements of the transfer standards are given in Table 2, 3, 4 and in Fig. 4.

The measurement protocol and the uncertainty budget of the participants are given in Annex 1 and Annex 2.

Table 2 The measurement results of deviations of the transfer standard 1.28 mm

No.	Organization	
Measurement	**NSC "Institute of Metrology"**	**GEOSTM**
	µm	**µm**
1	-0.11	-0.09
2	-0.10	-0.09
3	-0.10	-0.10
4	-0.12	-0.11
5	-0.10	-0.12
6	-0.11	-0.11
7	-0.11	-0.10
8	-0.10	-0.09
9	-0.12	-0.09
10	-0.11	-0.10
Aver.	**-0.11**	**-0.10**

Table 3 The measurement results of deviations of the transfer standard 70 mm

No.	Organisation	
Measurements	**NSC "Institute of Metrology"**	**GEOSTM**
	µm	**µm**
1	0.04	0.00
2	0.03	0.01
3	0.04	0.02
4	0.03	0.01
5	0.04	0.00
6	0.04	0.01
7	0.04	0.02
8	0.05	0.01
9	0.04	0.02
10	0.03	0.01
Aver.	**0.04**	**0.01**

Table 4 The measurement results of deviations of the transfer standard 100 mm

No. Measurements	Organisation	
	NSC “Institute of Metrology”	GEOSTM
	µm	µm
1	0.20	0.25
2	0.19	0.24
3	0.20	0.25
4	0.20	0.26
5	0.21	0.25
6	0.20	0.25
7	0.22	0.24
8	0.19	0.23
9	0.20	0.24
10	0.20	0.25
Aver.	**0.20**	**0.25**

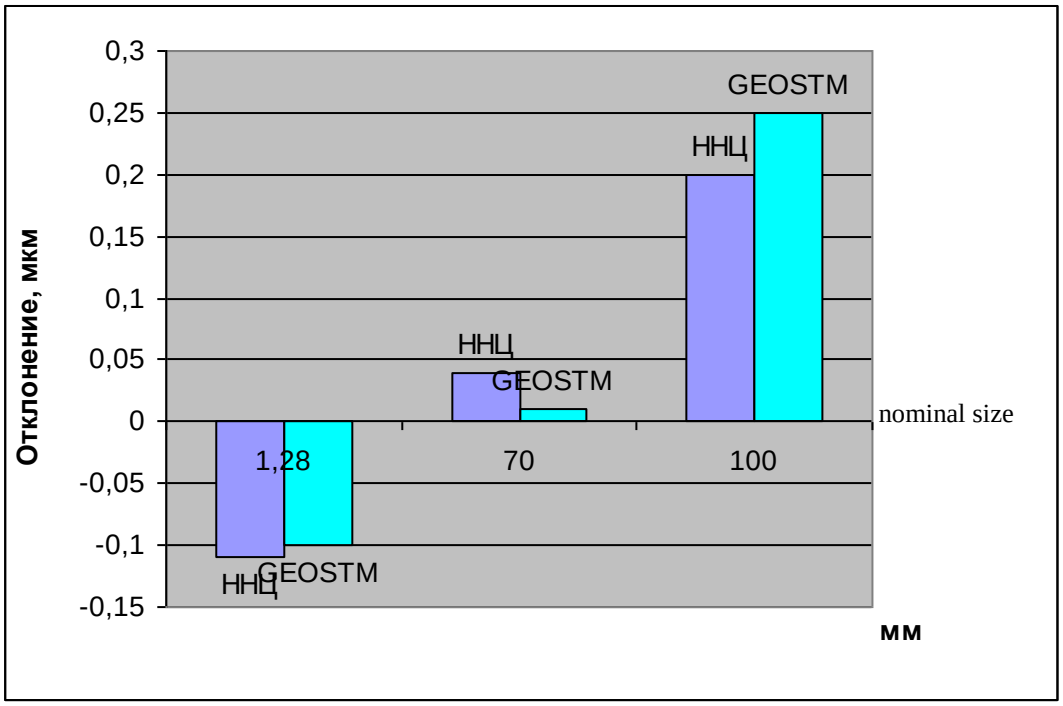

Fig.4. Measurement results of deviations of the median length of the comparison measures.

The measurement results of the median length of the transfer standards, taking into account the arithmetic average of 10 measurements of their deviations, are given in Table 5.

Table 5 The median length of the transfer standards

Nominal length of the transfer standards, mm	Median length of the transfer standards, mm	
	NSC “Institute of Metrology”	GEOSTM
1.28	1.27989	1.27990
70	70.00004	70.00001
100	100.00020	100.00025

10 Results of the comparison

10.1 Calculation of expanded uncertainty.

To assess the degree of equivalence of the measuring instruments being compared, it is necessary to have the values of the expanded uncertainty. The quantity of the expanded uncertainty was calculated in accordance with [2] and is given in Table 6 for the participants of comparison, taking into account their uncertainty budget.

Table 6 The expanded measurement uncertainty

Nominal length of the transfer standards, mm	The expanded uncertainty, nm	
	NSC “Institute of Metrology”	GEOSTM
1.28	49.1	46.6
70	86.8	80.0
100	104.3	103.8

10.2 Determination of the degree of equivalence

In accordance with [3], for bilateral comparisons it is sufficient to establish a pairwise degree of equivalence, i.e. the difference in results between measurements and the corresponding expanded uncertainty with a coverage factor of 2 and a confidence level of 0.95.

In determining the discrepancies between the measurement results, the arithmetic average of the correction to the nominal size of the transfer standards is taken as a result. The results of the calculations are presented in Table 7.

Table 7 The discrepancies between the measurement results

Nominal length of the transfer standards, mm	The arithmetic average of the deviations, nm		Discrepancies d, nm
	NSC "Institute of Metrology"	GEOSTM	
1.28	-110	-100	10
70	40	10	30
100	200	250	50

The expanded uncertainty $U(d)$ associated with the discrepancies between the measurement results - assumed as being uncorrelated - is determined as follows:

$$U(d) = 2u_c(d), \text{ where}$$

For 1.28 mm:

$$u_c(d) = \sqrt{{u_{c_{\text{st NSC}}}}^2 + {Uu_{c_{\text{st GEOSTM}}}}^2} = \sqrt{24.56^2 + 23.30^2} = 33.85 \text{ nm}$$

$U(d) = 2u_c(d) = 67.71$ nm.

For 70 mm:

$$u_c(d) = \sqrt{{u_{c_{\text{st NSC}}}}^2 + {u_{c_{\text{st GEOSTM}}}}^2} = \sqrt{43.42^2 + 40^2} = 59 \text{ nm}$$

$U(d) = 2u_c(d) = 118$ nm

For 100 mm:

$$u_c(d) = \sqrt{{u_{c_{\text{st NSC}}}}^2 + {u_{c_{\text{st GEOSTM}}}}^2} = \sqrt{52.15^2 + 51.9^2} = 73.57 \text{ nm}$$

$U(d_{sq}) = 2u_c(d_{sq}) = 147.14$ nm

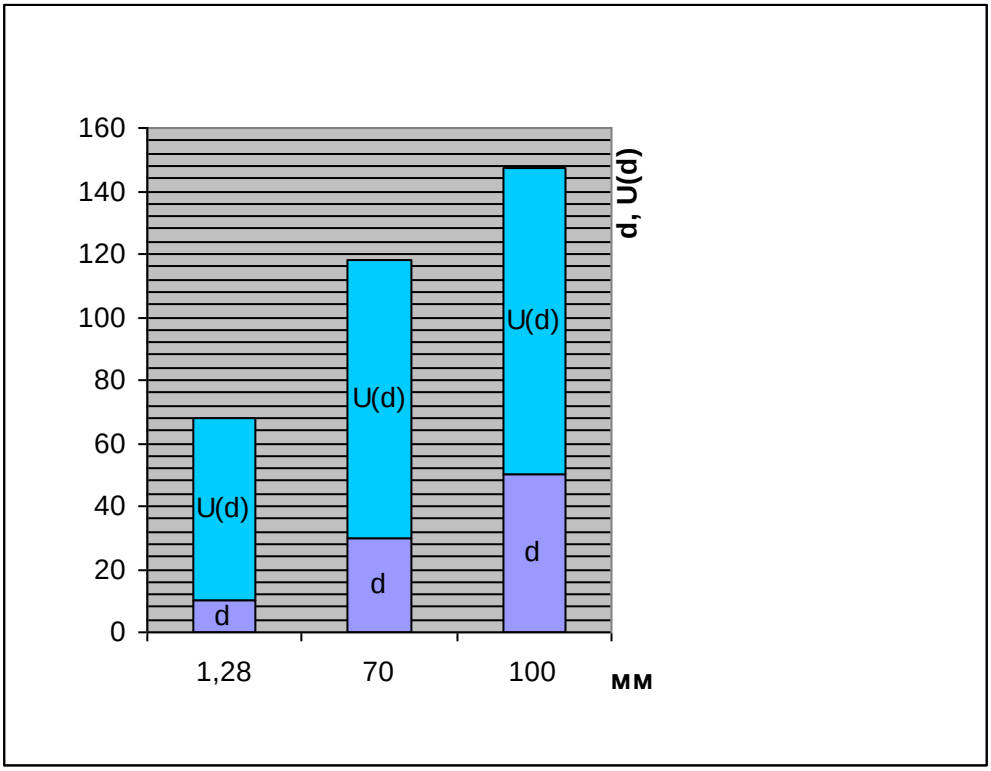

Fig.5 Degree of equivalence of comparison measurement standards

Conclusion:

From the above calculations [10<67.71; 30<118; 50<147] and Fig. 5, it can be seen that discrepancies between the measurement results of deviations are significantly less than the expanded uncertainty, which confirms a good degree of equivalence of the measuring installations of NSC “Institute of Metrology” of Ukraine and YuLOP “Georgian National Agency for Standards and Metrology” (GEOSTM) Institute of Metrology.

Annex 1

NSC «Institute of Metrology»

Protocol of calibration of transfer standards
according to the Technical Protocol
of bilateral comparisons **COOMET Project No. 765/UA/18**
Comparisons of standards of length for measuring end measures
in the range from 0.5 mm to 100 mm

December 2018

1. General information

When performing bilateral comparisons were used measures and comparator, given in Table 1.

Table 1 General information

<table>
<tr><td>Name</td><td colspan="2">Technical and metrological characteristics</td><td colspan="2" rowspan="4">Ser. № KTs-1</td></tr>
<tr><td rowspan="4">Set of end measures of length</td><td colspan="2">Material – steel
Total amount – 91</td></tr>
<tr><td>Nominal values of end measures, mm</td><td>Amount</td></tr>
<tr><td>1.001 1.002 1.003 . . . . . 1.009
1.01 1.02 1.03 . . . . . 1.49
0.5 1 1.5 1.6 1.7 1.8 1.9
2 2.5 3 3.5 . . . . . 9.5
10 20 30 40 50 60
70 80 90 100</td><td>9
49
7
16
6
4</td></tr>
<tr><td colspan="2">Producer:
“Carl Zeiss”, Germany</td></tr>
<tr><td rowspan="2">Comparator of end measures of length</td><td colspan="2">Measurement range, mm: (0.5÷170)
Measurement repeatability, µm : ± 0.01</td><td rowspan="2">Precimar 826 PC</td><td rowspan="2">1578/17
5350310</td></tr>
<tr><td colspan="2">Producer:
“MAHR”, Germany</td></tr>
</table>

2 Measurement conditions of transfer standards

Measurements of transfer standards were carried out in a thermostated room. The following conditions were met during the measurement:

- ambient air temperature 20.5 °C;
- temperature measurement during measurements, not more than 0.5 °C/hour;
- relative humidity is 62 %.

3 Performing measurements

The median length of the transfer standards was measured.

For each transfer standard, 10-fold measurements were performed. The arithmetic average of 10 measurements was taken as the measurement result.

The measurement result was recorded as follows:

$$L = l_{rm} + \Delta l, \text{ where}$$

L – the result of measurements of transfer standard;

l_{rm} – nominal value of reference measure of the laboratory-participant;

Δl – correction for the result of measurements;

For each measurement of each transfer standard, the uncertainty budget of the measurement results was calculated, indicating the main influencing quantities.

4 The results of measurements of deviations of the transfer standard for 1.28 mm and the reference measure of the laboratory of the NSC "Institute of Metrology" are given in Table 2

Table 2

No. of measurement	Measured values of length deviations of transfer standard and reference measure, μm	ΔX_i, μm	ΔX_i^2, μm	U_A
1	-0.11	0	0	3.74 nm
2	-0.10	0.01	0.0001	
3	-0.10	0.01	0.0001	
4	-0.12	0.02	0.0004	
5	-0.10	0	0	
6	-0,11	0.01	0.0001	
7	-0.11	0.01	0.0001	
8	-0.10	0	0	
9	-0.12	0.02	0.0004	
10	-0.11	0.01	0.0001	
Average	-0.11		$\sum \Delta X_i^2 = 0.0013$	

5 The results of measurements of deviations of the transfer standard for 70 mm and the reference measure of the laboratory of the NSC "Institute of Metrology" are given in table 3

Table 3

No. of measurement	Measured values of length deviations of transfer standard and reference measure, μm	ΔX_i, μm	ΔX_i^2, μm	U_A
1	0.04	0	0	
2	0.03	0.01	0.0001	
3	0.04	0	0	
4	0.03	0.01	0.0001	
5	0.04	0	0	
6	0.04	0	0	

7	0.04	0	0	2.0 nm
8	0.05	0.01	0.0001	
9	0.04	0	0	
10	0.03	0.01	0.0001	
Average	0.04		$\sum \Delta X_i^2 = 0.0004$	

6 The results of measurements of deviations of the transfer standard for 100 mm and the reference measure of the laboratory of the NSC "Institute of Metrology" are given in Table 4.

Table 4

No. of measurement	Measured values of length deviations of transfer standard and reference measure, μm	ΔX_i, μm	ΔX_i^2, μm	U_A
1	0.20	0	0	2.8 nm
2	0.19	0.01	0.0001	
3	0.20	0	0	
4	0.20	0		
5	0.21	0.01	0.001	
6	0.20	0	0	
7	0.22	0.02	0.004	
8	0.19	0.01	0.0001	
9	0.20	0	0	
10	0.20	0	0.0001	
Average	0.20		$\sum \Delta X_i^2 = 0.0007$	

7. Budget of uncertainty of the results of measurements of end measure of length for 1.28 mm (NSC "Institute of Metrology") is given in Table 5

Table 5 Uncertainty budget for the transfer standard 1.28 mm

Value X_i	Estimation x_i	Standard uncertainty $u(x_i)$	Distribution	Sensitivity coefficient c_i	Contribution to measurement uncertainty $u_i(y)$
l_S	1.280 000 mm	15.0 nm	Normal	1.0	15.0 nm
δl_D	0 mm	10 nm	Triangular	1.0	10 nm
δl	0.000 01 mm	3.74 nm	Normal	1.0	3.74 nm
δl_C	0 mm	15.0 nm	Rectangular	1.0	15.0 nm
δt	0 ^{0}C	0.0289 ^{0}C	Rectangular	-14.85 nm (^{0} C)$^{-1}$	0.5 nm
$\delta\alpha \cdot \Delta\bar{t}$	0	0.236×10^{-6}	Special	1.28 mm	0.7 nm
δl_V	0 mm	3.8 nm	Rectangular	-1.0	3.8 nm

$$U_{\text{p } 1.28} = 49.11 \text{ nm}$$

In the table the quantities X_i have the following values:

l_S – uncertainty of measurement of length standards (from the protocol of calibration);

δl_D – uncertainty related to the size of drift of length standard;

δl – The uncertainty caused by random variables in measuring deviations between transfer standards and the length standard of the laboratory-participant (Type A uncertainty (U_A));

δl_C – uncertainty associated with the used comparator;

δt – uncertainty associated with temperature quantities;

$\delta\alpha \cdot \Delta\bar{t}$ – uncertainty associated with temperature coefficient of linear expansion;

δl_V – uncertainty associated with deviation from the measurement center on the measure.

8. Budget of uncertainty of the results of measurements of end measure of length for 70 mm (NSC "Institute of Metrology") is given in Table 6

Table 6 Uncertainty budget for the transfer standard 70 mm

Value X_i	Estimation x_i	Standard uncertainty $u(x_i)$	Distribution	Sensitivity coefficient c_i	Contribution to measurement uncertainty $u_i(y)$
l_S	70.00004 mm	16.1 nm	Normal	1.0	16,1 nm
δl_D	0 mm	17.5 nm	Triangular	1.0	17.5 nm
δl	0.000 04 mm	2.0 nm	Normal	1.0	2.0 nm
δl_C	0 mm	18.5 nm	Rectangular	1.0	18.5 nm
δt	0 ^{0}C	0.0289 ^{0}C	Rectangular	-812.35 nm (^{0} C)$^{-1}$	20.7 nm
$\delta\alpha \cdot \Delta\bar{t}$	0	0.391×10^{-6}	Special	70.00 mm	22.5 nm
δl_V	0 mm	3.8 nm	Rectangular	-1.0	3.8 nm

$$U_{\text{p } 70} = 86.84 \text{ nm}$$

9. Budget of uncertainty of the results of measurements of end measure of length for 100 mm (NSC "Institute of Metrology") is given in Table 7

Table 7 Uncertainty budget for the transfer standard 100 mm

Value X_i	Estimation x_i	Standard uncertainty $u(x_i)$	Distribution	Sensitivity coefficient c_i	Contribution to measurement uncertainty $u_i(y)$
l_S	100.00020 mm	18.2 nm	Normal	1.0	18.2 nm
δl_D	0 mm	19.5 nm	Triangular	1.0	19.5 nm
δl	0.000 20 mm	2.83 nm	Normal	1,0	2.83 nm
δl_C	0 mm	21.5 nm	Rectangular	1.0	21.5 nm
δt	0 ^{0}C	0.0289 ^{0}C	Rectangular	-1160.5 nm (^{0} C)$^{-1}$	32.7 nm
$\delta\alpha \cdot \Delta\overline{t}$	0	0.236×10^{-6}	Special	100 mm	23.6 nm
δl_V	0 mm	3.8 nm	Rectangular	-1.0	3.8 nm

$U_{p\,100} = 104.3$ nm

Director of SC-2 V.S. Kupko

Measurements performed by I.N. Zadorozhnaya

Annex 2

YuLOP “Georgian National Agency for Standards and Metrology” (GeoSTM)

Institute of Metrology

Technical Protocol of Calibration of Transfer Standards
according to the bilateral comparisons on COOMET Project
No. 765/UA/18

“Comparison of length standards for measuring end measures in the range from 0,5 mm to 100 mm”

Participants of comparisons:

1. NSC "Institute of metrology", Kharkov, Ukraine:
   Laboratory of geometrical measurements (Laboratory-coordinator);
2. YuLOP “Georgian National Agency for Standards and Metrology” (GeoSTM), Tbilisi, Georgia:
   Department of geometrical measurements (Laboratory-participant).

December – 2018

1. General information

1.1. Used in the comparisons reference measurement instruments of GeoSTM

Brief information on reference measuring instruments of GeoSTM are given in Table 1:

Table 1

<table>
<tr><th>Name</th><th colspan="2">Technical and metrological characteristics</th><th>Type</th><th>Serial. №</th></tr>
<tr><td rowspan="3">Set of end measures of length</td><td colspan="2">Material – steel
Total amount – 122</td><td rowspan="3">K</td><td rowspan="3">88808</td></tr>
<tr><td>Nominal values of end measures, mm</td><td>Amount</td></tr>
<tr><td>1.0005
1.001 1.002 1.003 . . . . . 1.009
1.01 1.02 1.03 . . . . . 1.49
0.5 1 1.5 1.6 1.7 1.8 1.9
2 2.5 3 25
30 40 50 60 70
75 80 90 100</td><td>1
9
49
7
47
5
4</td></tr>
<tr><td rowspan="2">Comparator of end measures of length</td><td colspan="2">Measurement range, mm: (0.5÷170)
Measurement repeatability, µm: ± 0.01</td><td rowspan="2">Precimar 826 PC</td><td rowspan="2">5350310</td></tr>
<tr><td colspan="2">Producer:
“MAHR”, Germany</td></tr>
</table>

1.2. Climate conditions in measurements of transfer standards

Measurements of transfer standards were carried out in a thermostated room, in which environmental conditions are maintained within the following limits, not more:

- air temperature – 20.5 °C;
- relative humidity of air – 62 %;
- one-hour change in temperature – not more than 0.5 °C.

1.3. Measurand and measurement requirements and requirements for processing and presenting the results

The average length of transfer standards was measured, and it was determined in accordance with the requirements of International Standard ISO 3650.

The length of each transfer standard was measured 10 times, and the arithmetic average of 10 measurements was taken as the measurement result.

Due to the fact that the comparator of end measures Precimar 826 PC provides the automatic correction of measurement results taking into account the temperature correction and the correction for the deviation of the reference measure from the nominal value, the experimentally obtained results for the differences of the length of the reference measure and the transfer standard were used directly and the measurement results were recorded in the following way:

$$L = l_{эм} + \Delta l, \text{ where}$$

L – measurement results of transfer standard;

l_{rm} – nominal value of reference measure of the laboratory-participant;

Δl – correction for the result of measurements.

For each measured transfer standard, uncertainty budgets for measurement results were drawn up with a list of the main components of uncertainties in accordance with ISO/IEC Guide 98-3:2008 “Uncertainty of measurements – Part 3. Guide on expression of uncertainty in measurements (GUM:1995)”. At the same time, the specified expanded measurement uncertainty was obtained by multiplying the total standard uncertainty by the coverage factor k = 2, corresponding to a confidence level of approximately 95 % assuming a normal distribution of measurement results.

2. Experimental results of performed measurements and their metrological processing

Transfer standard – end measure of length for 1.28 mm.

Results of measurements of end measure of length for 1.28 mm are given in Table 2.

Table 2 Measurement results and type A uncertainty calculation

No. of measurement	Measured values of the difference between the lengths of the reference measure and the transfer standard, μm	The arithmetic average of the measurement results, μm	Standard uncertainty of measurements on type A, μm
1	-0.09	-0.100	0.0033
2	-0.09		
3	-0.10		
4	-0.11		
5	-0.12		
6	-0.11		
7	-0.10		
8	-0.09		
9	-0.09		
10	-0.10		

Budget of uncertainty of the results of measurements of end measure of length for 1,28 mm is given in Table 3.

Table 3 Uncertainty budget

Value X_i	Estimation x_i	Standard uncertainty $u(x_i)$	Distribution	Sensitivity coefficient c_i	Contribution to measurement uncertainty $u_i(y)$
l_S	1.280 000 mm	15.0 nm	Normal	1.0	15.0 nm
δl_D	0 mm	8.2 nm	Triangular	1,0	8.2 nm
δl	-0.000 100 mm	3.3 nm	Normal	1.0	3.3 nm
δl_C	0 mm	15.0 nm	Rectangular	1.0	15.0 nm
δt	0 ^{0}C	0.0289 ^{0}C	Rectangular	-14.85 nm (^{0} C)$^{-1}$	-0.4 nm
$\delta\alpha \cdot \Delta\bar{t}$	0	0.236×10^{-6}	Special	1.28 mm	-0.3 nm
δl_V	0 mm	3.8 nm	Rectangular	-1.0	3.8 nm
l_X	1.279 900 mm				23.3 nm
Expanded uncertainty of measurements $U_{0.95}$, $k=2$					46.6 nm

The final result of the measurement:

The measured median length of the transfer standard – the end measure of a nominal length for 1.28 mm was 1.279 900 mm ± 47 nm.

Transfer standard – end measure of length for 70.00 mm

The results of measurements of the end measure of length for 70 mm are given in Table 4.

Table 4 Measurement results and type A uncertainty calculation

№ of measurement	Measured values of the deviation of the mean length of a measure from its nominal value, μm	The arithmetic average of the measurement results, μm	Standard uncertainty of measurements on type A, μm
1	0	0.011	0.0023
2	0.01		
3	0.02		
4	0.01		
5	0		
6	0.01		
7	0.02		
8	0.01		
9	0.02		

10	0.01		

Budget of uncertainty of the results of measurements of end measure of length for 70 mm is given in Table 5.

Table 5 Uncertainty budget

Value X_i	Estimation x_i	Standard uncertainty $u(x_i)$	Distribution	Sensitivity coefficient c_i	Contribution to measurement uncertainty $u_i(y)$
l_S	69.999 830 mm	16.6 nm	Normal	1.0	16.6 nm
δl_D	0 mm	10.8 nm	Triangular	1.0	10.8 nm
δl	0.000 010 mm	2.3 nm	Normal	1.0	2.3 nm
δl_C	0 mm	19.0 nm	Rectangular	1.0	19.0 nm
δt	0 ^{0}C	0.0289 ^{0}C	Rectangular	-812.35 nm (^{0} C)$^{-1}$	-23.5 nm
$\delta\alpha \cdot \Delta\bar{t}$	0	0.236×10^{-6}	Special	70 mm	-23.6 nm
δl_V	0 mm	3.8 nm	Rectangular	-1.0	3.8 nm
l_X	70.000 010 mm				40.0 nm
Expanded uncertainty of measurements $U_{0.95}$, $k=2$					80.0 nm

Final result of measurements:

The measured median length of the transfer standard of the end measure of nominal length for 70 mm was 70,000 010 mm ± 80 nm.

Transfer standard – end measure of length for 100.00 mm

The results of measurements of the end measure of length for 100 mm are given in Table 6.

Table 6 Measurement results and type A uncertainty calculation

No. of measurement	Measured values of the deviation of the mean length of a measure from its nominal value, μm	The arithmetic average of the measurement results, μm	Standard uncertainty of measurements on type A, μm
1	0.25	0.246	0.0027
2	0.24		
3	0.25		
4	0.26		
5	0.25		
6	0.25		
7	0.24		
8	0.23		
9	0.24		
10	0.25		

Budget of uncertainty of the results of measurements of end measure of length for 100 mm is given in Table 5.

Table 7 Uncertainty budget

Value X_i	Estimation x_i	Standard uncertainty $u(x_i)$	Distribution	Sensitivity coefficient c_i	Contribution to measurement uncertainty $u_i(y)$
l_S	99.999 850 mm	18.0 nm	Normal	1.0	18.0 nm
δl_D	0 mm	13.1 nm	Triangular	1.0	13.1 nm
δl	0.000 250 mm	2.7 nm	Normal	1.0	2.7 nm
δl_C	0 mm	22.4 nm	Rectangular	1.0	22.4 nm
δt	0 ^{0}C	0.0289 ^{0}C	Rectangular	-1160.5 nm (^{0} C)$^{-1}$	-33.5 nm
$\delta\alpha \cdot \Delta\bar{t}$	0	0.236×10^{-6}	Special	100 mm	-23.6 nm
δl_V	0 mm	3.8 nm	Rectangular	-1.0	3.8 nm
l_X	100.000 250 mm				51.9 nm
Expanded uncertainty of measurements $U_{0.95}$, $k=2$					103.8 nm

The final result of measurements:

The measured median length of the transfer standard of the end measure of nominal length for 100 mm was 100.000 250 mm ± 104 nm.

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Measurements performed by:
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