Slovenský metrologický ústav
Slovak Institute of Metrology
Slowakisches Institut für Metrologie

EUROMET Supplementary Comparison #910

Comparison of squareness measurements

Final Report

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File: Project_SQUARE_910-Final Report An.doc / Issue 13. 4. 2010

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 (GUM) 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 organized 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
Central Office of Measures	GUM	ul. Elektoralna 2, 00-950 Warszawa, P-10, Poland	Anna Kapinska-Kiszko	length@gum.gov.pl	+48 22 581 9406

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	November 2007
GUM	PL	June 2008
SMU	SK	September 2008

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

5 Description of the Standard

Cylindrical squareness standard of steel with 102 mm diameter and 401,5 mm height with marked positions for the profile lines, weight 25 kg.

6 Measurement instructions

6.1 Definitions

Angle between fitting line (in the case of the cylindrical standard) – the angles are understood as the interior angles between the corresponding LS regression-lines fitted through the measured profiles at 30°, 120°, 210°, 300° and the envelope plane of the basis (see Fig. 1).

The measured profiles – the generatrix profiles at 30°, 120°, 210°, 300° (marked on the "TOP" plane) around the circumference of a cylinder.

The starting point of measurement – 5 mm from the zero point. 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".

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

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

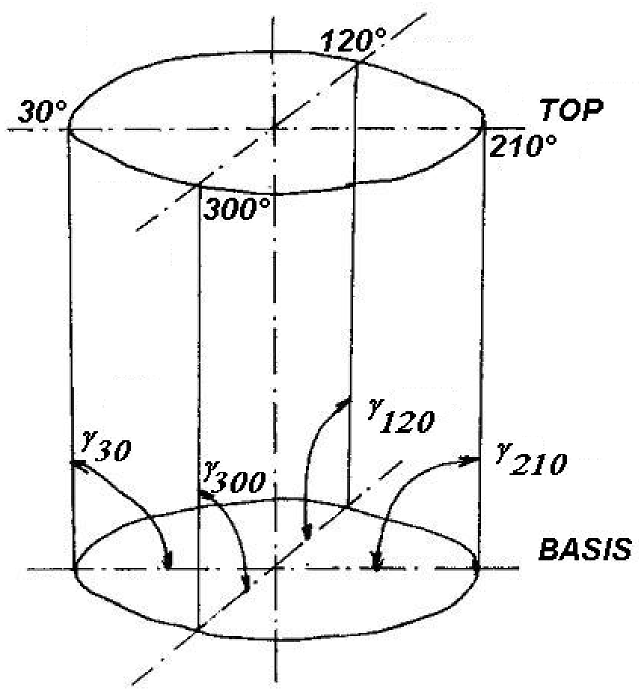


Fig. 1

Squareness shall be measured using the technique currently used by the participant. This method shall be in details described by each participant in the "Measurement Report".

7 Measurands

The following parameters have to be calibrated:

- interior angles between the LS regression-line fitted through the measurement profiles at 30°, 120°, 210°, 300° and the envelope plane of the basis (resting on a surface plate),
- local LS straightness deviation for all measured profiles (4) of standard (results 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 base 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 GUM

Description of measuring device:

Coordinate measuring machine CMM5 Nr 302

manufacturer: SIP firm, Switzerland,

measuring range: up to 700 mm along X axis, up to 500 mm along Y and Z axis

axial measuring accuracy : 0,5 µm + L/1200mm

spatial measuring accuracy: 0,8 µm + L/1200mm

The machine can measure both in “point to point” mode and scanning mode

Procedure of measurement:

The cylindrical square was measured in vertical position in ZX measuring plane of the machine. It was placed on the granite surface plate which was set on measuring table of the machine (Fig.1). This surface plate was established a measuring basis.

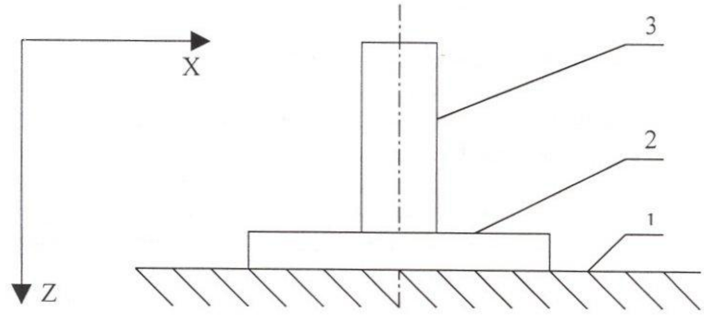


Fig.1. The position of cylindrical square in measuring space of the machine.

1) measuring table of the machine, 2) surface plate, 3) cylindrical square

The corresponding LS fitting lines were measured using two methods of measurement. Firstly by probing points using special program for line measurement. Secondly by probing points using scanning mode. The density of measuring points on each line was about 0,5 mm in both used methods of measurement. The angles between the respective LS fitting lines (30°, 120°, 210°,300°) and envelope plane of the basis were measured five times. The reference system was established according to the axis of the cylindrical square. These two methods of measurement were used for comparison of the results.

Procedure of result calculation:

The angles between the respective LS fitting lines (30°, 120°, 210°, 300°) and the basis were calculated as a mean value obtained from all measurements made for the each line. The calculations were carried out for the two methods of measurement separately.

As regards the local straightness deviation the corresponding LS fitting lines were estimated from all measured points probed using special program for line measurement. Then the distances between the respective points and corresponding points laying on these lines were calculated. As a result the worst deviations from the respective LS fitting lines were chosen from all measured lines.

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

Uncertainty evaluation of angles between respective LS fitting lines and the basis.

The total uncertainty of angles between respective LS fitting lines and the basis was evaluated taking into account the following influences:

I) short term reproducibility of LS line position,

2) short term reproducibility of the surface plate position including flatness deviation,

3) error of the angle between two axes of the machine,

4) error emerging from temperature gradient in measuring plane of the machine,

5) error emerging from used method of measurement.

Short term reproducibility of every LS fitting line position (30°, 120°, 210°, 300°) was evaluated as a maximal difference between obtained values of the respective LS fitting line measured five times and repetition of the measuring program for a few days. As a result the worst value obtained from all measurement for each line was accepted.

Short term reproducibility of the surface plate position including flatness deviation was evaluated as a sum of the influences emerging from measurement of the surface plate position and influences emerging from measurement of its flatness. The surface plate position was measured every time before measurement of LS fitting line position. The worst value obtained from all measurements was accepted as a result. Flatness of the surface plate was measured before starting of measuring program and then its influence for angle measurement was estimated.

Error of the angle between two axes of the machine was taken from calibration certificate of the machine. Error emerging from temperature gradient in measuring plane of the machine was estimated as the following:

temperature gradient in measuring plane of the machine during measurement was 0,08 °C,

thermal expansive coefficient for steel is $11{,}5 * 10^{-6} * °C^{-1}$,

the value of the length taken into ca1culation is 400 mm,

so $0{,}08\ °C * 11{,}5 * 10^{-6} * °C^{-1} * 400\ mm = 0{,}000368\ mm$,

the change of the angle is a = 0,00000092 rad,

a = 180°/3,14*0,00000092 = 0,00005° (about 0,2").

The error emerging from used method of measurement was calculated as a maximal difference between the value of the angle obtained from the first method and the value of the angle obtained from the second method. This difference is 0,2"

Uncertainty budget of local straightness deviation for the cylindrical square

Source of uncertainty	**Magnitude**	**Type of distribution**	**Standard uncertainty**	**Sensitivity coefficient**	**Uncertainty**
Short termreproducibility of the local straightness measurement	0,6 µm	Rect.	0,35 µm	1	0,35 µm
Probing error	0,3 µm	Norm.	0,10 µm	1	0,1 µm
Error emerging from temperature gradient in measuring plane	0,5 µm	Rect.	0,29 µm	1	0,29 µm

Total uncertainty of local straightness deviation for k = 1 is 0,47 µm

Uncertainty budget of angle measurement between LS fitting line and the basis

Source of uncertainty	Magnitude	Type of distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty
Short term reproducibility of LS fitting line position	0,7"	Rect.	0,41"	1	0,41"
Short term reproducibility of the surface plate position including flatness deviation	0,7"	Rect.	0,41"	1	0,41"
Error of the angle between two axes of the machine	0,3"	Rect.	0,18"	1	0,18"
Error emerging from temperature gradient in measuring plane of the machine	0,2"	Rect.	0,12"	1	0,12"
Error emerging from used method of measurement	0,2"	Rect.	0,12"	1	0,12"

Total uncertainty of the angle measurement between LS fitting line and the basis for k = 1 is 0,64".

Comments:

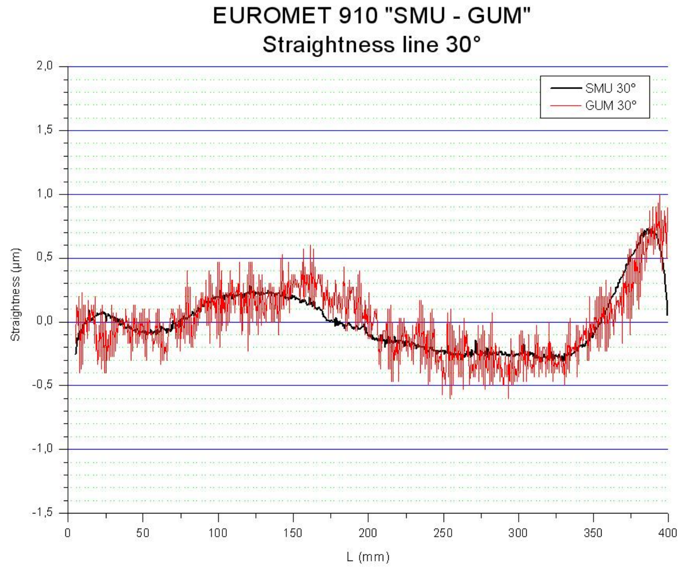
The density of probed points during measurement of cylindrical square is not exactly 0,5 mm because of the measuring software of the machine. Although the entered value is 0,5 mm the software corrected this value by itself in measuring range.

10 Results

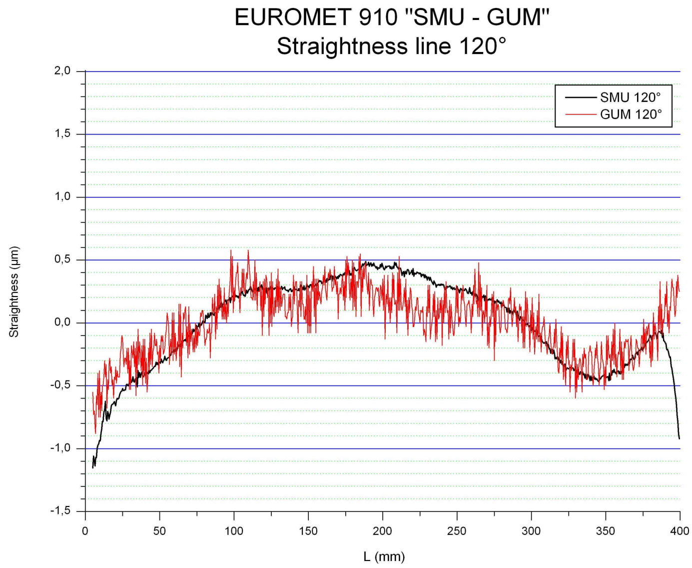
10.1 Straightness

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

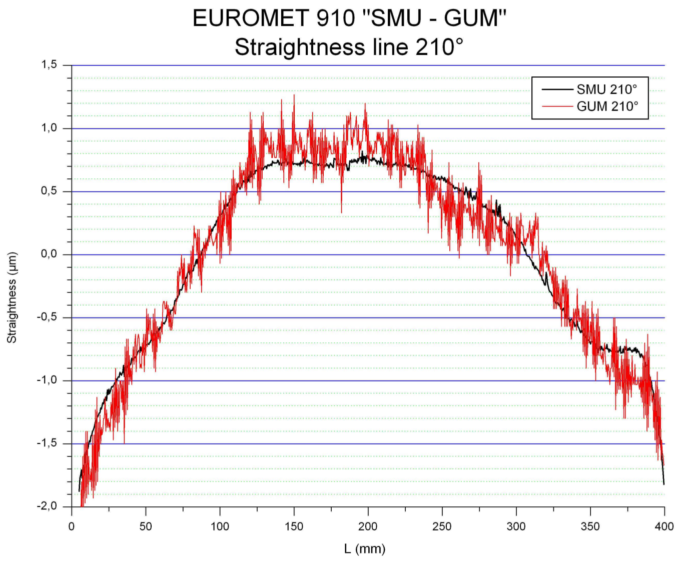
Measurements of profile 30°:



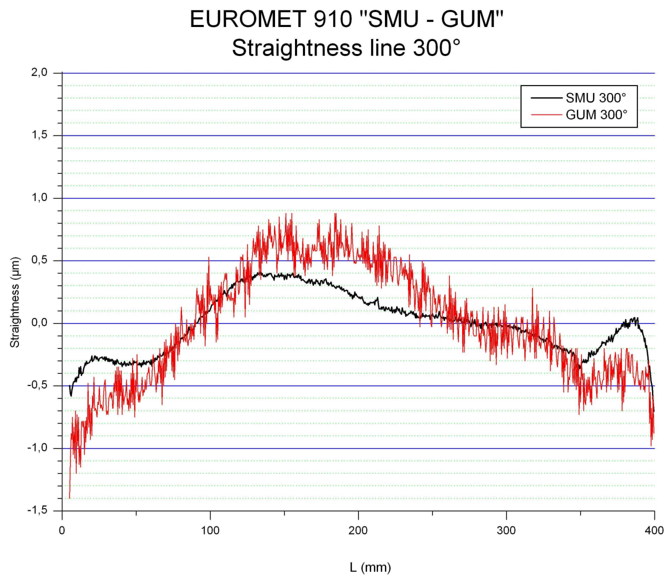
Measurements of profile 120°:



Measurements of profile 210°:

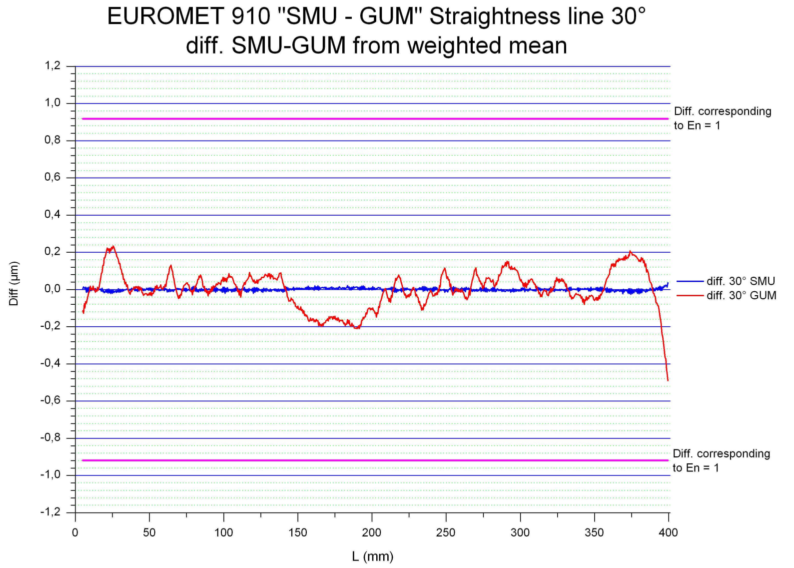


Measurements of profile 300°:

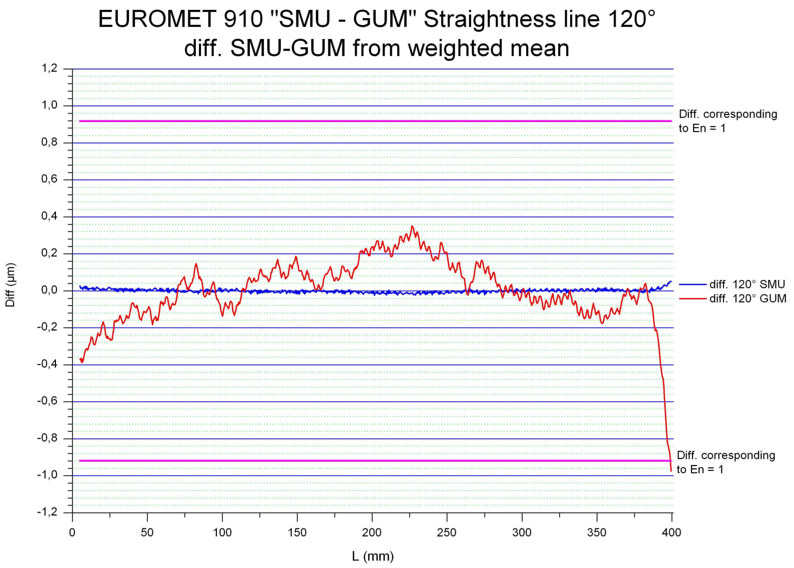


The following graphs show the deviations of indidual profiles from the weighted mean and limits corresponding to the *En* = 1 (for U_{SMU} = 0,20 µm, U_{GUM} = 0,94 µm).

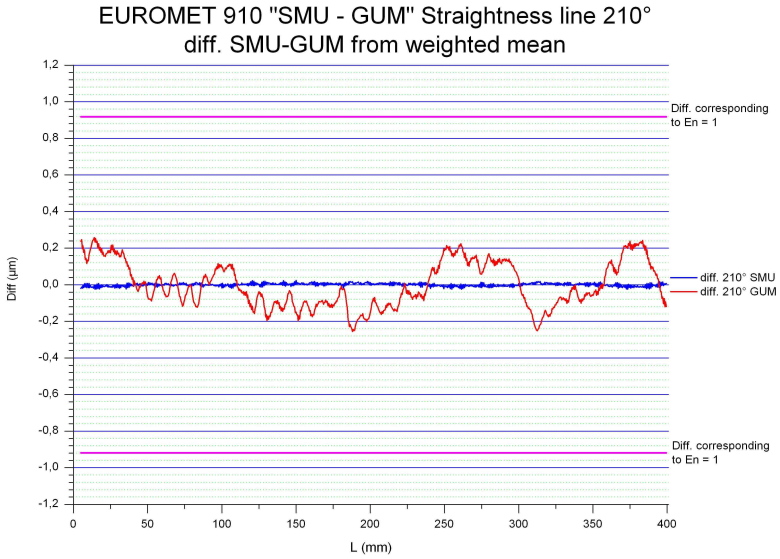
Differences of profile 30°:



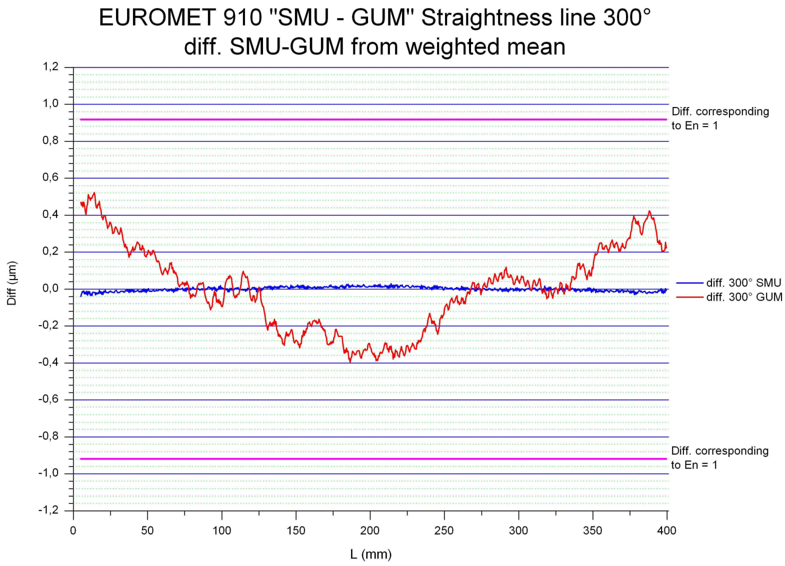
Differences of profile 120°:



Differences of profile 210°:



Differences of profile 300°:



Comments to the graphs:

En values exceed 1 just for the 120°profile, namely 4 last points from the total number of 790. It is well bellow the expected number (39 or 40), corresponding to the *P* = 95% uncertainty.

Squareness

Angle deviations of individual NMIs from 90°:

Profiles	Angle deviations γ SMU (")	Angle deviations γ GUM (")	Diff. SMU (")	Diff. GUM (")	*En* value (")
30°	2,19	1,94	-0,02	0,22	0,26
120°	-1,54	-1,98	-0,04	0,40	0,46
210°	-3,10	-3,02	0,01	-0,07	0,08
300°	1,10	1,40	0,03	-0,28	0,32

The reference values were calculated as the weighted mean deviations from 90° for each profile (U_{SMU} = 0,20", U_{GUM} = 1,28")

11 Conclusion

Taking into account the calculated value of *En*, the results of measured straightness can be (with the comments to the graphs) claimed as consistent.

Taking into account the calculated value of *En*, the difference between values of measured angle submitted by both participants can be claimed as consistent.

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