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SUPPLEMENTARY COMPARISON

INTERNATIONAL COMPARISONS OF NATIONAL STANDARDS IN THE FIELD OF MEASUREMENTS OF DEVIATIONS FROM STRAIGHTNESS AND FLATNESS WITH THE MEASUREMENT RANGE OF DEVIATIONS FROM STRAIGHTNESS FROM 0 TO 50 μM, THE LENGTH OF SURFACE FROM 0,4 TO 5 M

FINAL REPORT

The pilot laboratory: Laboratory of mass, force and linear quantity measurement metrology, FGUP "UNIIM"
NMI's name and abbreviation: Federal State Unitary Enterprise "The Urals Research Institute for Metrology (FGUP "UNIIM")

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Introduction

The aim of the project is to ensure the reliability of the length measurement unit transfer in the field of measurement of deviations from straightness and flatness and to confirm the claimed measurement capabilities of the national state measurement standards of Republic of Belarus, Republic of Kazakhstan and Russia. The comparison is conducted on a granite bridge of Kazakhstan measurement standard by the measurement of its deviations from straightness using measurement instruments, being the parts of the national measurement standards of comparison participants. The measurement results are processed, the uncertainty budget and the confidence level are determined.

1 Participants

Table 1

№	NMI	Postal address for dispatch	NMI abbrevia-tion	Contact Person	E-mail, Telephone, Fax
1	Belarusian State Institute for Metrology	Republic of Belarus, 93, Starovilensky tract, Minsk, 220053	BelGim	Anna E. Demidova	E-mail demidova@belgim.by Tel. (+ 37517) 239 23 38 Fax (+ 37517) 288 09 38
2	South- Kazakhstan Branch of RGP "Kazakh Institute for Metrology"	Republic of Kazakhstan, 83, Altynsharin str. Almaty, 050035	UKF RGP KazInMetr	Irina Z. Suvorova	E-mail metrology@nursat.kz Tel. (+7 3272) 21 36 16 Fax (+7 3272) 21 65 59
3	Federal State Unitary Enterprise "The Urals Research Institute for Metrology"	Russia 4, Krasnoarmeyskaya str. Ekaterinburg, Russia, 620000	FGUP "UNIIM"	Ella K. Biryukova	E-mail uniim@uniim.ru Tel. (+7 343) 355 38 17 Fax (+7 343) 350 20 39

2 Organization of comparisons

2.1 Comparison scheme: round robin

2.2 Comparison principle

The comparison principle is as follows: according to the symmetrized scheme participants make tenfold measurements of the deviations from straightness with a 100-mm step of one and the same surface (the bridge of the national measurement standard of Republic of Kazakhstan) by measurement instruments, being the parts of their national measurement standards. The results of deviation from straightness in each examined point of the bridge surface are compared. The uncertainties and the degree of confidence are calculated.

2.3 Comparison schedule:

- 10 September – arrival of participants and preparation for measurements
- 11 – 15 September - measurements of the bridge of measurement standard of Republic of Kazakhstan by each participant (per two measurements by each participant every day according to the symmetrized scheme)
- 16-18 September – departure of the participants
- 19-26 September – processing of the results by all the participants at their enterprises and submitting them to FGUP "UNIIM"
- October – preparation of the report on the comparison results by FGUP "UNIIM"

2.4 Общие данные о сличаемых эталонах

The comparison was conducted on a granite bridge of Kazakhstan measurement standard by the measurement of its deviations from straightness using measurement instruments, being the

parts of the national measurement standards of comparison participants: 2 autocollimators from Republic of Kazakhstan; 2 electronic levels, produced by “WYLER” (Switzerland): one of them is a reference instrument, the other is a working one from Republic of Belarus and autonomous electronic measurement system, developed by UNIIM, from Russia. The measurement results are processed, the uncertainty budget and the confidence level are determined.

Measurement instruments were brought by comparison participants.

The comparison principle is as follows: according to the symmetrized scheme participants make tenfold measurements of the deviations from straightness with a 100-mm step of one and the same surface (the bridge of the national measurement standard of Republic of Kazakhstan) by measurement instruments, being the parts of their national measurement standards. The results of deviation from straightness in each examined point of the bridge surface are compared. The uncertainties and the degree of confidence are calculated.

Table 2

NMI	Range	Длина моста, m	Expended uncertainty		
			Value, мкм	Coverage factor	Level confidience
BelGim	0 to 50 μm	0,2 to 3	0.2L, L in m	2	95%
UKF RGP KazInMetr	0 to 50 μm	0,2 to 4	0.2L, L in m	2	95%
FGUP “UNIIM”	0 to 50 μm	0,2 to 5	0.2L, L in m	2	95%

3 Procedure of measurements

3.1 Measurand description

Measurement standards, containing the unit of length, the specificity of which is in the measurement method and in the nature of the measurement object were compared. The deviation from straightness in μm is measured using step-by-step method (a step is 100 mm) through the inclination angle in each area of the surface, followed by mathematical treatment of measurement results. The object of measurement is an extended surface, having the deviation from straightness no more, than 50 μm. The range of the angle measurement using measurement systems of standards in each area is no more, than ± 10". The length of the surface to be measured is 4 m. The number of steps is 40. The flatness deviation is calculated using the deviation from straightness in different sections of surface. The uncertainty of flatness deviation is a functional dependence on the uncertainty of deviation from straightness. When comparing the standards were not compared with respect to this parameter.

3.2 Measurement conditions

The ambient temperature is 20,5°C ÷ 20,8 °C

The temperature variation is no more, than 0,3°C during the working day.

3.3 Requirements for the measurement procedure

The measurement procedure should contain:

- the information on the required number of measurements to be made by each participant of comparisons;
- the formulae for mathematical treatment of measurement results, including the calculations of the uncertainty and the degree of confidence;
- the information on the availability of the programme of measurement results treatment.

The measurement procedure is given in annex 1

3.4 Tests to be carried out prior to the measurements

Prior to the measurement the participating countries should test metrological characteristics of measurement systems of standards to be used during comparisons.

3.5 The requirements for the use and handling of the transfer standard during measurements

When using the bridge of the measurement standard and measurement instruments to be used during comparisons, their service instructions, set out in the maintenance manual, should be observed.

3.6 Equation of measurements

The deviation from the line which connects extreme points of the profile at a point.

$$y_{kj} = 4{,}8 \cdot 10^{-6} (l \sum_{\kappa=1}^{i} \vartheta_{kj} - \frac{i}{40} l \sum_{k=1}^{40} \vartheta_{kj}) \quad \mu m \qquad (1)$$

where

y_{kj} *is the deviation from the line which connects extreme points of the profile at the point k in measurement No. j, μm;*

l *is the distance between the holders of the primary transducers of the measurement systems of standards, μm;*

ϑ_i *is the difference between the reading of the angle in the area with an order number i and the reading of the angle in the first area, ".*

k *is the number of the point on the bridge surface of the standard, in which the amount of deviation from straightness is calculated;*

i *is a test point at the surface of the bridge;*

j *is the number of measurement*

(in the numbering the points from 0 to n, the order numbers of points and areas coincide)

The deviation from straightness of the bridge of the measurement standard.

$$H = h_{max} - h_{min} \ , \ \mu m \qquad (2)$$

where H *is a deviation from straightness of the bridge of the measurement standard, μm*

h_{max} *and* h_{min} *are the maximum value of all the positive values and the minimum value of all the negative deviations from straightness along the whole length of the bridge of the measurement standard from 40 points of the profile, μm.*

4 Comparison results

4.1 Preparation of the measurement standard

Prior to measurements the surface of the bridge of Kazakhstan measurement standard was thoroughly washed with spirit and wiped by dry napkin without fibre.

The bridge of the measurement standard was leveled-off lengthwise and crosswise using the level within ±6".

4.2 Measurement results

The deviations from straightness of the central longitudinal section of the bridge of Kazakhstan measurement standard 4 m long (hereinafter referred to as “the bridge”) were measured by each measurement system of the standards being compared with a 100-mm step. The points on the bridge were numerated, the starting point was the one with number 0. The number of measured areas was 40 (the first area corresponds to the position of the transducer holders between the 0^{th} and the 1^{st} points). The transducer holders and (carriages) with mirrors of autocollimators were placed opposite to the points, marked on the side face of the bridge. Measurements were made in the following sequence: two measurements were made using autocollimators by a scientific custodian and the assistant of the scientific custodian of the measurement standard of UKF RGP

KazInMetr; two measurements were made using "WYLER" electronic levels by a scientific custodian of the measurement standard of BelGim and two measurements were made using autonomous electronic system, developed in UNIIM, by a scientific custodian of the measurement standard of FGUP "UNIIM". The readings of the angle value were recorded in the protocol. Then the measurements were made in the reverse sequence. This procedure was proposed to have equal distribution of the variation of the bridge profile due to the variation of the temperature conditions for each participant of comparisons. Each participant made a total of 10 measurements.

Table 3

The values of angles in each area of the bridge, obtained by the measurement using autocollimator No.1, 2 of the standard of UKF RGP KazInMetr

Area number	Obtained angle value in" for measurement:																			
	№1		№2		№3		№4		№5		№6		№7		№8		№9		№10	
	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	4,80	5,00	4,60	5,00	5,30	5,60	5,10	4,50	5,20	5,00	4,55	5,20	4,70	5,20	4,85	4,40	4,85	4,50	4,40	4,10
2	4,35	6,80	4,60	5,00	5,20	5,70	5,10	4,60	5,20	5,00	4,45	5,40	4,60	5,60	5,00	4,40	4,80	4,55	4,25	4,10
3	7,22	5,40	6,42	3,50	7,15	3,95	7,00	3,40	6,60	3,70	6,20	4,30	6,90	3,90	6,40	2,90	7,00	3,50	6,25	2,50
4	5,20	5,40	4,42	5,30	5,05	5,60	5,02	4,35	5,10	4,90	4,35	5,40	5,40	5,60	4,85	4,30	5,20	4,60	4,05	4,00
5	4,02	5,80	4,62	5,20	5,05	5,55	5,10	4,30	5,10	4,80	4,45	5,40	5,10	5,62	4,80	4,40	5,20	4,60	4,30	4,00
6	4,80	5,60	4,15	5,40	4,60	6,05	4,60	4,40	4,70	5,20	4,00	5,80	4,85	5,20	4,35	4,60	4,60	4,60	4,10	4,10
7	5,00	5,60	4,20	5,45	4,65	5,80	4,80	4,20	5,00	4,95	4,00	5,70	4,85	5,30	4,50	4,65	4,70	4,63	4,10	3,95
8	4,25	6,20	3,88	5,80	3,85	6,30	4,20	4,40	4,25	5,95	3,75	6,00	4,55	5,50	4,15	4,75	4,00	4,80	3,60	4,45
9	3,80	5,80	3,38	6,35	3,78	7,00	4,00	4,40	3,80	6,15	3,05	6,45	4,00	6,25	3,60	5,50	3,90	5,30	3,00	4,45
10	3,85	6,50	3,38	6,35	4,30	6,60	4,00	4,40	3,95	5,60	3,25	6,40	4,20	5,80	3,80	5,10	4,20	5,40	3,15	4,45
11	4,80	6,20	3,38	6,35	4,30	6,70	4,18	4,60	4,15	5,60	3,40	6,20	4,44	5,75	4,00	5,00	4,40	5,00	3,80	4,40
12	4,20	6,50	4,00	6,30	4,40	6,65	4,18	5,00	4,40	5,70	3,45	6,25	4,44	5,50	3,90	4,90	4,00	5,05	3,60	4,40
13	4,22	6,60	4,50	6,05	4,40	6,75	4,35	5,35	4,10	5,75	3,85	6,20	4,15	5,50	2,85	5,00	3,95	5,10	3,55	4,40
14	4,25	6,80	4,25	6,60	5,00	7,00	4,35	5,10	4,10	5,70	3,85	6,20	4,10	5,50	4,00	4,80	4,40	5,15	3,75	4,40
15	4,75	6,20	4,78	6,50	5,67	6,65	4,90	5,15	4,30	5,25	4,00	6,00	4,85	4,80	4,40	4,65	4,30	5,00	4,30	4,00
16	5,18	6,05	5,75	6,00	5,40	5,80	5,15	4,90	5,35	4,80	4,80	5,40	5,40	4,80	5,00	4,20	5,35	4,45	4,40	3,80
17	5,10	6,20	5,60	6,80	5,45	6,20	4,80	4,95	4,95	5,10	4,80	5,80	5,00	4,80	4,75	4,50	4,80	4,60	4,40	3,80
18	5,70	6,10	5,20	6,20	5,40	5,95	5,20	4,85	5,20	5,20	4,45	5,50	5,00	4,60	4,95	4,50	5,10	4,60	4,60	3,80
19	5,20	7,20	4,30	6,30	4,72	6,60	4,25	5,45	4,60	5,80	3,90	6,05	4,40	5,15	4,25	5,15	4,20	5,25	4,15	4,85
20	4,30	7,50	4,30	6,50	4,85	6,60	4,50	5,55	4,15	5,90	3,80	6,35	4,20	5,25	4,20	5,23	4,10	5,85	4,80	5,15
21	4,82	7,70	4,37	6,20	5,02	6,40	5,00	5,55	5,00	5,90	4,45	6,10	4,60	5,10	5,00	5,15	5,30	5,40	4,50	5,05
22	4,80	6,70	4,80	6,15	5,02	5,95	5,60	5,40	5,30	5,80	4,60	6,10	4,80	4,70	5,00	5,40	5,40	5,45	4,55	4,05
23	4,80	6,80	4,62	6,15	4,85	5,95	5,22	5,30	5,25	5,95	5,20	6,15	4,60	4,70	5,00	5,40	5,00	5,15	4,80	4,20
24	4,52	6,80	4,42	6,15	4,35	6,35	4,60	5,50	4,70	6,00	4,40	6,60	4,20	5,10	4,25	5,43	4,50	5,35	4,15	4,75
25	4,60	6,90	4,20	6,10	4,38	6,11	4,60	5,45	4,60	6,20	4,95	7,00	4,00	5,10	4,45	5,40	4,30	5,50	4,10	4,75

Area number	Obtained angle value in" for measurement:																			
	№1		№2		№3		№4		№5		№6		№7		№8		№9		№10	
	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2	АК-1	АК-2
26	3,40	7,60	3,00	7,10	3,62	7,35	3,60	6,50	3,35	7,15	3,55	7,80	3,40	6,10	3,40	6,30	3,40	6,60	2,70	5,60
27	2,80	7,80	2,72	7,60	3,00	7,80	2,80	7,00	2,75	7,75	2,80	8,20	2,75	6,80	2,50	7,00	2,30	7,05	2,20	6,00
28	2,45	8,60	2,15	7,80	2,80	8,00	2,40	7,35	2,45	8,00	2,65	8,25	2,55	7,00	2,30	7,10	2,00	7,05	2,20	6,25
29	2,20	8,60	1,90	8,00	2,60	8,05	2,40	7,40	2,00	8,00	2,40	8,30	2,40	7,20	2,00	7,30	2,00	7,20	2,25	6,45
30	2,20	8,80	1,95	8,15	2,42	8,20	2,20	7,50	2,20	8,05	2,20	8,35	2,90	7,25	2,10	7,20	2,00	7,25	1,85	6,55
31	2,20	8,70	1,95	8,20	2,42	8,30	1,80	7,50	2,00	8,05	1,90	8,40	3,10	7,40	2,05	7,20	2,05	7,35	1,80	6,55
32	2,20	8,70	2,15	7,90	2,60	8,30	2,30	7,20	1,95	8,00	2,20	8,35	3,15	7,38	2,20	7,20	2,20	7,30	1,80	6,45
33	3,42	7,60	3,60	7,20	3,78	7,00	3,20	6,25	2,60	6,60	2,55	7,10	4,20	6,10	3,60	6,20	3,40	6,00	3,40	5,35
34	4,87	6,80	4,80	6,00	5,05	6,00	4,60	5,30	4,80	5,70	4,45	6,10	5,00	5,20	4,45	4,90	4,40	5,40	4,40	4,30
35	5,42	6,80	5,10	5,70	5,25	5,80	4,82	5,00	5,00	5,55	4,60	5,70	5,45	4,95	4,60	4,80	4,90	5,00	4,60	3,80
36	5,80	6,20	5,60	5,70	5,40	5,75	4,62	4,80	4,85	5,50	4,65	5,70	5,20	4,80	4,80	4,75	4,20	5,00	4,40	3,90
37	6,40	6,20	5,60	5,70	5,02	5,75	4,75	5,20	4,60	5,75	4,65	5,95	5,15	4,85	4,35	5,00	4,20	5,25	4,20	4,10
38	5,60	6,30	6,20	5,30	6,20	5,40	5,50	4,80	4,90	5,15	5,00	5,70	5,85	4,30	5,20	4,10	5,20	4,80	5,00	3,60
39	7,00	5,40	6,90	4,80	7,52	5,00	6,20	4,30	5,80	4,90	5,60	4,85	6,20	2,80	5,60	3,80	5,70	4,10	5,50	3,10
40	6,50	5,20	7,80	4,20	8,20	4,60	6,80	3,40	6,30	4,70	5,15	5,30	5,10	4,40	4,40	4,60	4,75	-0,40	4,60	4,20

Table 4

The values of angles in each area of the bridge, obtained by the measurement using "WYLER" electronic level of the standard of BelGim

Area number	Obtained angle value in " for measurement:									
	№ 1	№ 2	№ 3	№ 4	№ 5	№ 6	№ 7	№ 8	№ 9	№ 10
1	-1,6	-0,4	-0,8	0,2	-0,2	0,2	0,2	-0,2	-0,6	-2,0
2	-2,2	-0,8	-1,4	-0,4	-0,6	-0,2	-0,2	-0,8	-1,0	-2,6
3	0,8	2,0	1,6	2,6	2,2	2,6	2,6	2,0	1,8	0,2
4	-1,8	-0,4	-0,6	0,4	-0,2	0,4	0,2	-0,4	-0,4	-1,8
5	-1,6	-0,4	-0,6	0,6	0,0	0,4	0,6	-0,2	-0,4	-2,0
6	-1,8	-0,6	-0,8	0,0	-0,4	0,0	0,0	-0,6	-0,8	-2,2
7	-1,6	-0,6	-0,8	0,0	-0,2	0,2	0,0	-0,6	-0,6	-2,2
8	-2,2	-1,0	-1,2	-0,2	-0,6	-0,2	-0,2	-1,0	-1,0	-2,6
9	-2,6	-1,4	-1,8	-0,6	-1,0	-0,6	-0,8	-1,4	-1,4	-3,2
10	-2,6	-1,4	-1,6	-0,6	-1,0	-0,6	-0,6	-1,2	-1,4	-3,0
11	-2,2	-1,0	-1,2	-0,2	-0,6	-0,2	-0,4	-0,8	-1,0	-2,6
12	-2,2	-1,2	-1,4	-0,4	-0,8	-0,2	-0,4	-1,0	-1,2	-2,6
13	-2,2	-1,0	-1,4	-0,2	-0,8	-0,2	-0,4	-1,0	-1,2	-2,6
14	-2,2	-1,0	-1,4	-0,4	-0,8	-0,4	-0,4	-1,0	-1,2	-2,6
15	-1,6	-0,4	-0,8	0,2	-0,2	0,2	0,2	-0,4	-0,6	-2,0
16	-1,2	-0,2	-0,4	0,4	0,2	0,8	0,4	-0,2	-0,2	-1,6
17	-1,4	-0,2	-0,6	0,4	0,0	0,6	0,4	-0,2	-0,4	-1,8
18	-1,4	-0,2	-0,6	0,2	0,0	0,8	0,4	-0,2	-0,4	-1,8
19	-1,8	-0,6	-1,0	-0,2	-0,4	0,4	-0,2	-0,8	-0,8	-2,2
20	-2,4	-1,2	-1,6	-0,6	-0,8	-0,4	-0,8	-1,2	-1,4	-2,8
21	-2,0	-0,6	-1,0	-0,2	-0,6	0,2	-0,2	-0,8	-1,0	-2,2
22	-1,8	-0,4	-0,8	0,0	-0,4	0,4	0,0	-0,6	-0,8	-2,0
23	-1,8	-0,6	-1,0	-0,2	-0,4	0,4	-0,2	-0,8	-0,8	-2,0
24	-2,2	-1,0	-1,4	-0,6	-0,8	0,0	-0,6	-1,2	-1,4	-2,4
25	-2,2	-1,0	-1,4	-0,6	-0,8	-0,2	-0,6	-1,2	-1,4	-2,4
26	-3,0	-1,8	-2,2	-1,6	-1,6	-1,0	-1,4	-2,0	-2,2	-3,2
27	-3,8	-2,6	-3,0	-2,2	-2,4	-1,8	-2,2	-2,8	-3,0	-4,0
28	-4,0	-2,8	-3,4	-2,6	-2,8	-2,0	-2,6	-3,2	-3,2	-4,4
29	-4,4	-3,2	-3,4	-2,8	-3,0	-2,4	-2,8	-3,4	-3,6	-4,6
30	-4,4	-3,2	-3,4	-2,8	-2,8	-2,2	-2,8	-3,4	-3,4	-4,6
31	-4,6	-3,4	-3,8	-3,0	-3,2	-2,6	-3,2	-3,6	-3,8	-5,0
32	-4,4	-3,0	-3,4	-2,8	-2,8	-1,8	-2,8	-3,4	-3,4	-4,4
33	-3,2	-2,0	-2,4	-1,6	-1,8	-1,4	-1,8	-2,2	-2,6	-3,6
34	-1,8	-0,8	-1,2	-0,4	-0,4	0,2	-0,4	-1,0	-1,2	-2,2
35	-1,8	-0,4	-1,0	0,0	-0,2	0,6	-0,2	-0,8	-0,8	-2,0
36	-1,6	-0,2	-0,8	0,0	-0,2	0,4	-0,2	-0,6	-0,8	-1,8
37	-1,8	-0,6	-1,0	-0,2	-0,2	0,4	-0,2	-0,8	-1,0	-2,0
38	-1,6	-0,2	-0,6	0,2	0,2	0,8	0,0	-0,4	-0,8	-1,8
39	-0,6	0,6	0,4	1,0	1,0	1,6	0,8	0,4	0,2	-1,0
40	-1,4	-0,2	-0,4	0,4	0,2	0,8	-0,2	-0,4	-0,6	-1,6

Table 5

The values of angles in each area of the bridge, obtained by the measurement using autonomous electronic measurement system of the standard of FGUP "UNIIM"

Area number	Obtained angle value in " for measurement:									
	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No 10
1	1,65	0,01	0,53	1,36	-0,32	-0,22	0,82	0,76	2,12	0,48
2	0,03	-0,67	-0,31	0,46	-1,55	-0,62	0,13	-0,02	1,47	-0,29
3	3,62	2,74	3,18	3,46	1,67	2,76	3,32	2,96	4,71	2,63
4	0,93	0,38	0,61	0,94	-0,09	0,40	0,96	0,76	2,33	0,51
5	1,17	0,38	0,62	1,41	-0,09	0,30	1,07	0,77	2,20	1,30
6	0,51	0,11	0,08	0,55	-0,28	-0,09	0,49	0,34	1,66	0,16
7	0,63	0,28	0,32	0,51	0,00	0,03	0,59	0,46	1,78	0,15
8	0,01	0,06	-0,01	0,28	-0,19	-0,15	0,11	0,02	1,35	-0,34
9	-0,38	-0,32	-0,79	-0,32	-0,68	-0,94	-0,48	-0,38	0,91	-0,82
10	-0,04	-0,35	-0,8	0,31	-0,56	-0,58	-0,50	-0,62	0,64	-0,58
11	0,52	0,30	0,08	1,04	-0,16	-0,17	0,36	0,07	1,68	-0,12
12	0,13	0,22	-0,30	0,87	-0,14	-0,12	-0,06	-0,36	1,08	-0,47
13	0,31	0,18	-0,26	0,82	-0,22	-0,21	0,02	-0,07	1,26	-0,10
14	0,02	0,42	-0,15	1,20	-0,18	0,03	0,21	0,03	1,34	-0,12
15	1,04	0,93	0,48	1,52	0,66	0,48	0,71	0,63	2,05	0,41
16	1,12	1,17	0,68	1,62	0,90	0,63	0,90	0,71	2,14	0,63
17	0,78	0,93	0,6	1,39	0,85	0,45	1,11	0,77	2,17	0,67
18	0,99	0,95	0,69	1,77	0,77	0,74	0,99	0,83	2,20	0,59
19	0,69	0,93	0,50	1,30	0,66	0,47	0,83	0,78	1,96	0,32
20	0,09	0,59	-0,24	0,78	0,16	0,10	0,11	0,08	1,36	-0,29
21	0,42	0,99	0,45	1,43	0,52	0,45	0,69	0,63	1,63	0,11
22	0,62	0,96	0,53	1,64	0,76	0,45	0,97	0,58	1,76	0,16
23	0,41	0,98	0,27	1,27	0,60	0,42	0,57	0,51	1,71	0,28
24	0,07	0,76	-0,17	0,94	0,13	0,20	0,36	0,36	1,34	-0,22
25	0,07	0,51	-0,13	1,14	0,03	0,05	-0,17	0,07	1,23	-0,31
26	-0,86	-0,35	-0,97	-0,14	-0,81	-0,84	-0,81	-0,81	0,41	-1,14
27	-1,3	-0,84	-1,54	-0,22	-1,29	-1,29	-1,41	-1,3	0,05	-1,87
28	-1,23	-1,32	-1,91	-0,71	-1,75	-1,71	-1,62	-1,67	-0,43	-1,49
29	-1,95	-1,5	-2,16	-0,89	-1,89	-2,01	-1,85	-1,74	-0,73	-1,92
30	-2,17	-1,72	-2,29	-1,22	-2,02	-1,99	-1,99	-2,07	-0,81	-2,00
31	-2,59	-2,08	-2,70	-1,76	-2,52	-2,32	-2,29	-2,22	-1,20	-2,34
32	-1,87	-1,36	-2,08	-0,71	-1,94	-1,74	-1,76	-1,77	-0,76	-1,74
33	-1,02	-0,36	-1,15	-0,58	-0,74	-0,99	-0,93	-0,89	0,39	-0,80
34	0,41	0,65	0,28	1,02	0,30	0,31	0,33	0,42	1,57	0,53
35	0,54	0,78	0,31	0,92	0,57	0,42	0,62	0,44	1,56	0,56
36	0,66	1,07	0,34	1,02	0,86	0,75	0,70	0,60	1,79	0,76
37	0,50	0,59	0,24	0,87	0,75	0,32	0,29	0,39	1,52	0,59
38	0,99	1,35	0,67	1,42	0,99	1,09	0,84	1,01	2,19	1,36
39	2,08	2,28	2,03	2,67	2,09	2,09	2,07	2,08	3,44	1,83
40	1,20	1,10	0,66	1,40	1,25	1,16	1,23	0,86	2,51	0,83

4.3 Determining values of deviation from the line which connects extreme points of the profile.

Mathematical treatment of measurement results, obtained in the angle values, to obtain the values of the deviations from straightness is performed by the formulae (1, 2). For calculations by the given formula the programme, based on EXCEL was developed. The obtained results of the deviations from the bridge straightness in each point are given in tables 6-8.

Table 6

The deviation from the line which connects extreme points of the profile at each point of the bridge, obtained as mean value for 2 autocollimators of the standard of UKF RGP KazInMetr

Point number	Deviation from the line which connects extreme points of the profile, μm for measurement No									
	No 1	No 2	No 3	№ 4	No 5	No 6	No 7	No 8	No 9	No 10
0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1	0,35	0,33	0,34	0,41	0,40	0,10	0,36	0,34	0,23	0,48
2	0,70	0,62	0,66	0,83	0,72	0,09	0,76	0,67	0,43	0,41
3	1,85	1,80	1,74	1,89	1,74	1,04	1,85	1,77	1,50	1,37
4	2,09	2,08	2,10	2,31	2,04	1,22	2,24	2,18	1,67	1,85
5	2,39	2,36	2,49	2,74	2,37	1,31	2,59	2,59	1,91	1,94
6	2,53	2,42	2,74	2,99	2,49	1,45	2,78	2,85	2,07	2,27
7	2,68	2,54	3,08	3,36	2,63	1,57	2,99	3,12	2,27	2,65
8	2,66	2,36	3,23	3,32	2,64	1,57	3,09	3,19	2,22	2,71
9	2,38	1,98	3,33	3,11	2,37	1,24	2,88	3,11	2,03	2,75
10	2,11	1,83	3,43	3,08	2,16	1,08	2,82	3,08	1,88	2,63
11	1,81	1,66	3,53	3,09	2,04	0,99	2,83	3,19	1,89	2,81
12	1,70	1,52	3,53	3,14	1,92	0,96	2,84	3,20	1,86	2,78
13	1,77	1,35	3,49	3,10	1,90	0,85	2,56	3,18	1,81	2,73
14	1,65	1,28	3,50	3,08	1,89	0,74	2,62	3,26	1,82	2,64
15	1,68	1,44	3,64	3,21	1,96	0,98	2,81	3,35	2,05	2,81
16	2,06	1,75	3,90	3,71	2,37	1,35	3,26	3,82	2,36	3,12
17	2,22	1,98	4,06	4,04	2,69	1,62	3,57	4,13	2,66	3,38
18	2,42	2,25	4,35	4,41	2,99	1,94	3,93	4,51	3,02	3,81
19	2,38	2,20	4,25	4,48	3,02	1,99	3,96	4,52	3,01	3,85
20	2,30	2,19	4,20	4,42	2,96	1,96	3,96	4,36	3,09	3,60
21	2,30	2,26	4,26	4,57	3,11	2,06	4,17	4,59	3,11	3,43
22	2,42	2,44	4,51	4,81	3,31	2,31	4,33	4,84	3,40	3,49
23	2,49	2,58	4,69	5,00	3,63	2,51	4,48	5,06	3,70	3,53
24	2,52	2,50	4,67	5,05	3,65	2,52	4,44	5,12	3,72	3,50
25	2,50	2,49	4,66	5,03	3,71	2,48	4,46	5,09	3,72	3,47
26	1,96	1,99	4,16	4,47	3,24	2,05	4,01	4,57	3,18	2,98
27	1,22	1,23	3,34	3,63	2,49	1,29	3,17	3,68	2,42	2,29
28	0,30	0,38	2,34	2,64	1,68	0,44	2,26	2,71	1,60	1,32
29	-0,74	-0,54	1,32	1,55	0,81	-0,50	1,22	1,71	0,74	0,29
30	-1,80	-1,53	0,24	0,50	-0,13	-1,33	0,24	0,70	-0,24	-0,78
31	-2,86	-2,55	-0,95	-0,60	-1,15	-2,15	-0,76	-0,33	-1,23	-1,83
32	-3,81	-3,53	-1,94	-1,70	-2,08	-2,95	-1,72	-1,30	-2,20	-2,88
33	-4,24	-3,90	-2,48	-2,31	-2,63	-3,19	-2,10	-1,67	-2,51	-3,37
34	-4,08	-3,72	-2,45	-2,16	-2,47	-3,01	-1,96	-1,66	-2,32	-3,31
35	-3,78	-3,45	-2,30	-1,93	-2,19	-2,67	-1,76	-1,42	-1,97	-3,11
36	-3,36	-3,13	-2,14	-1,73	-1,88	-2,34	-1,50	-1,36	-1,69	-2,68
37	-2,94	-2,90	-2,05	-1,64	-1,64	-2,05	-1,41	-1,35	-1,50	-2,11
38	-2,27	-2,30	-1,68	-1,34	-1,26	-1,44	-0,89	-0,99	-1,00	-1,75
39	-1,32	-1,28	-1,02	-0,75	-0,52	-0,39	-0,20	-0,34	-0,26	-0,84
40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Deviation from traightness (H), μm	6,49	7,32	7,37	6,70	6,03	7,01	6,33	5,77	6,49	7,32

Table 7
The deviation from the line which connects extreme points of the profile at each point, obtained using the measurement system of the standard of BelGim

Point number	Deviation fromthe line which connects extreme points of the profile, μm for measurement No:									
	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No10
0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1	0,29	0,28	0,26	0,32	0,26	0,17	0,35	0,43	0,31	0,26
2	0,30	0,37	0,23	0,36	0,32	0,15	0,51	0,57	0,43	0,22
3	1,75	1,82	1,66	1,85	1,74	1,48	2,02	2,06	1,91	1,55
4	1,95	2,10	2,02	2,27	2,00	1,75	2,38	2,40	2,32	1,90
5	2,24	2,39	2,38	2,79	2,35	2,01	2,92	2,83	2,73	2,16
6	2,44	2,58	2,64	3,02	2,51	2,09	3,18	3,06	2,94	2,32
7	2,73	2,76	2,90	3,24	2,77	2,26	3,43	3,30	3,26	2,48
8	2,74	2,75	2,97	3,38	2,83	2,23	3,59	3,34	3,38	2,44
9	2,54	2,55	2,75	3,31	2,70	2,01	3,46	3,18	3,30	2,12
10	2,35	2,35	2,62	3,25	2,57	1,79	3,42	3,13	3,23	1,89
11	2,35	2,34	2,69	3,38	2,63	1,77	3,48	3,27	3,34	1,86
12	2,36	2,24	2,66	3,41	2,60	1,75	3,54	3,31	3,37	1,82
13	2,36	2,23	2,63	3,55	2,57	1,72	3,60	3,35	3,39	1,79
14	2,36	2,23	2,60	3,58	2,53	1,60	3,66	3,39	3,41	1,76
15	2,66	2,51	2,86	3,90	2,79	1,77	4,01	3,72	3,72	2,01
16	3,14	2,89	3,32	4,33	3,24	2,23	4,46	4,15	4,23	2,46
17	3,53	3,27	3,68	4,75	3,59	2,59	4,91	4,58	4,64	2,82
18	3,92	3,65	4,04	5,07	3,95	3,06	5,36	5,01	5,05	3,17
19	4,12	3,84	4,20	5,20	4,11	3,32	5,52	5,15	5,26	3,33
20	4,03	3,73	4,07	5,14	4,07	3,20	5,38	5,09	5,19	3,20
21	4,12	3,92	4,24	5,27	4,14	3,37	5,54	5,23	5,31	3,36
22	4,32	4,20	4,50	5,50	4,30	3,64	5,80	5,47	5,52	3,62
23	4,52	4,39	4,67	5,63	4,46	3,90	5,95	5,60	5,74	3,88
24	4,52	4,38	4,64	5,57	4,42	3,98	5,92	5,55	5,66	3,94
25	4,52	4,38	4,61	5,50	4,39	3,95	5,88	5,49	5,59	4,00
26	4,14	3,98	4,19	4,96	3,97	3,54	5,46	5,05	5,13	3,68
27	3,36	3,20	3,39	4,12	3,16	2,74	4,64	4,22	4,28	2,96
28	2,49	2,32	2,39	3,08	2,15	1,84	3,64	3,19	3,33	2,06
29	1,43	1,24	1,39	1,95	1,05	0,75	2,53	2,07	2,18	1,05
30	0,36	0,17	0,39	0,82	0,05	-0,24	1,43	0,95	1,14	0,05
31	-0,80	-1,00	-0,81	-0,40	-1,15	-1,43	0,13	-0,27	-0,10	-1,15
32	-1,86	-1,98	-1,80	-1,53	-2,15	-2,23	-0,97	-1,40	-1,14	-2,06
33	-2,34	-2,47	-2,32	-2,08	-2,67	-2,84	-1,59	-1,94	-1,80	-2,58
34	-2,15	-2,38	-2,25	-2,05	-2,51	-2,67	-1,53	-1,90	-1,78	-2,42
35	-1,95	-2,10	-2,09	-1,82	-2,26	-2,30	-1,37	-1,76	-1,56	-2,16
36	-1,66	-1,72	-1,82	-1,59	-2,00	-2,04	-1,21	-1,52	-1,35	-1,80
37	-1,46	-1,53	-1,66	-1,46	-1,74	-1,77	-1,05	-1,38	-1,23	-1,55
38	-1,17	-1,15	-1,30	-1,13	-1,29	-1,31	-0,80	-1,05	-1,01	-1,19
39	-0,39	-0,38	-0,46	-0,42	-0,45	-0,46	-0,16	-0,33	-0,31	-0,45
40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Deviation from straightness (H), μm	6,58	6,87	6,86	6,98	7,71	7,13	6,27	6,81	7,54	7,54

Table 8

The deviation from the line which connects extreme points of the profile at each point of the bridge, obtained using the measurement system of the standard of FGUP UNIIM

Point number	Deviation fromthe line which connects extreme points of the profile, μm for measurement No:									
	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No 10
0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1	0,69	-0,14	0,30	0,29	-0,12	-0,08	0,31	0,32	0,35	0,26
2	0,60	-0,60	0,20	0,14	-0,84	-0,36	0,28	0,26	0,39	0,14
3	2,25	0,58	1,79	1,44	0,01	1,00	1,80	1,65	2,00	1,44
4	2,59	0,62	2,13	1,52	0,00	1,22	2,17	1,97	2,46	1,72
5	3,06	0,67	2,48	1,83	-0,01	1,39	2,60	2,29	2,85	2,37
6	3,20	0,58	2,56	1,73	-0,11	1,36	2,75	2,41	2,98	2,48
7	3,40	0,57	2,76	1,60	-0,07	1,40	2,94	2,59	3,17	2,57
8	3,29	0,46	2,80	1,36	-0,13	1,35	2,90	2,55	3,15	2,43
9	3,00	0,16	2,47	0,84	-0,43	0,92	2,58	2,31	2,92	2,06
10	2,88	-0,15	2,13	0,61	-0,66	0,66	2,24	1,96	2,56	1,81
11	3,02	-0,15	2,21	0,74	-0,70	0,60	2,33	1,95	2,70	1,77
12	2,98	-0,18	2,11	0,79	-0,74	0,57	2,21	1,73	2,55	1,57
13	3,02	-0,24	2,03	0,82	-0,81	0,49	2,13	1,64	2,49	1,55
14	2,92	-0,18	2,00	1,03	-0,86	0,52	2,14	1,61	2,46	1,52
15	3,32	0,13	2,28	1,39	-0,51	0,78	2,39	1,87	2,78	1,74
16	3,76	0,56	2,66	1,80	-0,03	1,11	2,73	2,16	3,15	2,07
17	4,03	0,87	3,00	2,10	0,41	1,35	3,18	2,49	3,53	2,42
18	4,40	1,18	3,38	2,59	0,82	1,73	3,57	2,84	3,92	2,73
19	4,63	1,49	3,67	2,85	1,18	1,98	3,88	3,17	4,20	2,91
20	4,57	1,64	3,60	2,85	1,29	2,05	3,84	3,16	4,18	2,80
21	4,67	1,97	3,86	3,17	1,58	2,30	4,09	3,42	4,30	2,88
22	4,86	2,30	4,16	3,59	1,98	2,54	4,47	3,65	4,48	2,98
23	4,95	2,63	4,34	3,84	2,31	2,76	4,65	3,85	4,63	3,14
24	4,88	2,86	4,30	3,92	2,41	2,88	4,73	3,98	4,61	3,06
25	4,81	2,96	4,29	4,10	2,46	2,93	4,56	3,96	4,53	2,94
26	4,28	2,65	3,86	3,66	2,10	2,55	4,08	3,52	4,06	2,41
27	3,55	2,10	3,16	3,18	1,51	1,94	3,30	2,84	3,41	1,53
28	2,84	1,32	2,28	2,46	0,69	1,14	2,42	1,98	2,52	0,83
29	1,79	0,45	1,28	1,66	-0,19	0,18	1,44	1,09	1,50	-0,08
30	0,63	-0,53	0,22	0,69	-1,13	-0,76	0,38	0,04	0,43	-1,02
31	-0,73	-1,68	-1,05	-0,54	-2,32	-1,86	-0,82	-1,09	-0,83	-2,13
32	-1,75	-2,48	-2,01	-1,25	-3,23	-2,68	-1,77	-1,99	-1,87	-2,95
33	-2,35	-2,80	-2,52	-1,91	-3,55	-3,14	-2,31	-2,47	-2,35	-3,31
34	-2,26	-2,62	-2,34	-1,79	-3,37	-2,97	-2,24	-2,32	-2,27	-3,03
35	-2,10	-2,39	-2,14	-1,71	-3,06	-2,74	-2,03	-2,15	-2,18	-2,73
36	-1,89	-2,01	-1,93	-1,59	-2,60	-2,35	-1,78	-1,91	-1,99	-2,34
37	-1,75	-1,87	-1,77	-1,54	-2,21	-2,17	-1,73	-1,77	-1,93	-2,03
38	-1,38	-1,35	-1,40	-1,23	-1,69	-1,62	-1,42	-1,33	-1,54	-1,34
39	-0,48	-0,39	-0,37	-0,31	-0,64	-0,59	-0,51	-0,37	-0,54	-0,43
40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Deviation from straightness(H), μm	7,3	5,76	6,86	6,01	6,01	6,07	7,04	6,45	6,98	6,45

The results were graphically processed. The graphs of the obtained profiles are given in figures 1-3

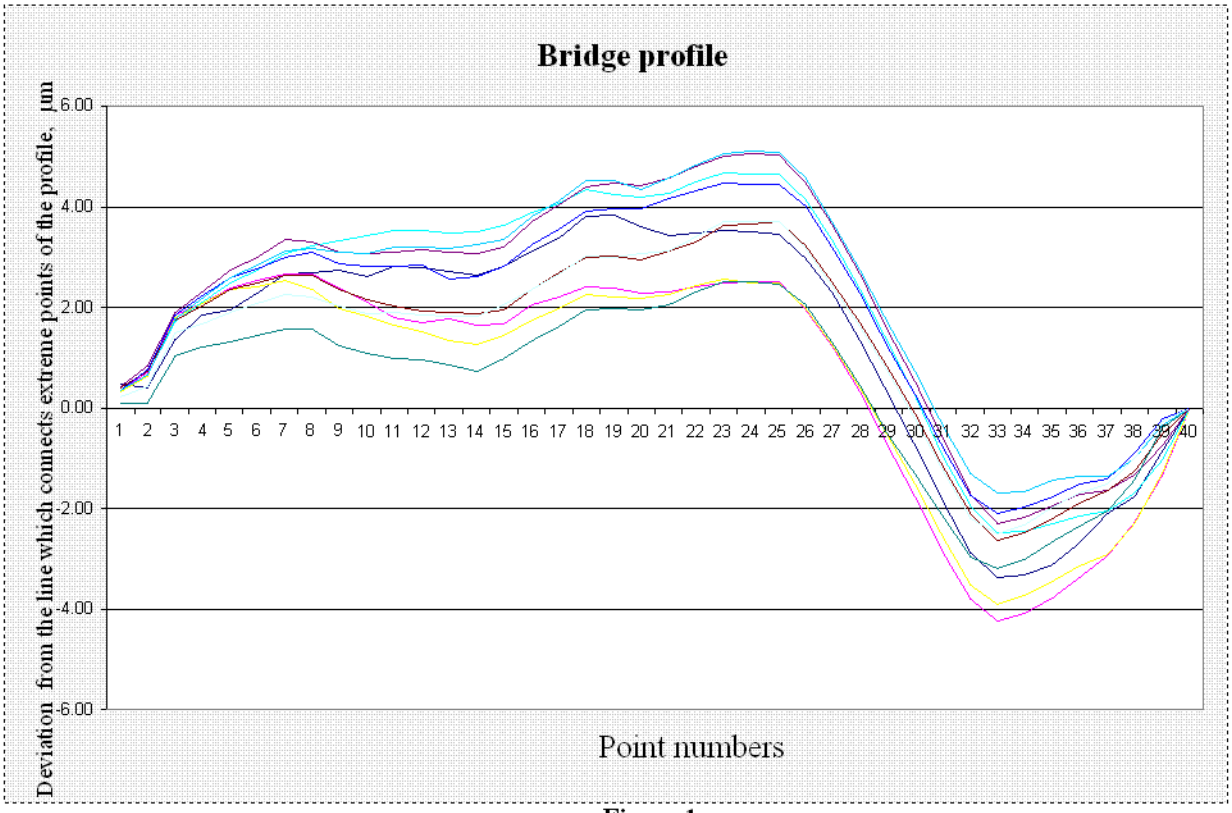

Figure 1

The graph of the bridge deviations, obtained using measurement system of the standard of UKF RGP KazInMetr

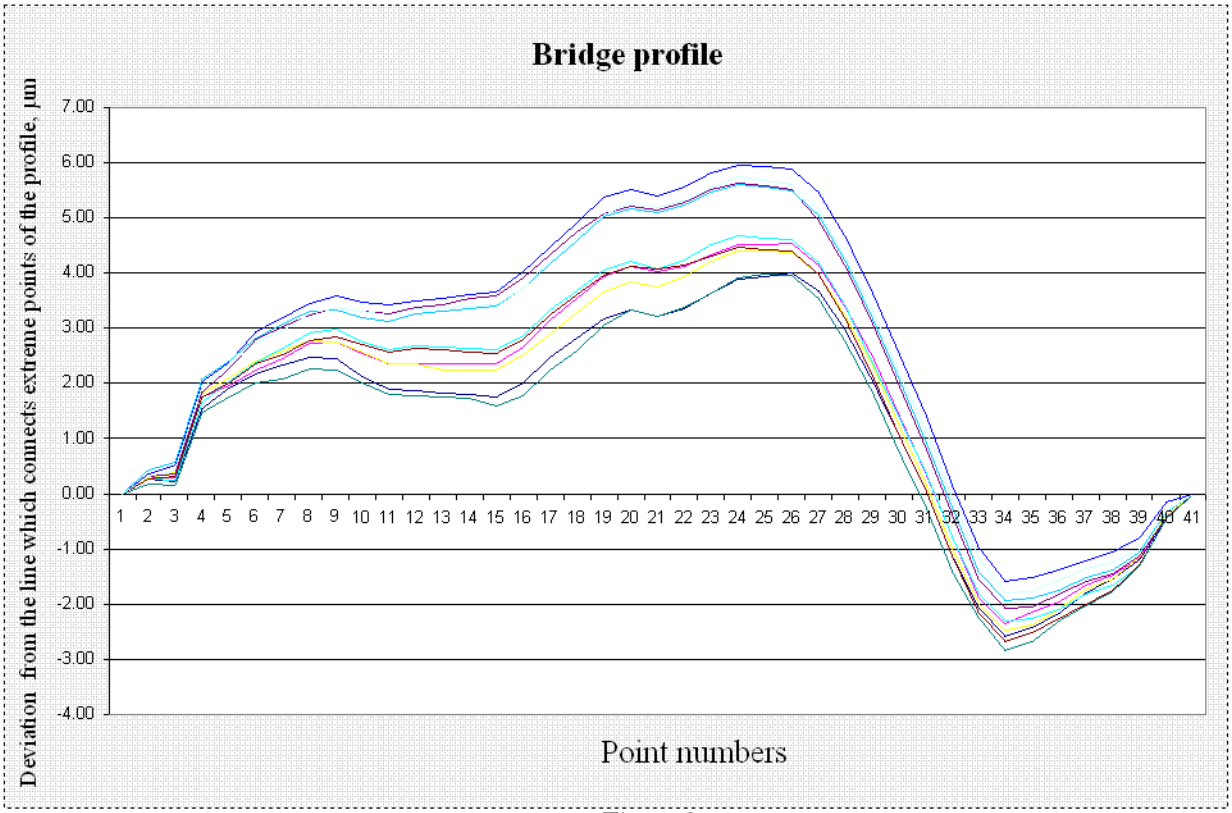

Figure 2

The graph of the bridge deviations, obtained using measurement system of the standard of BelGim

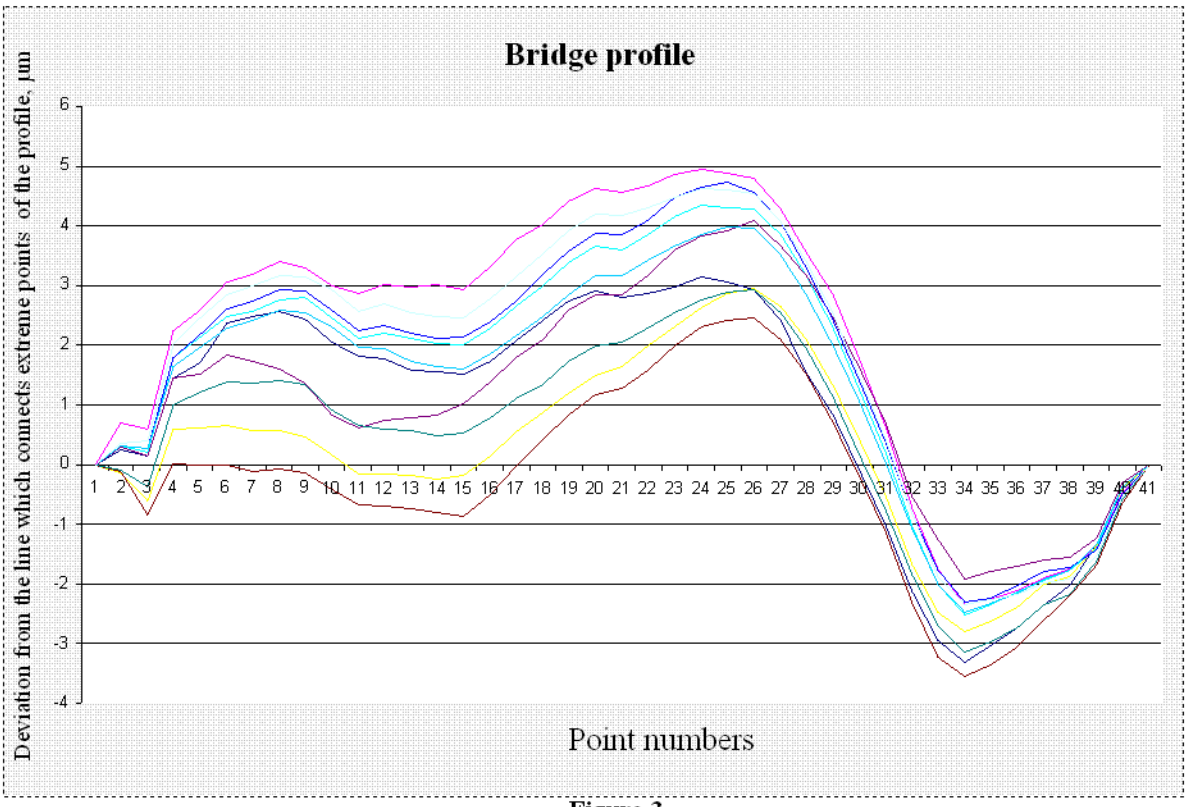

Figure 3

The graph of the bridge deviations, obtained using measurement system of the standard of FGUP "UNIIM"

4.4 Estimate of uncertainty

Uncertainty budgets, calculated according to FGUP "UNIIM" procedure (Annex A), for one measurement system.

Таблица 1 - The uncertainty budget

	UKF RGP KazInMetr	*BelGim*	*FGUP "UNIIM"*
Число измерений	10	10	10
Standard uncertainty по типу A, µm	0,33	0,36	0,40
Standard uncertainty по типу B, µm	0,34	0,25	0,25
Combined standard uncertainty, µm	0,47	0,46	0,47
Effective number of degrees of freedom	31,15	21	18
Coverage factor	2,07	2,08	2,10
Expanded uncertainty, µm	0,98	0,91	0,99
Confidence level	0,95	0,95	0,95

4.5 Analysis of measurement results

The following values were calculated to calculate the reference value:

- arithmetical mean of measurement results;
- weighted arithmetical mean of measurement results;
- median.

The obtained results are listed in the tables 10 and 11.

Table 9
The choice of reference value of deviation from the line which connects extreme points at the each point of the bridge

Point number	Deviation from the line which connects extreme points of the profile, μm					
	UKF RGP KazInMetr	BelGim	FGUP "UNIIM"	Arithmetical mean ($\overline{y}_k$)	Median (m_k)	Weighted arithmetical mean, ($\overline{y}_{kp}$)
0	0,00	0,00	0,00	0,00	0,00	0,00
1	0,34	0,29	0,22	0,28	0,29	0,30
2	0,59	0,35	0,02	0,32	0,35	0,40
3	1,66	1,78	1,41	1,62	1,66	1,72
4	1,98	2,11	1,66	1,92	1,98	2,05
5	2,27	2,48	1,99	2,25	2,27	2,38
6	2,46	2,68	2,03	2,39	2,46	2,56
7	2,69	2,91	2,12	2,57	2,69	2,78
8	2,70	2,96	2,05	2,57	2,70	2,79
9	2,52	2,79	1,72	2,34	2,52	2,59
10	2,41	2,66	1,44	2,17	2,41	2,42
11	2,38	2,71	1,48	2,19	2,38	2,43
12	2,34	2,71	1,38	2,14	2,34	2,38
13	2,28	2,72	1,33	2,11	2,28	2,34
14	2,25	2,71	1,32	2,09	2,25	2,29
15	2,39	3,00	1,62	2,34	2,39	2,50
16	2,77	3,45	1,99	2,74	2,77	2,90
17	3,04	3,84	2,33	3,07	3,04	3,22
18	3,36	4,23	2,70	3,43	3,36	3,59
19	3,37	4,41	2,97	3,58	3,37	3,74
20	3,30	4,31	2,97	3,53	3,30	3,63
21	3,39	4,45	3,18	3,67	3,39	3,77
22	3,58	4,69	3,45	3,91	3,58	4,01
23	3,77	4,87	3,65	4,10	3,77	4,20
24	3,77	4,86	3,70	4,11	3,77	4,23
25	3,76	4,83	3,67	4,09	3,76	4,21
26	3,26	4,41	3,23	3,63	3,26	3,78
27	2,47	3,61	2,56	2,88	2,56	3,03
28	1,57	2,65	1,76	1,99	1,76	2,14
29	0,59	1,57	0,82	0,99	0,82	1,13
30	-0,41	0,51	-0,20	-0,03	-0,20	0,11
31	-1,44	-0,70	-1,39	-1,18	-1,39	-1,06
32	-2,41	-1,71	-2,28	-2,13	-2,28	-1,98
33	-2,84	-2,26	-2,75	-2,62	-2,75	-2,50
34	-2,72	-2,16	-2,58	-2,49	-2,58	-2,36
35	-2,46	-1,94	-2,38	-2,26	-2,38	-2,14
36	-2,18	-1,67	-2,09	-1,98	-2,09	-1,88
37	-1,96	-1,48	-1,92	-1,79	-1,92	-1,73
38	-1,49	-1,14	-1,46	-1,36	-1,46	-1,32
39	-0,69	-0,38	-0,47	-0,51	-0,47	-0,43
40	0,00	0,00	0,00	0,00	0,00	0,00

Table 10
The choice of reference value of deviation from the straightness of the bridge

Analysis method	Reference value, μm	Standard deviation, μm
Arithmetical mean of measurement results	6,75	0,35
Weighted arithmetical mean of measurement results	6,72	0,35
Median	6,84	0,68

The weighted arithmetic mean with respect to measurement results of all comparison participants is taken as the reference value. The consistency of the data of adopted model was checked using criteria χ^2 with number of degrees of freedom (N-1). The value of criteria which was calculated by formula [1]: $\chi^2_{выч}$=5,56 is less than the critical value χ^2=5,99, found out using a chi-square distribution table for the given level of significance (p = 0,05).

The figure 4 displays the graphs of the profiles of the bridge of the standard obtained based on measurement results of each comparison participant and the weighted arithmetical mean of the measurement results of all comparison participants.

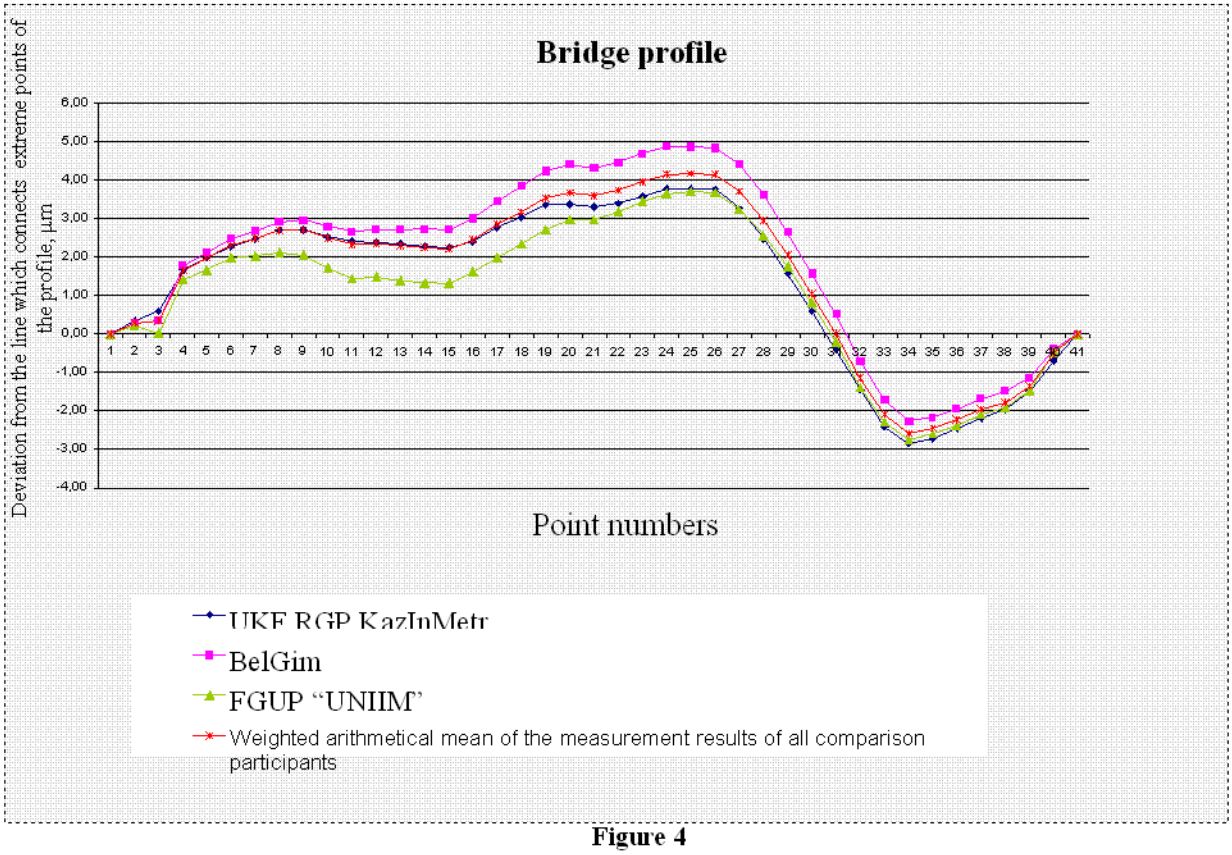

Figure 4
The graph of deviation from the line which connects extreme points of the profile of the bridge

Table 11

Equivalence degrees of the national standards to the reference value of deviation from straightness of the bridge

	UKF RGP KazInMetr	BelGim	FGUP "UNIIM"
Deviation from the reference value (d_i), µm	-0,04	0,27	-0,26
Standard uncertainty of deviation $u(d_i)$, µm	0,29	0,23	0,24
Expended uncertainty of deviation $U(d_i)$, µm	0,57	0,46	0,48

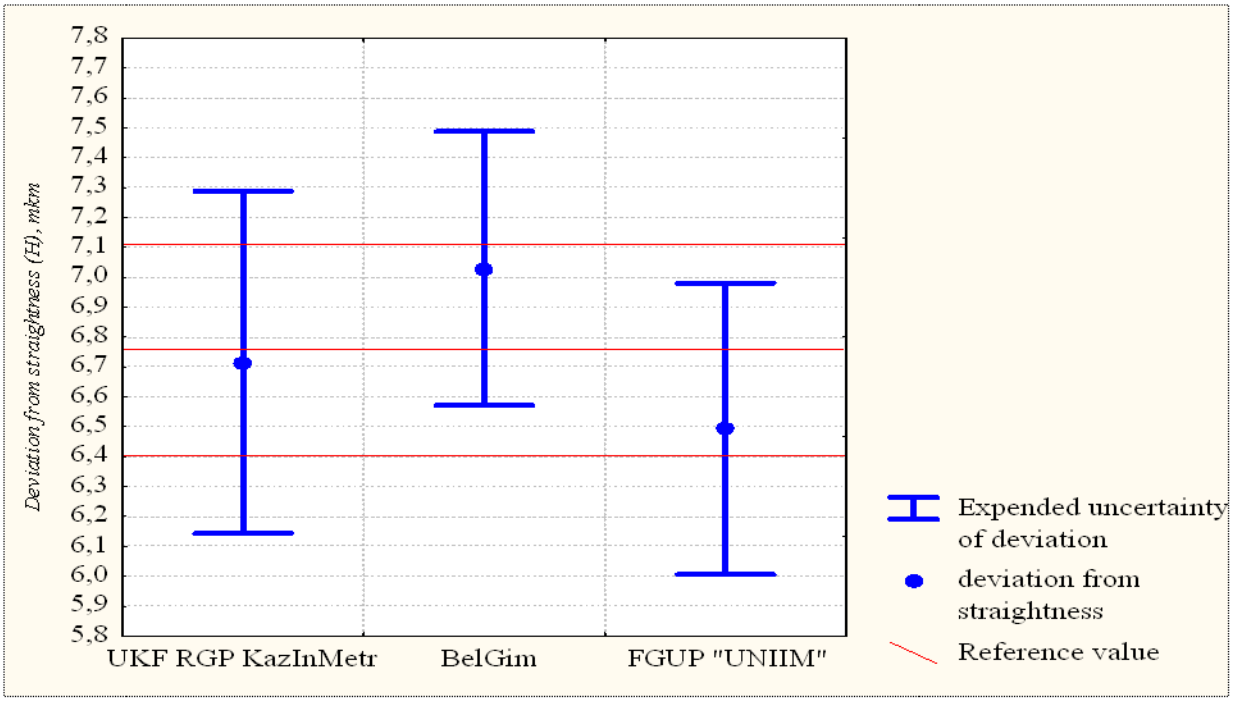

Figure 5

Equivalence degrees of the national standards to the reference value of deviation from straightness with respect to comparison results (values of expanded uncertainty of the reference value and deviations from the reference value, k = 2)

Table 12

Degrees of pairwise equivalence of the standards when defining the deviation from straightness of the bridge

	UKF RGP KazInMetr - BelGim	BelGim - FGUP "UNIIM"	FGUP "UNIIM"- UKF RGP KazInMetr
Difference of measurement results (d_{ij}), µm	-0,31	0,54	-0,22
Standard uncertainty of difference $u(d_{ij})$, µm	0,44	0,42	0,45
Expanded uncertainty of deviation $U(d_{ij})$, µm	0,89	0,83	0,90

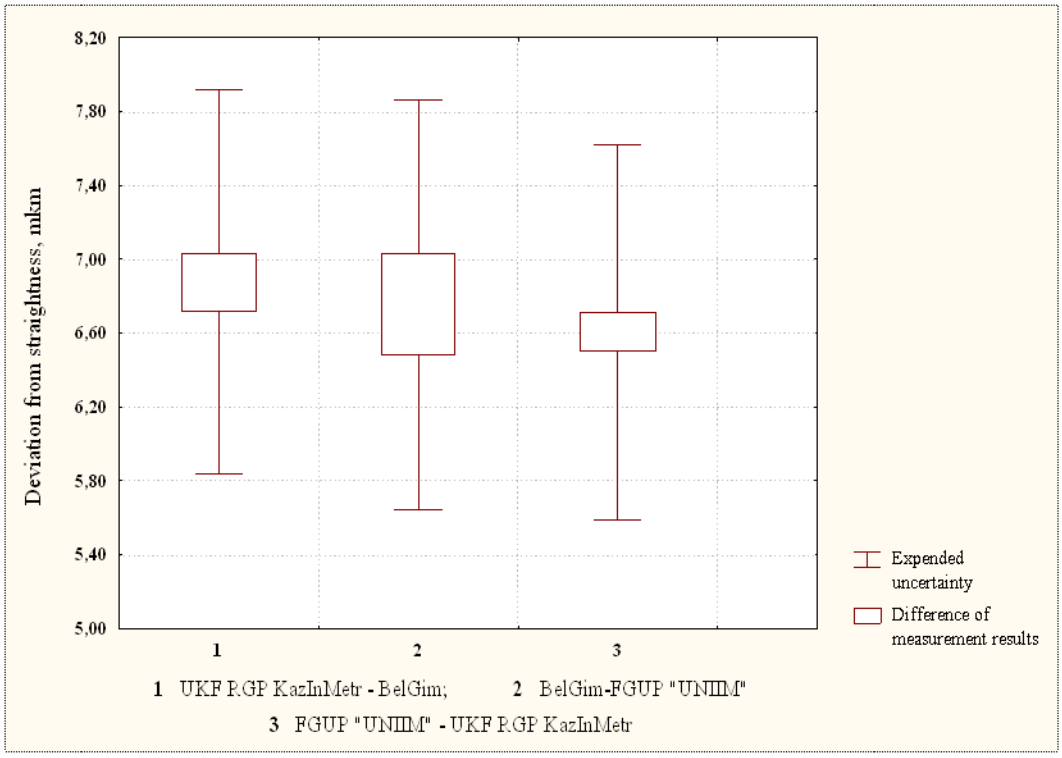

Figure 6

Degrees of pairwise equivalence of the national standards based on comparison results (values of expended uncertainty, k=2)

5 Resume

5.1 The comparison has been carried out. The obtained results have confirmed the measuring capabilities claimed by the comparison participants.

5.2 The reference value has been calculated using arithmetical mean, weighted arithmetical mean and median of deviation from straightness of the bridge. In addition $H_{оп}$=6,86 μm has been taken as the reference value of deviation from straightness of the bridge, the associated expanded standard uncertainty is equal to 0,52 μm. The deviation of measurement result from the reference value of each comparison participant satisfies the condition $|d_i| \le 2u(di)$.

5.3 The analysis of pairwise equivalence shows that the estimate of difference of measurement results (systematic bias) of each of possible pairs of comparison participants does not exceed the expended uncertainty of this estimate that is $|d_{ij}| \le 2u(d_{ij})$.

5.4 The obtained results confirm the equivalence of participating laboratories. The results of additional comparisons which have been carried out can be presented on site COOMET and BIMP.

6 References

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Annex 1

Comparison Procedure

1 Thoroughly wash with spirit as per GOST 18300-87 the surface of the bridge of Kazakhstan measurement standard and wipe it by dry napkin without fibre.
2 Level-off the bridge of the measurement standard lengthwise and crosswise within ±6".
3 Make measurement of the profile of the bridge of Kazakhstan measurement standard with the use of each measurement system of the standards being compared, moving the primary transducers along the central section of the bridge surface with a 100-mm step, so that the holders of the transducers were opposite to the points, marked on the side face of the bridge. Make measurements according to a symmetric scheme, for example, the first measurement of the bridge profile: Republic of Kazakhstan, Russia, Republic of Belarus; the second measurement: in the reverse sequence. Write down the readings of the angle value in the protocol, which should be kept by each participant of comparison. The example of recording the results is given in table 1. Repeat this process nine more times and in so doing each participant should make 10 measurements of the bridge profile.

Table 1

The interval of the bridge, on which the angle is measured	The angle value" in the points in measurement No.:									
	1	2	3	4	5	6	7	8	9	10
1	2	3	4	5	6	7	8	9	10	11
0 – 1										
1 - 2										
2 - 3										
3 – 4										
4 - 5										
5 - 6										
…										
38 – 39										
39 - 40										

4 Mathematical treatment of measurement results, obtained in the angle values, is performed by the formula to obtain the values of deviation from the line which connects extreme points of the profile

$$y_{kj} = 4{,}8 \cdot 10^{-6} (l \sum_{\kappa=1}^{i} \vartheta_{kj} - \frac{i}{40} l \sum_{k=1}^{40} \vartheta_{kj}) \quad \mu m \qquad (1)$$

where

y_{kj} *is the deviation from the line which connects extreme points of the bridge at point k in measurement No. j,μm;*

l *is the distance between the holders of the primary transducers of the measurement systems of standards, μm;*

ϑ_i *is the difference between the reading of the angle in the area with an order number i and the reading of the angle in the first area, ".*

k *is the number of the point on the bridge surface of the standard, in which the amount of deviation from straightness is calculated;*

i *is a test point at the surface of the bridge;*

j is the number of measurement (in the numbering the points from 0 to n, the order numbers of points and areas coincide)

The value of deviation from straightness of the bridge of the standard UKF RGB KazInMetr (N, μm) is calculated by formula

$$H = h_{max} - h_{min}\ ,\ \mu m \qquad (2)$$

Where H *is the deviation from straightness of the bridge of the standard*

h_{max} *u* h_{min} *are the maximum value of all the positive values and the minimum value of all the negative deviations from straightness along the whole length of the bridge of measurement standard from 40 points of the profile, μm*

5 Mathematical treatment of the results of the deviations from straightness is performed by the formulae (3) – (7) to obtain the uncertainties.

$$u_{Ak} = \sqrt{\frac{\sum_{j=1}^{n}(y_{jk} - \overline{y_k})^2}{19}} \qquad (3)$$

$$\overline{y_k} = \frac{\sum_{j=1}^{n} y_{jk}}{10} \qquad (4)$$

where y_{kj} *is the deviation from straightness in the* k^{th} *test point, obtained in the* j^{th} *measurement,*

$$u_B = \sqrt{\left[\sum_{i=1}^{\frac{N-1}{2}} \vartheta_{ij} - \frac{1}{2}\sum_{i=1}^{N-1} \vartheta_{ij}\right]^2 \cdot u^2(l) + l^2 \frac{29}{4} u^2(\vartheta)} \qquad (5)$$

$$u^2(\vartheta) = \frac{\Delta^2(\vartheta)}{3} \qquad (6)$$

$$u^2(l) = \frac{\Delta^2(l)}{3} \qquad (7)$$

where

$\Delta^2(\vartheta)$ is the error of measuring the angle by the measurement instrument of the standard;

$\Delta^2(l)$ is the error of the step of the measurement instrument of the standard;

6 For measurement standards, realizing the dependent reproducibility, it should be specified, from which country standard the size of the unit is obtained and the traceability of the standard, participating in the comparison, to this standard. The list of the main components of the measurement result uncertainty to be evaluated by each participant of comparison (NMIs, participating in the comparison, may add other components, which they consider to be important) and the recommendations on the method of uncertainty evaluation.

For mathematical treatment of results use the programme “EXCEL” or any other programme, certified by an established procedure.

7 Determining equivalence of the standards to the reference value and pairwise equivalence with respect to [1] and [5].

7.1 The deviation from the reference value and the uncertainty of this dev iation is calculated by formulae (8) – (10)

$$d_i = x_i - x_{ref} \quad (8)$$

where d_i *is the deviation from the reference value of deviation from straightness of* i^{th} *comparison participant, μm*

x_i *is the deviation from straightness obtained by* i^{th} *comparison participant, μm ;*

x_{ref} *is the reference value of deviation from straightness of the bridge of the standard, μm.*

$$u^2(d_i) = u^2(x_i) + u^2(x_{ref}) \quad (9)$$

where $u^2(d_i)$ *is the standard uncertainty of deviation from the reference value of deviation from straightness of* i^{th} *comparison participant, μm*

$u(x_i)$ *is the standard uncertainty of the value of deviation from straightness of the bridge obtained by* i^{th} *comparison participant, μm;*

$u(x_{ref})$ *is the standard uncertainty of the reference value of deviation from straightness of the bridge of the standard, μm.*

$$U(d_i) = 2u(d_i) \quad (10)$$

where $U(d_i)$ *is the expended uncertainty of deviation from the reference value of deviation from straightness of* i^{th} *comparison participant, μm*

7.2 Characteristics of pairwise equivalence is calculated by formulae (11)- (13)

$$d_{ij} = x_i - x_j \quad (11)$$

where d_{ij} *is the difference of measurement results of deviation from straightness of the bridge of* i^{th} *and* j^{th} *comparison participants, μm*

x_i *is the deviation from straightness of the bridge obtained by* i^{th} *comparison participant, μm;*

x_j *is the deviation from straightness of the bridge obtained by* j^{th} *comparison participant*.

$$u^2(d_{ij}) = u^2(x_i) + u^2(x_j) \quad (12)$$

where $u^2(d_{ij})$ *is the standard uncertainty of the difference of measurement results of deviation from straightness of the bridge of* i^{th} *and* j^{th} *comparison participants, μm*

$u(x_i)$ *is the standard uncertainty of the value of deviation from straightness of the bridge obtained by* i^{th} *comparison participant, μm;*

$u(x_j)$ *is the standard uncertainty of the value of deviation from straightness of the bridge obtained by* j^{th} *comparison participant, μm .*

$$U(d_{ij}) = 2u(d_{ij}) \quad (13)$$

where $U(d_i)$ *is the expended uncertainty of the difference of measurement results of deviation from straightness of the bridge of* i^{th} *and* j^{th} *comparison participants, μm;*