Slovenský metrologický ústav
Slovak Institute of Metrology
Slowakisches Institut für Metrologie

EUROMET Supplementary Comparison #905

Comparison of squareness measurements

Final Report

Jiri Mokros, SMU, Bratislava, September 2009

Content

1 Introduction

The comparison of squareness measurement was aimed to compare and verify the declared calibration measurement capabilities of participating after the installation of new measurement setup following the project EUROMET #570.

As regards the technical parameters, the standard corresponds to the standard currently used in the metrological praxis. It makes possible to compare the standard devices in the real conditions.

The standard was calibrated by the measurement process currently used in the participant's laboratory (e.g. in the horizontal or vertical position of the square).

This comparison was carried out according to the same Technical protocol as that of the project EUROMET #570.

2 Organisation

This comparison was submitted as the EUROMET supplementary comparison in the framework of the Mutual Recognition Arrangement (MRA) of the Metre Convention and was aimed to support a confidence in calibration and measurement certificates issued by the participating national metrology institutes (NMI).

The comparison was organised according to the rules set up by the BIPM[1].

3 Participants

NMI		Address	Name	E-mail	Telephone
Slovak Institute of Metrology	SMU	Karloveská 63, SK-842 55 Bratislava Slovakia	Jirko Mokroš	mokros@smu.gov.sk	+421 2 60294 253
MIKES Konepajametrologia	MIKES	Centre for Metrology and Accreditation (MIKES) P.O. box 9 FIN-02151 Espoo Finland	Antti Lassila	Antti.Lassila@mikes.fi	+358 10 6054 413

4 Time schedule

The time schedule was currently modified few times, reflecting the requirements of participants. The real time schedule is shown in the following table.

Laboratory	Country	Date
SMU	SK	July – August 2006
MIKES	FI	August – September 2006
SMU	SK	September – October 2006

[1] T.J. Quinn, Guidelines for CIPM key comparisons (Appendix F to the MRA, 1. March 1999, BIPM, Paris)

5 Description of the Standard

Granite squareness standard of rectangular shape (500x300x70) mm with four marked functional surfaces, weight 26 kg,

6 Measurement instructions

6.1 Definitions

Zero point of the coordinate system – the intersection of the functional planes and the measurement plane (see Fig. 1).

Local deviation from straightness – the distance between the measured point and the LS regression-line fitted through the measured profile in the measured plane; the positive value corresponded to the orientation outside from the material of square (see Fig. 1).

Angle between fitting lines (in the case of granite standard) – interior angle γ_{LS} between the LS regression-lines fitted through the measured profiles BA and BD (see Fig. 1). The fitting line of the profile BD could be replaced by the envelope regression line (interior angle γ_B) – see Fig. 1.

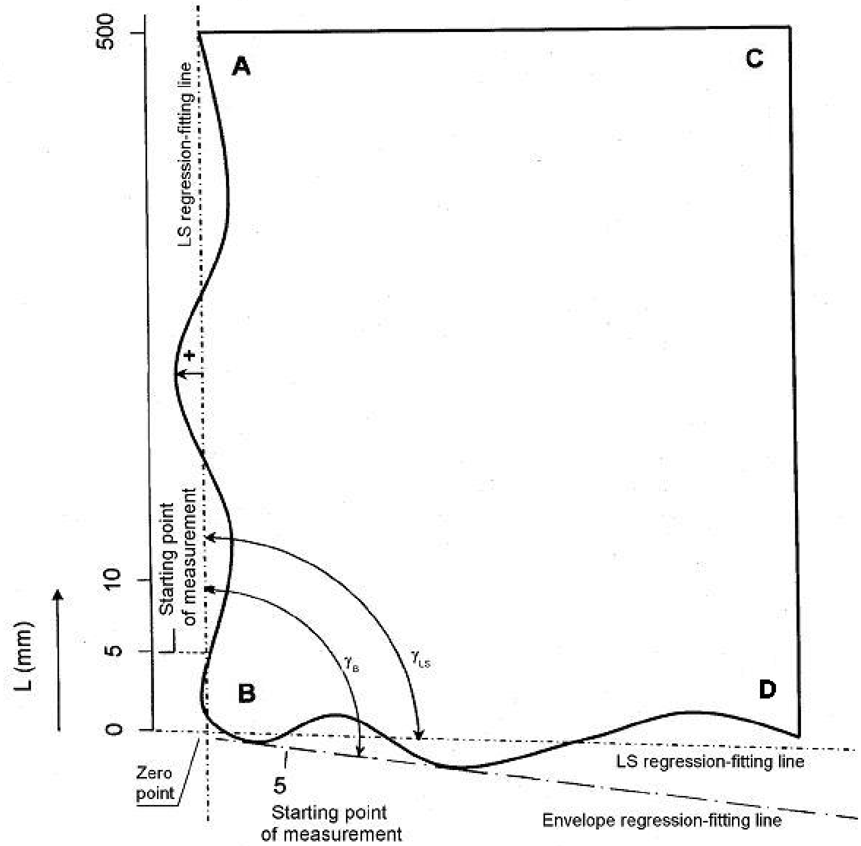


Fig. 1
Specification of the granite square

The measured profiles (in the case of the granite standard) are defined in the longitudinal axis in the middle of each functional plane.

The starting point of measurement – 5 mm from the zero point (defined above). In the case of cylindrical squareness standard, four zero points are given by the inter-section of four generatrix profiles with BASIS plane. The density of measuring points of the profile shall be 0,5 mm (in extra cases should be allowed the integer multiple of 0,5 mm, max. 2 mm).

Angles of the squares were measured using the technique currently applied by the participant. This method was described in details by each participant in the annex A2 "Measurement Report".

The squares were measured in the position currently used in the laboratory – horizontally or vertically.

7 Measurands

The following parameters had to be calibrated:

- interior angle γ_B between two lines BA and BD (envelope - LS regression) fitted through the measured profiles,

and / or

- interior angle γ_{LS} between two LS regression-lines BA and BD fitted through the measured profiles,
- local LS straightness deviation for all measured profiles (results had to be reported in electronic format only).

Supplementary data:

- radius of the probe tip,
- ambient temperature and its time drift during the measurement period,
- description of the standard device on which the calibration has been performed,
- description of the measurement methods and the data evaluation,
- the method of calculation of the combined standard uncertainty u_C (k = 1) related to the angle between fitting lines and uncertainty of local deviation from straightness,
- measurement uncertainty budget.

8 Measurement uncertainty

The combined standard uncertainty u_C (k = 1) of all measurement results had to be estimated according to the *ISO Guide for the Expression of Uncertainty in Measurement*.

Participants were asked to report their measurement uncertainty budget in the annex A2 "Measurement Report".

9 Measuring devices and procedures

The measuring devices used by the participants are shortly described below. The required form of data reporting was designed in order to reveal possible error sources of individual NMIs.

9.1 SMU

Description of measuring device:

The measuring device NME 90° (with 1300 mm straightness column, resting on a surface plate and air bearing carriage) compares form and angle position of vertical arm of measured rectangular standard with form and position of measuring column. Air bearing carriage bears two inductive sensors, which read a profile line of the measured square. The square standard under test is placed on a granite base plate so its horizontal arm is connected with this plate (envelope plane). The angle of square is defined by the fitting line (evaluated from individual measured points on vertical arm) and by the horizontal plane, given by the granite base plate of device. Such a determination of square was chosen by the device producers, because this way is usually used in industry.

Procedure of measurement:

For the measurement of angle standard the well-known method of error separation technique (reversal technique) by means of “self-calibration” is used. This method allows the evaluation of the profile of square vertical arm without beforehand information about the profile of the measuring column. Process of the measurement consists of two steps – measurement of the square standard in 0° position and in 180° position.

Procedure of result calculation:

Measurement profiles are transferred to an Excel worksheet. The slope of the profiles is calculated by linear regression, resulting in the angle of the squareness standard. Deviation of each measured point from the LS regression line is the local straightness deviation

Uncertainty evaluation and budget of angle between fitting lines and uncertainty evaluation and budget of local straightness:

For straightness:

Quantity X_i	*Estimate* x_i	*Standard uncertainty* $u(x_i)$	*Probability distribution*	*Sensitivity coefficient* c_i	*Uncertainty contribution* $u_i(y)$ *[µm]*
reading of inductive sensor	0 µm	0,03 µm	rectangular	1	0,03
flank leading of air bearing	0 µm	4 µm	normal	0,001	0,004
insufficient compensation of leading of air bearing due to different initial height	0 µm	25 µm	normal	0,002	0,05
quality of contact of sensor with the tested surface	0 µm	0,04 µm	normal	1	0,04
Vibrations	0 µm	0,07 µm	normal	1	0,07
u_c					0,10
Expanded uncertainty U (for k=2)					**0,20**

For Angle:

Quantity X_i	*Estimate* x_i	*Standard uncertainty* $u(x_i)$	*Probability distribution*	*Sensitivity coefficien* c_i	*Uncertainty contribution* $u_i(y)$
Local deviations of square and base plate	0 µm/m	0,4 µm/m	normal	0,3	0,12 µm/m
Temperature change of the arm of sensor carrier	0 °C	0,012 °C	normal	8 µm/(m .°C)	0,10 µm/m
Temperature dilatation coefficient of the arm of the sensor carrier	24 µm/(m.°C)	0,6 µm/(m.°C)	rectagular	0,06 °C	0,036 µm/m
Change of temperature difference between top and bottom baseplate surface	0 °C	0,096 °C	normal	96 µm/(m .°C)	0,96 µm/m
Influence of the dilatation temperature coefficient uncertainty through the change of temperature gradient in vertical direction	3,8 µm/(m.°C)	0,1 µm/(m.°C)	rectagular	0,6 °C	0,06 µm/m
Straightness uncertainty	0 µm	0,10 µm	normal	0,5 m^{-1}	0,05 µm/m
u_c					0,98 µm/m 0,20 ″
Expanded uncertainty U (for k=2)					**1,96 µm/m** **0,40 "**

9.2 MIKES

Description of measuring device, (type, model, manufacturer, measurement range of “L” and “o”, accuracy, other specifications and modes of usage):

- linear movements horizontal 1200 mm and vertical 150 mm (made by Microplan Italy)
  - straightness error < 1 µm
  - repeatability < 0,1 µm
  - position accuracy on x- and y-axis <0,01 mm
- inductive length measuring instrument (Tesa Sa) (sensor GT 31 and amplifier) (z – axis in the measurements),
  - uncertainty 0,05 µm + 1 % of the reading
- stone lineal 1000 x 120 mm (made by VTT) (used for calibration)
  - flatness error < 1 µm
- rotary table 360 ° (made by Eimeldingen Ltd) (can be used even vertically),
  - accuracy < 1”
  - repeatability 0,1”
- 12 sided polygon (made by Nikon) (used for calibration)
  - accuracy < 1”

- two autokollimators (made by Möller Wedell Optical Gmbh) (used for calbration).
  - Elkomat HR
    - Measuring range 300 x 300 “
    - Accuracy ± 0.01”
  - Elkomat 3000
    - Measuring range 2000 x 2000 “
    - Accuracy ± 0,1 “

Procedure of measurement:
Measurement of angle

The angle was measured using rotary table and linear movement. Between the straightness measurement the rotary table was rotated 90°. The rotary table was calibrated using error separation technique with 12 sided polygon and two autocollimators.

Measurement of straightness

The measured lines have been compared with the linear movement which was calibrated using error separation technique. The measurement was done on 490 mm length on side AB and 290 mm length on side BD with 0,5 mm steps (starting at 5 mm distance from the corner B).

Procedure of result calculation:

The angle between linear movement and the measured line was calculated using LS technique. The difference between LS line and the envelope line was calculated manually by tilting the LS line.

The straightness was calculated using LS technique.

Uncertainty evaluation and budget of angle between fitting lines and uncertainty evaluation and budget of local straightness:
The angle γ_{ls} was obtained from the relation:

$\gamma_{ls} = \gamma_e + \gamma_{AB} + \gamma_{BD} + \Delta T_w * \alpha_w * L_{w1} * k / L_{w2}$ where:

γ_{ls} is the angle between sides AB and BD

γ_e is the angle rotated with the rotating table

γ_{AB} is the angle between the linear movement and the side AB of the square (LS),

γ_{BD} is the angle between the linear movement and the side BD of the square (LS),

ΔT_w is the temperature gradient in the square (0,1 °K),

α_w is the temperature expansion coefficient of the square (5,6 x 10^{-6}/°C),

L_{w1} is the length of the longer side of the square (500 mm),

k is coefficient for small angles (k = 180x3600/3,14 “) and

L_{w2} is the length of the shorter side of the square (290 mm).

Quantity X_i	*Estimate* x_i	*Standard uncertainty* $u(x_i)$	*Probability distribution*	*Sensitivity coefficient ci*	*Uncertainty contribution* $u_i(y)$ *[µm]*
γ_e	0,2 "	0,1 "	normal	1	0,10
γ_{AB}	0,1 "	0,06 "	normal	1	0,06
γ_{BD}	0,15 "	0,087 µm	normal	1	0,09
ΔT_w	0,1 °K	0,058 N	normal	2 µm/°K	0,12
u_C					0,18
Expanded uncertainty when k=2		<u>0,37</u> "			

The straightness error S_{ix} of the lines were obtained from the relation:

$S_{ix} = s_{ir} + l_{id} + \delta l_{is} + L_s{*}\alpha_b{*}\Delta T_d + \Delta T_w{*}\alpha_w{*}L_w /8{*}B_w$ where:

- s_{ir} is the local straightness error of the linear movement and
- l_{id} is the local length difference between the reference and the square
- δl_{is} is the correction due the accuracy of the sensor
- L_s is the distance between the reference movement and the measured line (100 mm)
- α_b is the expansion coefficient of the bar ($11{,}6 \times 10^{-6}$/°K),
- ΔT_d is the drift of the temperature during the measurement (0,009 °K)
- ΔT_w is the temperature difference in the work piece (0,1 °K),
- α_w is the expansion coefficient of the work piece ($5{,}6 \times 10^{-6}$/°K),
- L_w is the measured length (490 mm or 290 mm),
- B_w is the with of the work piece (300 mm or 500 mm).

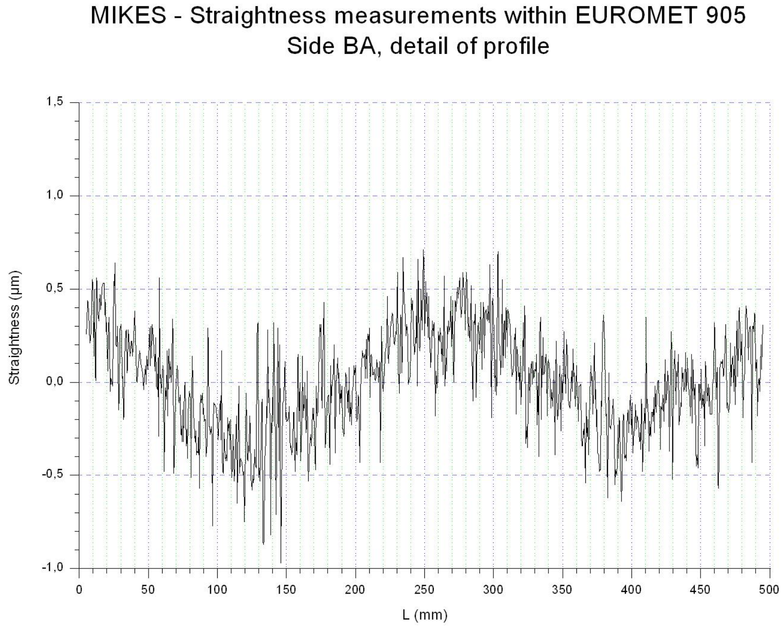
Quantity X_i	*Estimate* x_i	*Standard uncertainty* $u(x_i)$	*Probability distribution*	*Sensitivity coefficient ci*	*Uncertainty contribution* $u_i(y)$ *[µm]*
s_{ir}	0,3 µm	0,15 µm	normal	1	0,15
l_{id}	0,2 µm	0,12 µm	normal	1	0,12
l_{is}	0,09 µm	0,052 µm	normal	1	0,05
delta T_d	0,009 °K	0,005 °K	normal	1,16 µm/°K	0,01
delta T_w	0,1 °K	0,058 N	normal	0,0012 µm/°K	0,00
u_C					0,20
Expanded uncertainty when k=2		<u>0,393 µm</u>			

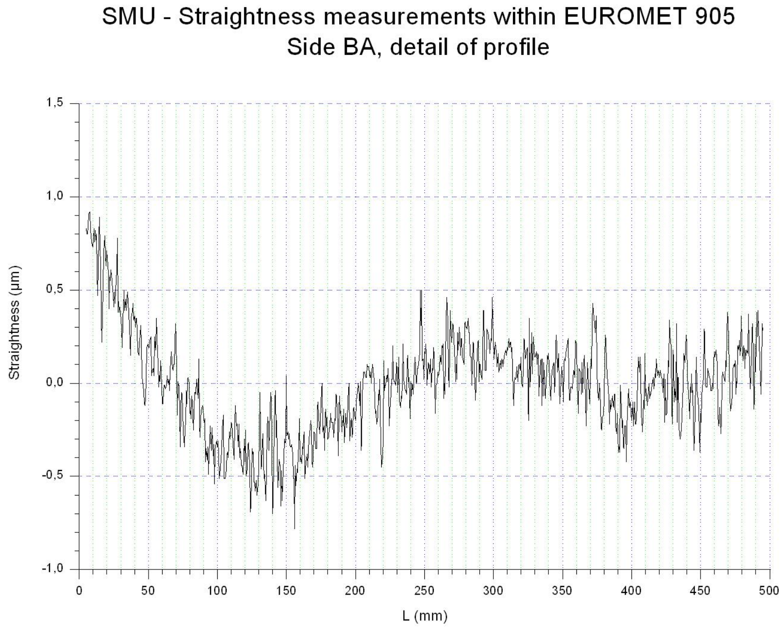
10 Results

10.1 Straightness

Since the measured profile was unknown beforehand and just two NMIs participated, the results are presented in terms of differences of results submitted by participants.

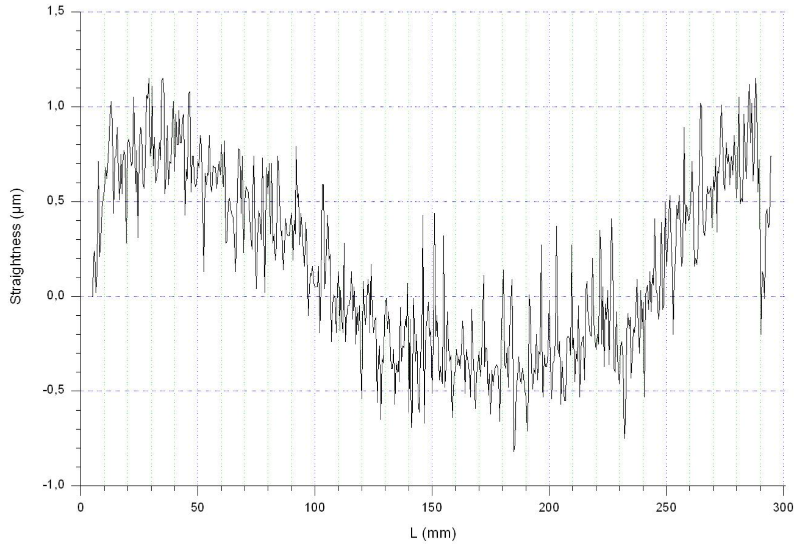
Measurements of profile BA:



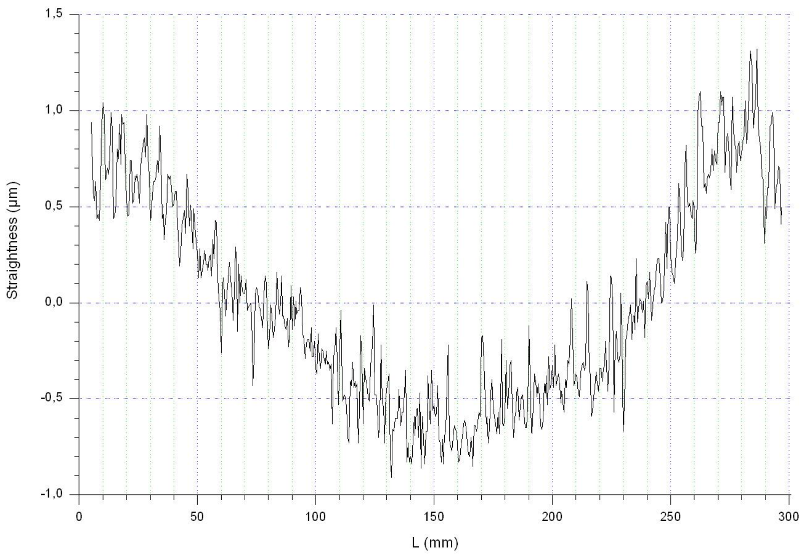


Measurements of profile BD

MIKES - Straightness measurements within EUROMET 905
Side BD, detail of profile



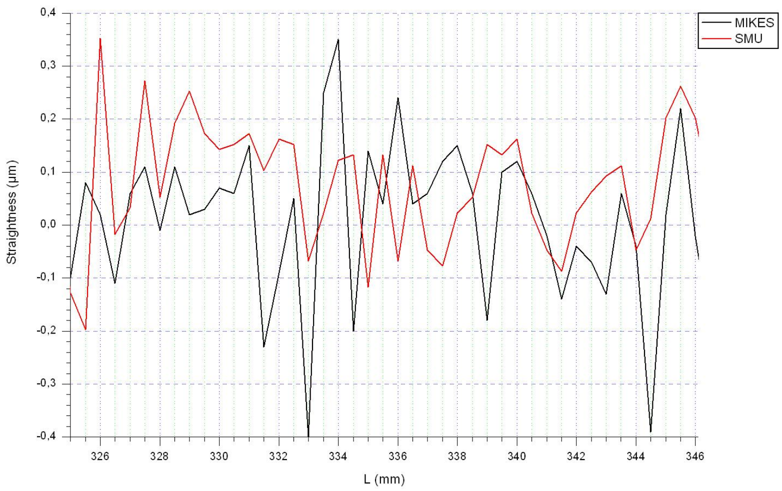
SMU - Straightness measurements within EUROMET 905
Side BD, detail of profile



The influence of the contact part of the sensor is obvious – the ball diameter was 2 mm (MIKES) and 8 mm (SMU) respectively.

The influence of the surface granularity can be seen on the following graph showing the same magnified part of the profile as measured by both NMIs.

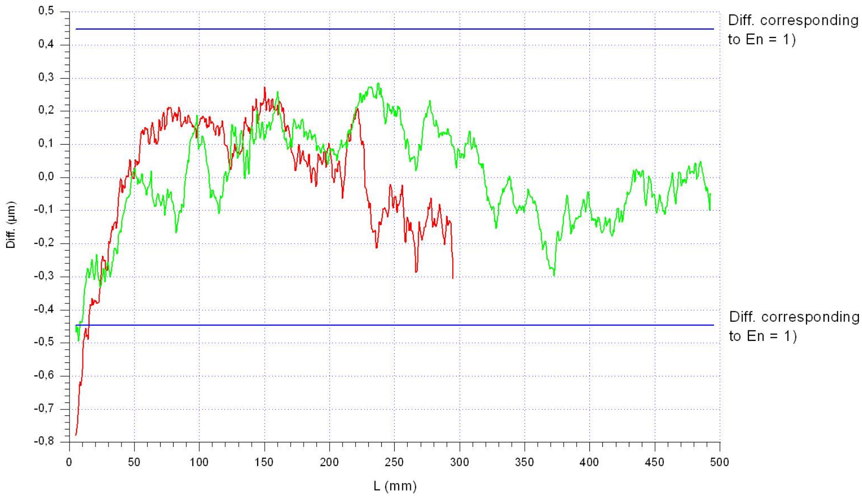
MIKES and SMU - Straightness measurements within EUROMET 905
Side BA, detail of profile



That is why this short-wave component was eliminated by the filtration using the drifting arithmetic mean with length of 10 mm. The resulting differences SMU - MIKES were calculated from the submitted profiles after the filtration had been done.

For both profiles, the largest differencies (exceeding the claimed uncertainties) correspond to the first 50 mm. These two differencies (for BA and BD) are shown together on a single graph:

MIKES and SMU - Straightness measurements within EUROMET 905
Side BA and BD (MZ) - smoothet (20 point) diff. SMU - MIKES



Comments to the graphs:

In the frame of #570, no significant deviations were observed at the beginning of measured profiles. Although the measurements performed within this bilateral comparison do not enable the thorough analysis of casual error sources, we assume that from the statistical point of view approximately 5% of results are allowed to exceed the claimed limits (En based on the expanded uncertainty with covering factor k = 2).

10.2 Squareness

Angle deviations of individual NMIs:

MIKES: γ_B = 1,4″
SMU: γ_B = 1,24″

Mean value: γ_B = 1,32″

Combined standard uncertainty u_C = 0,2″ (MIKES and SMU)

En = 0,28

Therefore the results of measured angle can be claimed as consistent.

11 Conclusion

Diff. of angles: $\Delta\gamma_B$ = 0,16″ En-value = 0,28

Tables summarizing the straightness measurement:

Profile BA:

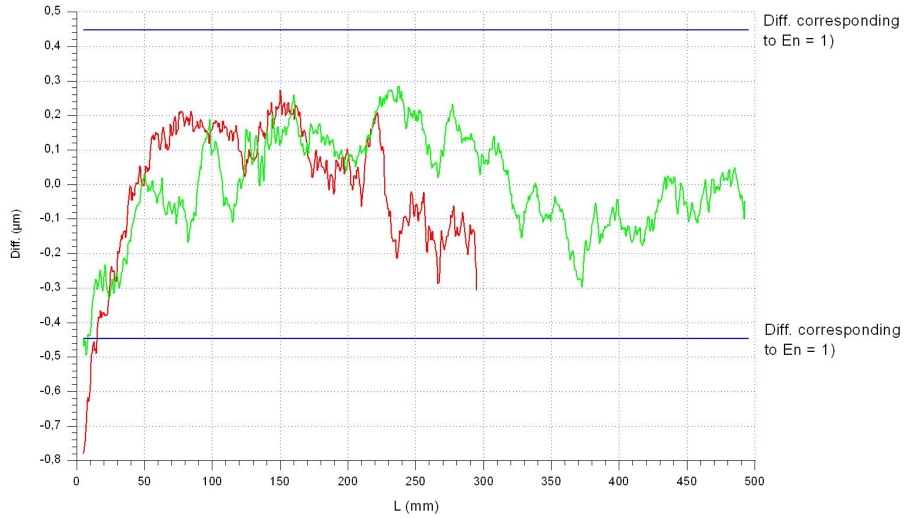
	Mean of $\lvert BA_{MIKES} - BA_{SMU} \rvert$* (µm)	En value	sd of $\lvert BA_{MIKES} - BA_{SMU} \rvert$* (µm)	Min BA (µm)	Max BA (µm)
MIKES - SMU	0,12	0,27	0,15	-0,49	+0,28
MIKES – SMU without first 50 mm	0,11	0,25	0,12	-0,30	+0,28

Profile BD:

	Mean of $\lvert BD_{MIKES} - BD_{SMU} \rvert$* (µm)	En value	sd of $\lvert BD_{MIKES} - BD_{SMU} \rvert$* (µm)	Min BD (µm)	Max BD (µm)
MIKES - SMU	0,15	0,34	0,19	-0,78	+0,27
MIKES – SMU without first 50 mm	0,13	0,29	0,13	-0,31	+0,27

Graphs of profiles:

MIKES and SMU - Straightness measurements within EUROMET 905
Side BA and BD (MZ) - smoothet (20 point) diff. SMU - MIKES



Taking into account the calculated value of En, the difference between values of measured angle submitted by both participants are within the claimed uncertainties.

The mean value, calculated from the absolute values of differences for each measuring point, is affected by the noticeable local differences corresponding to first 50 mm section of BA and BD. After removing of data for the first 50 mm, the results improve considerably (see the last line of the table).

It can be seen that the value En = 1 is exceeded just within the first 15 mm.

Therefore it can be concluded that both NMIs meet the MRA criteria required for the acceptation of claimed uncertainties for both parameters (squareness, straightness).