COOMET PROJECT No. 563/RU/12

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Type of comparisons
Supplementary

COMPARISON OF THE MEASUREMENT STANDARDS OF THE LENGTH UNIT IN THE FIELD OF ROUNDNESS DEVIATIONS MEASUREMENTS

FINAL REPORT

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INTRODUCTION

In accordance with the COOMET Program of comparisons for 2013 – 2014, the comparisons of the measurement standards of the length unit in the field of roundness deviations measurements on the COOMET Project 563/RU/12 were carried out. Pilot laboratory: Federal State Unitary Enterprise All-Russian Scientific Research Institute of Metrological Service (VNIIMS, Russia).

The results of the measurements of gauges are given in Section 7 of this report.

1 PARTICIPANTS OF COMPARISONS

Table 1

No.	COUNTRY / NMI	CONTACT PERSON / ADDRESS
1	Russia (Pilot laboratory) Federal State Unitary Enterprise All-Russian Scientific Research Institute of Metrological Service (VNIIMS)	Lysenko Valeriy Grigorevich Department of metrological assurance of measurements of geometric parameters Ozernaya Str. 46, Moscow 119361, Russia Tel.: + 8 (495) 665-30-87 Fax: + 7 (495) 437-34-29 E-mail: ivannikova@vniims.ru
2	Ukraine National Scientific Centre "Institute of Metrology" (NSC "IM")	Kupko Vladimir Semenovich Scientific center of space-time measurements Mironositskaya Str., 42, Kharkov 61002, Ukraine Tel.: +38 (057) 704-98-54 Fax: +38 (057) 700-34-47 E-mail: kupko@metrology.kharkov.ua
3	Republic of Belarus Belarussian State Institute of Metrology (BelGIM)	Makarevich Vladimir Bronislavovich Production and research department of measurements of geometric quantities Starovilensky trakt, 93, Minsk 220053, Republic of Belarus Tel.: +375 (17) 233-35-82 Fax: +375 (17) 288-09-38 E-mail: makarevich@belgim.by

2 ORGANISATION OF COMPARISONS

2.1 The purpose of comparisons is to establish the degree of equivalence of national measurement standards.

2.2 The scheme of comparisons – the comparisons are round-robin.

2.3 The principle of comparison.

Participants of comparison measure using their measurement standards the roundness standard and the flatted magnification standard in accordance with the requirements of section “Procedure of measurements.”

Using the obtained results, the following values for each gauge are calculated:

– reference value and the standard uncertainty of the reference value;

– expanded uncertainty of the reference value;

– degree of equivalence of measurement standards.

2.4 Dates of holding the measurements by participants are shown in Table 2

Table 2

Laboratory	Dates of measurements	
	Acc. to the schedule	**Actual**
VNIIMS	February 2014	February 2014
BelGIM	March 2014	March 2014
NSC “IM”	August 2014	August 2014

3 TRANSFER STANDARDS

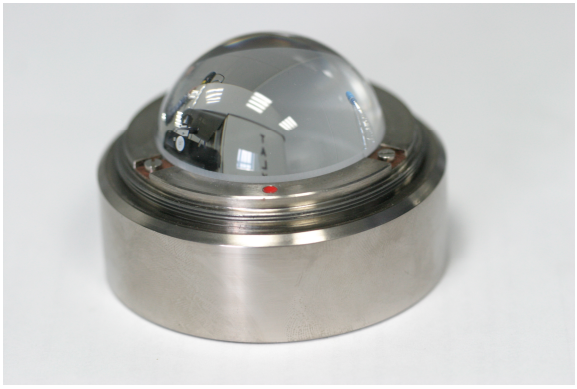

Figure 1 – Transfer standard (Roundness standard)

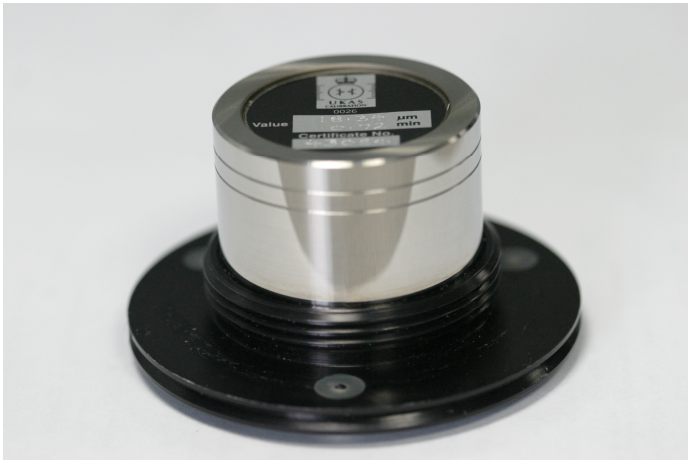

Figure 2 –Transfer standard (Magnification standard)

3.1 Roundness standard (reference hemisphere) No. 7328 (Fig. 1)

3.2 Flatted magnification standard No. X341 (Fig. 2)

3.3 Main parameters of the gauges are given in Table 3.

Table 3

GAUGES	Serial number	Nominal value
Reference hemisphere	7328	0.016 μm
Flatted gauge	X341	296.5 μm

4 PROCEDURE OF MEASUREMENTS

4.1 The measurements of roundness deviation from the roundness standard were carried out at a height of 3 mm from the metal base. All measurements were performed using a stylus with a length of 53.5 mm and a radius of 6.4 mm (VNIIMS and NSC “IM”) and a stylus with a length of 100 mm with a round tip of 2 mm in diameter (BelGIM), rotation speed – 6 rpm, number of points - 2000, resolution - 1.2 nm (VNIIMS and NSC “IM”), 0.3 nm (BelGIM). Analysis of the results was performed using a Gaussian filter with the bandpass of 1 – 50 UPR, the basic element - the middle line of least squares (LSC). Roundness deviation (RONt) was determined using Ultra Roundness Software.

4.2 Size measurement of a flat were performed by a stylus with a length of 53.5 mm with a radius of 6.4 mm (NSC "IM") and a stylus with a length of 100 mm with a round tip with a diameter of 2 mm (VNIIMS and BelGIM), rotation speed – 6 rpm, number of points - 2000, resolution - 1.2 nm (NSC "IM"), 8 nm (VNIIMS and BelGIM) of 10 sections, equally spaced in the work area.

Analysis of the results was carried out without the use of a filter, basic element is the minimal circumscribed circle (MC). Roundness deviation of valleys (RONv) was determined using Ultra Roundness Software.

5 ENVIRONMENTAL CONDITIONS DURING COMPARISONS

5.1 Environmental conditions during the measurements of the roundness standard and the flatted gauge of roundness deviation are given in Table 4.

Table 4

Parameter description	Acceptable value
Environment temperature	(20 ± 0,5) °C
Relative humidity	40 % to 50 %
Change of air temperature, not more than	1,0 °C/h

6 BRIEF DESCRIPTION OF THE MEASUREMENT STANDARDS

6.1 General view of the measurement standard of BelGIM is shown in Figure 3.

Figure 3 – General view of the measurement standard of BelGIM

The measurement standard includes the following basic equipment:

– Talyrond roundness measuring instruments of Taylor Hobson® company (England) with inductive sensor Talymin 5 and Ultra Roundness Software

– roundness standard, glass plate, reference cylinder;

– set of end gauges for the sensor's calibrations;

6.2 General view of the measurement standard of VNIIMS is shown in Figure 4.

Figure 4 – General view of the measurement standard of VNIIMS

The measurement standard includes the following basic equipment:

– interferometric unit for the transferring of the discrete values of the length unit;

– set of measures of form and position deviations of revolution surfaces;

– unit that realizes the measurement method of radii-vectors deviations in polar coordinate system;

– unit that realizes the measurement method of radii-vectors deviations in cylindrical coordinate system;

6.3 General view of the measurement standard of NSC "IM" is shown in Figure 5.

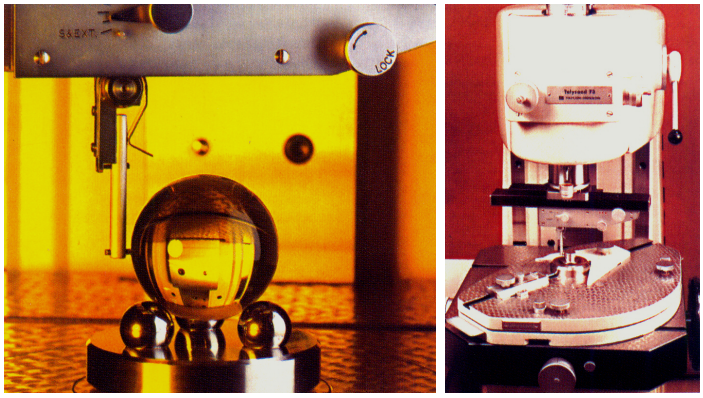

Figure 5 – General view of the measurement standard of NSC "IM"

The measurement standard includes the following basic equipment:

– measurement system Talyrond 73 including Ultra Roundness software;

– set of measures of form and position deviations of revolution surfaces.

6.4 Comparisons of the types of devices used in the measurement standards

Table 5

Laboratory	**Type of sensor**	**Type of spindle**	**System of data processing**
VNNIMS	Inductive	Hydrodynamic air bearing	ECU, PC, Ultra roundness software
BelGIM	Inductive	Air bearing	ECU, PC, Ultra roundness software
NSC "IM"	Inductive	Hydrodynamic bearing	ECU, PC, Ultra roundness software

7 Mathematical model of measurements

7.1 The value of the quantity of the deviation from roundness is calculated by the formula:

$$Y = X_u + \delta s + \delta_{FR} + \delta_R + \delta_L + \delta_C \ , \qquad (1)$$

where

Y – deviation from the roundness standard, μm;

X_u – arithmetic mean of measurement results, μm;

δS – gauge uncertainty (RMS mean), μm;

δ_{FR} – spindle uncertainty, μm;

δ_R – sensor resolution correction, μm;

δ_L – sensor nonlinearity correction, μm;

δ_C – calibration gauge correction, μm.

8 RESULTS OF MEASUREMENTS

8.1 Measurement results of the roundness standard (reference hemisphere) and the flatted gauge using the national measurement standards are shown in Table 6 and 7.

Table 6 Measurement results of the roundness standard (reference hemisphere)

Parameter	**Laboratory**		
	VNIIMS	**BelGIM**	**NSC "IM"**
RONt, μm	0.0273	0.0283	0.0315
Declared expanded uncertainty U, μm (k = 2, p = 95 %)	0.028	0.028	0.036

Table 7 Measurement results of the flatted gauge

Parameter	**Laboratory**		
	VNIIMS	**BelGIM**	**NSC "IM"**
RONv, μm	296.534	296.537	296.559
Declared expanded uncertainty U, μm (k = 2, p = 95 %)	0.60	0.61	0.63

9 PROCEDURE OF EQUIVALENCY ASSESSMENT OF THE NATIONAL STANDARDS PARTICIPATING IN COMPARISONS

The results of measurements carried out by participants of comparisons were checked by two methods:

– *En*-criterion;

– degree of equivalence of the measurement standards $(d_j, u(d_j))$.

9.1 Checking the measurement results by En-criterion

To check the consistency of results of separate measurements *En*-criterion was used. For $k = 2$, $|En| \le 1$.

$$E_n = \frac{1}{k} \cdot \frac{x_j - x_{ref}}{\sqrt{u_j^2 - u_{ref}^2}}, \quad (2)$$

$$x_{ref} = \frac{\sum_{j=1}^{n} p_j \cdot x_j}{\sum_{j=1}^{n} p_j}, \quad (3)$$

$$u_{ref} = \frac{1}{\sqrt{\sum_{j=1}^{n} \frac{1}{u_j^2}}}, \quad (4)$$

$$p_j = \frac{1}{u_j^2}, \quad (5)$$

where x_j – measurements result of laboratory number j;

u_j – standard uncertainty declared by laboratory number j;

p_j – weight of measurements result of laboratory number j;

x_{ref} – reference value (weighted mean) of comparisons;

u_{ref} – standard uncertainty of the reference value;

n – number of participants of comparisons.

En-criterion values for the gauge of roundness deviation (reference hemisphere) are given in Table 8.

En-criterion values for the magnification standard (flatted gauge) are in Table 9.

All the values of criterion *En* for the gauge of roundness deviation (reference hemisphere) and the magnification standard (flatted gauge), obtained by the participants of comparisons, are below the established level $|En| \le 1$.

9.2 Checking the measurement results by the degree of equivalency of the measurement standards $(d_j, u(d_j))$

The degree of equivalence of d_j j-institute is determined as the deviation of the measurement result from the reference value and is calculated by the formula:

$$d_j = x_j - x_{ref}, \quad (6)$$

where x_{ref} – reference value of comparisons, calculated by formula (3).

Uncertainty of the degree of equivalence, $u(d_j)$, is calculated by formula:

$$u(d_j) = \sqrt{u^2(x_j) - u^2(x_{ref})} \,. \quad (7)$$

The minus sign in the formula (7) is caused by the correlation of the measurement result and the reference value calculated with account of this measurement result.

The measurement standards are equivalent, if the following condition is met

$$|d_j| \le 2 \cdot u(d_j) \text{ or} \quad (8)$$

$$|d_j| \le U(d_j) \,. \quad (9)$$

The results of the checking by the degree of equivalency for the gauge of roundness deviation (reference hemisphere) are shown in Table 8, for the magnification standard (flatted gauge) – in Table 9.

Table 8

Parameter description	Abbreviation of laboratory		
	VNIIMS	BelGIM	NSC "IM"
Measurement result of the laboratory x_j, μm	0,027	0,028	0,032
Combined standard uncertainty declared by the laboratory u_j, μm	0,014	0,014	0,018
Reference value (weighted mean) of comparisons x_{ref}, μm	0,028		
Standard uncertainty of the reference value u_{ref}, μm	0,0086		
Difference between measured and reference values d_j, μm	-0,001	0	0,004
Standard uncertainty of the degree of equivalence $u(d_j)$, μm	0,011	0,011	0,016
Expanded uncertainty of the degree of equivalence $U(d_j)$	0,022	0,022	0,032
Value of criterion *En*	0,045	0	-0,12

Table 9

Parameter description	Abbreviation of laboratory		
	VNIIMS	BelGIM	NSC "IM"
Measurement result of the laboratory x_j, μm	296,534	296,537	296,559
Combined standard uncertainty declared by the laboratory u_j, μm	0,30	0,31	0,32
Reference value (weighted mean) of comparisons x_{ref}, μm	296,542		
Standard uncertainty of the reference	0,178		

Parameter description	Abbreviation of laboratory		
	VNIIMS	BelGIM	NSC “IM”
value u_{ref}, µm			
Difference between measured and reference values d_j, µm	-0,008	-0,005	0,017
Standard uncertainty of the degree of equivalence $u(d_j)$, µm	0,241	0,253	0,265
Expanded uncertainty of the degree of equivalence $U(d_j)$	0,482	0,506	0,530
Value of criterion *En*	-0,016	-0,010	0,03

As Tables 8 and 9 show, when comparing d_j and $U(d_j)$, the condition (9) is met, therefore the compared measurement standards are equivalent.

9.3 Deviations of the measurement results from the reference value and the expanded uncertainties of these deviations for the gauge of roundness deviation (reference hemisphere) are shown in Figure 6, for the magnification standard (flatted gauge) in Figure 7.

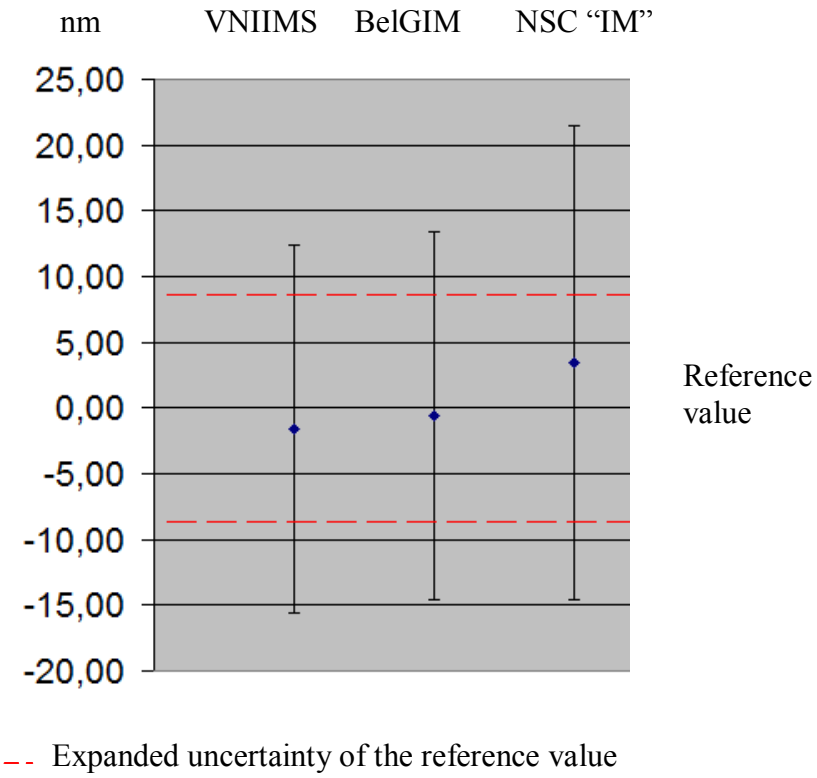

Figure 6 – Deviations of the measurement results from the reference value and the standard uncertainties of these deviations for the gauge of roundness deviation (reference hemisphere)

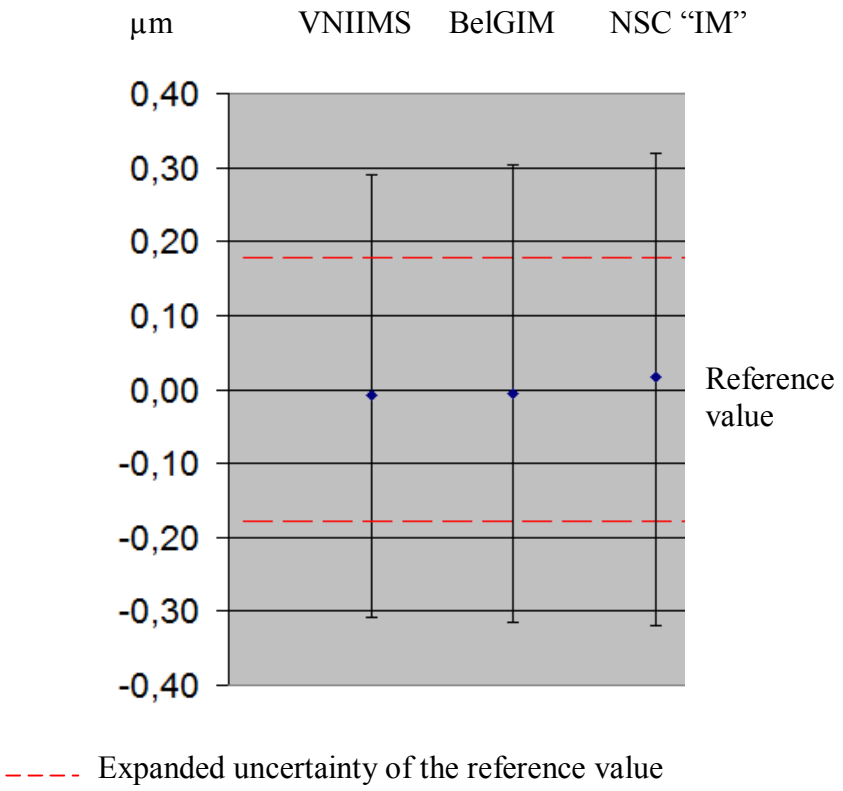

Figure 7 – Deviations of the measurement results from the reference value and the standard uncertainties of these deviations for the magnification standard (flatted gauge)

10 CONCLUSIONS

8.1 The results of comparisons show the correspondence of measurements uncertainties to the declared values.

8.2 The compared measurement standards are equivalent.

8.3 The results of the carried out comparisons of the measurement standards of the length unit in the field of roundness deviations measurements of VNNIMS, BelGIM and NSC "IM" can be accepted as positive.

References

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

[2] COOMET R/GM/11:2010 Regulations for Comparison of Measurement Standards from the National Metrology Institutes of COOMET.

[3] COOMET R/GM/14:2006 Guidelines for Data Evaluation of COOMET Key Comparisons.