LABORATORY FOR PRODUCTION MEASUREMENT

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SOP 13

CALIBRATION OF GAUGE RING DIAMETERS

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Evidence of changes (regarding the previous issue)

Amendment No.	Changed	Removed	Added
	Chapter	Chapter	Chapter
1	10.1		
2	10.2		
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CONTENTS

1 INTRODUCTION

This procedure describes steps taken when calibrating gauge rings of diameters 2 mm to 300 mm by two point method excluding form measurement, and by scanning procedure.

1.1 General

Ring gauges are used as standards for internal diameters. In our laboratory are they mostly used for comparative task related calibration of the CMM for all measurements and calibrations of internal diameters (screw ring gauges, industrial ring gauges etc.)

2 MEASUREMENT EQUIPMENT

Standard rings 14/50/150	-	Zeiss/Mitutoyo (set of 3)
Coordinate measuring machine	-	ZEISS UMC 850
Thermometer	-	ALMEMO 6290-7

3 RECEIPT

A gauge is received from the customer and is visually checked for any obvious defects like scratches or other defects (e.g. corrosion) which would impede the calibration. The customer's name, the type and an identification number of the gauge is also noted. It is checked whether the number of received gauges complies with the attached documentation.

4 CLEANING

Before the measurement, the measuring object is carefully cleaned (especially internal cylinder) with petroleum ether and checked by means of a magnifier. The measuring surface shall be perfectly clean, dry and smooth. Very damaged gauge rings (visible scratches) can be polished (after getting a confirmation of the customer). A micro-finishing film (Aluminium Oxide - 9µm) produced by 3M and special oil EXKA 10 (red) is used for this purpose. Polishing of the surface is performed by rolling the ring on a flat surface, while internal cylinder (measuring surface) is oiled with proper amount of micro-finishing film. This film is pushed against the surface with a finger under gentle pressure. Influence on the diameter change is negligible. Measuring surfaces of the standard rings, as well as the device probes and guides are cleaned with petroleum ether, as well.

5 TEMPERATURE STABILISATION

The gauge ring is stabilised at laboratory conditions for 5 hours. Environmental conditions (temperature, humidity and air pressure) during the measurement is measured with ALMEMO 710. The device temperature is measured with the material sensor ALMEMO 6290-7 and the result is corrected to 20 °C. During the scanning procedure, temperature of the fixing plate is measured as described in Chapter 6.2.

6 CALIBRATION – TWO POINT COMPARATIVE METHOD

6.1 Description of the method

Two-point comparative calibration of gauge rings is performed by means of CMM ZEISS - UMC 850. The calibration is limited to diameters from 2 mm to 300 mm. Reference gauge rings in this procedure are Carl Zeiss_0455 (diameter 14 mm), Carl Zeiss_005378 (diameter 50 mm) and Mitutoyo_970024 (diameter 150 mm).

6.2 Fixing the gauge rings on the base plate and temperature control

The calibrated and the reference (standard) ring (see Ch. 6.4) are put on a proper flat base and are fixed by using fixing elements on the working surface (see Fig. 3) in the way, that main probing direction is parallel with the Y-axis of the CMM. The rings shall be as close as possible to each other on the same height (z axis). Before the measurement, the reference (standard) rings are carefully cleaned (especially internal cylinder) with petroleum ether.

The temperature is beside the cleanliness the most important influence quantity. Very important is the temperature difference between the calibrated and the reference gauge ring. Therefore, the temperature of the base plate is measured during the calibration by means of the contact thermometer ALMEMO 6290-7 (Id. No.: S40679). Measured temperature is considered as the mean temperature of both rings. The temperature sensor is positioned between the two rings on the base plate. The temperature during the measurement shall be between 19,5° C and 20,5 °C. The rings should be handled by using protection gloves to prevent the temperature flow from operator's hands. In order to achieve the specified temperature interval, the rings are stabilised after fixing them during a necessary period of time. The air conditioner can be adjusted for this purpose, as well.

6.3 CMM calibration by means of the standard (reference ring)

Proper reference gauge ring dimension and stylus diameter is chosen in accordance with the diameter of the ring to be calibrated. The following table is used for orientation:

Measurement range (mm)	Standard ring (mm)	Ident. No. of the reference ring	Stylus diameter (mm)
2,0 to 4,0	14	ZEISS - 0455	0,8
above 4,0 to 35	14	ZEISS - 0455	2,0
above 35 to 125	50	ZEISS - 005378	5,0
above 125 to 300	150	MITUTUYO - 970024	5,0

The reference ring should be aligned in such way, that direction of probing is parallel with the Y-axis of the CMM (lines on the upper rings surface).

The coordinate system of the reference ring is defined in the following way: the primary basis is defined on internal cylinder, which is scanned in a helix way (HELIX). The beginning and the end of the scanning way should be in a distance of about 10 % of the ring thickness from the front surfaces. CMM calibration is performed by probing the two most distant points in Y direction (X = 0,0000) on height H/2 (Z = -H/2), perpendicular to the cylinder axis and symmetrical between both surfaces of the standard ring. Distance between this two points in Y direction is measured by using the function "DISTANCE Y" (point1 – point2). The probe radius is corrected as long as the measured diameter is deviating from the calibrated ring diameter less than D_{cal} ±0,05 μm (D_{cal} is calibrated ring diameter). The measurement is repeated 10 times.

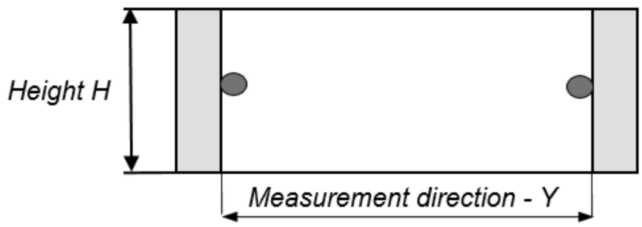

Figure 1: Measurement strategy

6.4 Measurement of the ring to be calibrated

The primary basis is defined in the same way as for the reference ring (Helix-path). Measurement is performed by probing the two most distant points in Y direction (X = 0,0000) on height H/2 (Z = -H/2), perpendicular to cylinder axis and symmetrical between both surfaces of ring. Distance between this two points in Y coordinate direction is measured by use of function "DISTANCE Y" (point1 – point2). The probe diameter is of course **not changed** during this measurement**!** The measurement is repeated 10 times. The final result is the mean value of all measurement results. The calibration result (deviation) is representing the difference between actual (measured) and nominal value of the ring. The gauge ring diameter is measured in the main probing direction lying in the plane P and oriented perpendicular to the ring axis (Figure 2). If this direction is marked on the ring, it is measured in the marked direction. If such direction is not marked, than the measurement direction is perpendicular to the direction going through indication inscriptions and is marked with a waterproof marker.

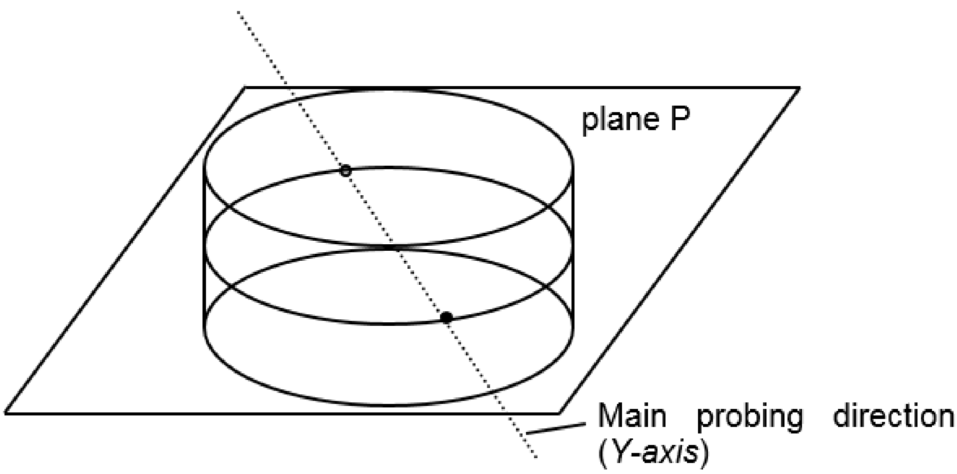

Figure 2: Probing direction on cylinder

6. A CALIBRATION - SCANNING PROCEDURE

6.1 A Description of the method

Gauge rings can also be calibrated by mans of a comparative method on the CMM ZEISS - UMC 850. The calibration is limited to diameters from 0,5 mm to 300 mm. Reference gauge rings in this procedure are Carl Zeiss_0455 (diameter 14 mm), Carl Zeiss_005378 (diameter 50 mm) and Mitutoyo_970024 (diameter 150 mm).

6.2 A Fixing the gauge rings on the base plate

The calibrated and the reference (standard) ring (see Ch. 6.4 A) are put on a proper flat base and are fixed by using fixing elements on the working surface of the rotary table (see Fig. 3). The rings shall be as close as possible to each other on the same height (z axis). Before fixing the rings, the table shall be turned counter-clockwise for -16° in 30′ . The purpose of this turn is to adjust the direction of the table groove parallel with the Y-axis of the CMM. After that, the table is not turned any more.

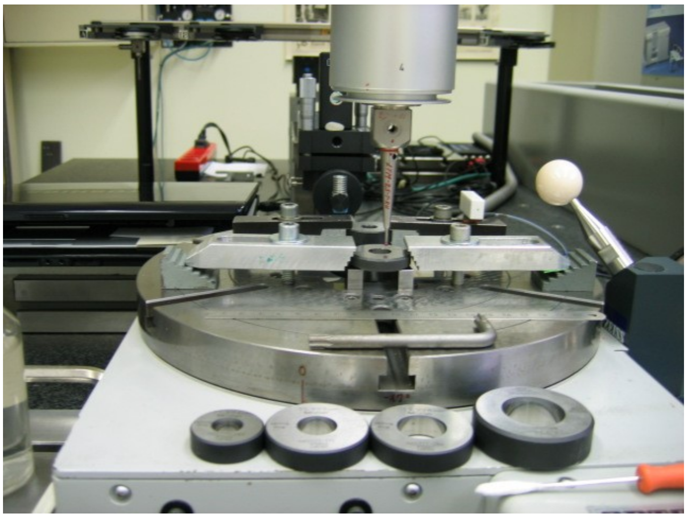

Figure 3: Fixing the gauge rings on the rotary table

6.3 A Temperature of the gauge rings

The temperature is beside the cleanliness the most important influence quantity. Very important is the temperature difference between the calibrated and the reference gauge ring. Therefore, the temperature of the base plate is measured during the calibration by means of the contact thermometer ALMEMO 6290-7 (Id. No.: S40679). Measured temperature is considered as the mean temperature of both rings. The temperature sensor is positioned between the two rings on the base plate. The temperature during the measurement shall be between 19,5 °C and 20,5 °C. The rings should be handled by using protection gloves. In order to achieve the specified temperature interval, the rings are stabilised after fixing them during a necessary period of time. The air conditioner can be adjusted for this purpose, as well.

6.4 A CMM calibration by means of the standard (reference ring)

This calibration is performed by following the procedure SOP 11. Proper reference gauge ring dimension is chosen in accordance with the diameter of the ring to be calibrated. The following table is used for orientation:

Measurement range	Chosen standard (reference ring)	Ident. No. of the reference ring	Probe diameter
(0,5 to 1,5) mm	14 mm	ZEISS - 0455	0,3 mm
(1,5 to 4,0) mm	14 mm	ZEISS - 0455	0,5 mm
(4,0 to 35) mm	14 mm	ZEISS - 0455	2,0 mm
(35 to 125) mm	50 mm	ZEISS - 005378	5,0 mm
(125 to 300) mm	150 mm	MITUTUYO - 970024	5,0 mm

The coordinate system on the gauge ring in the following way: the primary basis is defined on internal cylinder, which is scanned in a helix way (Helixbahn). The beginning and the end of the scanning way should be in a distance of about 10 % of the ring thickness from the front surfaces. Calibration is performed by scanning the circle, which is perpendicular to the internal cylinder axis and symmetrically to both front surfaces. Thy circle is measured by using SW function GAGE CORRECTION QUALIFICATION. The probe radius is corrected as long as the measured diameter is deviating from the calibrated ring diameter less than +/- 0,05 µm. The measurement is repeated 10 times..

6.5 A Comparative measurement of the ring to be calibrated

The primary basis is defined in the same way as for the reference ring (Helixbahn; see 6.4 A). The measurement circle is also defined in the same way (see 6.4 A). The measurement is performed by scanning the circle by using SW function GAGE CORRECTION. The probe diameter is of course not changed during this measurement. The measurement is repeated 10 times. The final result is the mean value of all measurement results.

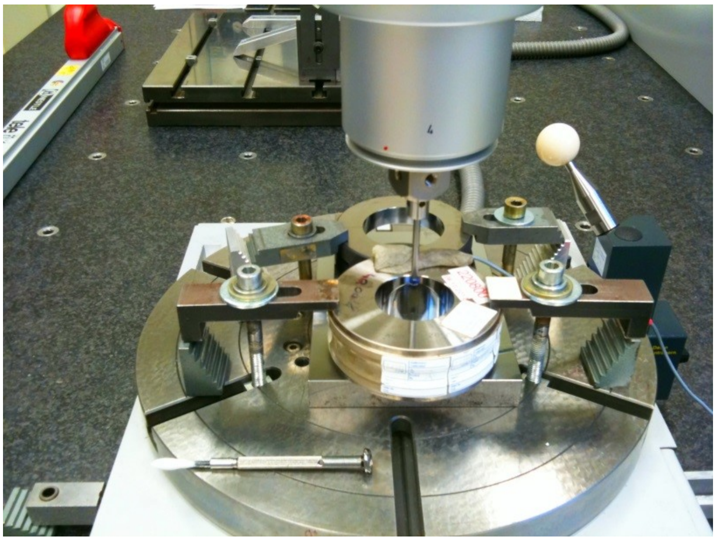

Figure 4: Comparative measurement of a gauge ring

7 EVALUATION OF MEASUREMENT RESULTS

Measurement results are stored in the protocol ZEISS CALYPSO. The calibration result is the mean value of 10 measurements (calculated in the ZEISS protocol). When the scanning procedure is applied, roundness is evaluated in the ZEISS protocol, as well. Measured (calculated) values are entered directly into the calibration certificate template (see Chapter 8!). No temperature correction is applied in the comparative measurements on the ZEISS CMM, because both rings have nearly equal temperature.

8 DOCUMENTATION

The calibration record (original ZEISS CALYPSO protocol) is sored into a relevant sub-folder (SOP 13/Zapisi, relevant year) of the folder »3-Zapisi in certifikati«. Instruction for storing records in Quality manual (Ch. 6.2) shall be followed. The second page of the calibration certificate is created by using a template »Predloga_2stran-SOP13.dotx«, which is stored in the folder »4-Sistem kakovosti/SOP/SOP13-Premer nastavnih obročev«. The calibration certificate is created and archived in accordance with instructions in the Quality Manual (Ch. 6.1).

9 PROTECTION

The ring gauges are oiled with special oil for measurement instruments.

10 UNCERTAINTY OF THE TWO POINT METHOD

10.1 Mathematical model of measurement

Since the measurement is repeated 10 times, the final result is calculated as an arithmetic mean of 10 measurements:

$$D = \frac{1}{10}\sum_{i=1}^{10} D_i \quad (1)$$

$$D_i = D_c - L(\bar{\alpha} \cdot \delta T + \delta\alpha \cdot \bar{\theta}) + p_a \quad (2)$$

where:

- D – calibration result (calibrated diameter) at 20 °C
- D_i – single measurement result at 20 °C
- D_c – diameter calculated by the CMM from measurement points
- L – nominal diameter (with no uncertainty)
- $\bar{\alpha}$ – average temperature expansion coefficient of the calibrated ring and the CMM measurement system
- δT – difference between the temperatures of the calibrated ring and the CMM measurement system
- $\delta\alpha$ – difference between the temperature expansion coefficients of the calibrated ring and the CMM measurement system

$\bar{\theta}$ – average temperature deviation of the calibrated ring and the CMM measurement system from 20 °C

p_a – deviation of the measured diameter due to the ring alignment (diameter not measured through the centre of the ring)

10.2 Standard uncertainty of a single measurement $u(D_i)$

Equation for calculating total standard uncertainty from [1] is in our case:

$$u_c^2(D_i) = c_{Dc}^2 u^2(D_c) + c_\alpha^2 u^2(\bar{\alpha}) + c_{\delta T}^2 u^2(\delta T) + c_{\delta\alpha}^2 u^2(\delta\alpha) + c_\theta^2 u^2(\bar{\theta}) + c_{pa}^2 u^2(p_a) \qquad (5)$$

where c_i are partial derivatives of the function f (4):

$c_{Dc} = \partial f/\partial D_c = 1$

$c_\alpha = \partial f/\partial \bar{\alpha} = -L \cdot \delta T$

$c_{\delta T} = \partial f/\partial \delta T = -L \cdot \bar{\alpha}$

$c_{\delta\alpha} = \partial f/\partial \delta\alpha = -L \cdot \bar{\theta}$

$c_\theta = \partial f/\partial \bar{\theta} = -L \cdot \delta\alpha$

$c_{pa} = \partial f/\partial p_a = 1$

a) Uncertainty of the calculated diameter $u(D_c)$

Standard uncertainty of the comparative measurement is evaluated in the procedure SOP 11 (experiment, presented in points 10.2.6 and 10.2.7 of SOP 11). Standard ring pairs (14 mm – 50 mm) and (50 mm – 150 mm) were used. Standard uncertainty u_s was calculated from 4 contributions (mean deviation from the calibrated value, standard deviation in 15 measurements, standard uncertainty of calibration – for 2 rings). The constant part was evaluated from the first two cases (14 mm – 50 mm and 50 mm – 14 mm). It is estimated to be:

$u_{sconst} = 0{,}08$ µm

Since the measurement is repeated 10 times in each calibration, the final standard uncertainty of the mean value is calculated as follows:

$$u(D_c)_{\text{const}} = \sqrt{u_{sconst}^2 + \frac{s^2}{10}}$$

where:

s - standard deviation from 10 measurements

Standard deviation s is normally within 0,1 µm (also in the test according to SOP 11), therefore:

$u(D_c)_{\text{const}} = 0{,}09$ µm

In addition, there is a linear contribution, evaluated according to SOP 11:

$u(D_c)_{\text{lin}} = 0{,}9 \cdot 10^{-6} \cdot L$

b) Uncertainty of the average temperature expansion $u(\bar{\alpha})$)

The interval $\pm 1 \cdot 10^{-6}$ °C^{-1} is defined based of the data from a handbook (for steel). Standard uncertainty at the supposed rectangular distribution is:

$$u(\alpha_m) = (1 \cdot 10^{-6} °\mathrm{C}^{-1})\sqrt{3} = 0{,}58 \cdot 10^{-6} °\mathrm{C}^{-1}$$

c) Uncertainty of the temperature difference $u(\delta T)$

The rings are fixed on the same base plate and the temperature of the plate is measured. The temperature of the plate during the measurement is limited to (20±0,2) °C (see chapter 6.3.A). The difference interval of 0,1 °C is defined based on some experiments. Standard uncertainty at the assumed normal distribution is:

$u(\delta T)$ = 0,1/2 °C = 0,05 °C

d) Uncertainty of the temperature expansion coefficient difference $u(\delta\alpha)$

Since the temperature expansion is not corrected, the difference between the temperature expansion of the CMM measurement system (producer's specification: $\alpha = 8 \cdot 10^{-6}$ °C^{-1}) and the calibrated ring (steel; $\alpha = 10{,}5 \cdot 10^{-6}$ °C^{-1}) $I_{\delta\alpha} = 2{,}5 \cdot 10^{-6}$ °C^{-1} is supposed as the deviation interval. Standard uncertainty at the supposed rectangular distribution is:

$u(\delta\alpha) = 2{,}5 \cdot 10^{-6}$ °C$^{-1}/\sqrt{3} = 1{,}44 \cdot 10^{-6}$ °C^{-1}

Since the measurement is comparative, this difference is influencing the measurement result only on the half measurement length in the worst case (when comparing 300 mm ring with the 150 mm ring). Therefore we use $L/2$ in the sensitivity coefficient!

e) Uncertainty of the average temperature deviation from 20 °C $u(\bar{\theta})$

The temperature expansion is not corrected, but the allowed temperature deviation during the calibration is limited to (20±0,5) °C. Standard uncertainty at the supposed rectangular distribution is:

$u(\theta_m) = 0{,}5$ °C $/\sqrt{3} = 0{,}29$ °C

Since the measurement is comparative, we apply mean difference in α in sensitivity coefficient calculation (in the worst case – calibration of 300 mm ring with the 150 mm reference, we take the difference in α between the reference ring and the ring under calibration (assumed not to excide $1 \cdot 10^{-6}$ °C^{-1}) on half length (150 mm) and on the other 150 mm the difference between the CMM measurement system and the ring under calibration (assumed not to excide $4 \cdot 10^{-6}$ °C^{-1}). Average difference in α is assumed to be $2{,}5 \cdot 10^{-6}$ °C^{-1}.

f) Uncertainty due to the ring alignment $u(p_a)$

Measurement direction for 2-point diameter measurement is defined by the CMM SW based on the initial cylinder measurement. Measurement plane is defined to be rectangular to the cylinder axis, while the measurement line (in this plane) should intersect the cylinder axis. Concerning the defined CMM uncertainty, maximum deviation of the calculated measurement line is estimated to be within ±2 µm. The biggest possible deviation is expected on the smallest ring measured by using this procedure (D_{min} = 2 mm). Simple calculation shows that the deviation of the measured diameter is within 2 nm, which is negligible in our uncertainty budget.

Table 2: Uncertainty budget for two-point measuring procedure

Quantity X_i		Estimated value x_i	Standard uncertainty $u(x_i)$	Distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y) = c_i \cdot u(x_i)$
D_c	*const*	0 mm	0,09 µm	Normal	1	0,09 µm
	lin	L	$0{,}9\cdot10^{-6}\cdot L$	Normal	1	$0{,}9\cdot10^{-6}\cdot L$
$\overline{\alpha}$		$9{,}5\cdot10^{-6}$ °C^{-1}	$0{,}58\cdot10^{-6}$ °C^{-1}	Rectangular	0,1 °C·L	$0{,}06\cdot10^{-6}\cdot L$
δT		0 °C	0,05 °C	Normal	$9{,}5\cdot10^{-6}$ °C$^{-1}\cdot L$	$0{,}47\cdot10^{-6}\cdot L$
$\delta\alpha$		$2{,}5\cdot10^{-6}$ °C^{-1}	$1{,}44\cdot10^{-6}$ °C^{-1}	Rectangular	0,5 °C·L	$0{,}72\cdot10^{-6}\cdot L$
$\overline{\theta}$		0 °C	0,29 °C	Rectangular	$2{,}5\cdot10^{-6}$ °C$^{-1}\cdot L$	$0{,}72\cdot10^{-6}\cdot L$
p_a		0 mm	0,002 µm	Rectangular	1	0,002 µm
					Total :	$\sqrt{(0{,}09\ \mu m)^2 + (1{,}4\cdot10^{-6}\cdot L)^2}$

10.3 Standard uncertainty of the calibration result *u*(*D*)

Calculated standard uncertainty is:

$$u = \sqrt{(0{,}09\ \mu m)^2 + (1{,}4 \cdot 10^{-6} \cdot L)^2}$$

10.4 Expanded uncertainty

According to EA coverage factor k=2 is used for the calculation of the expanded uncertainty. The best expanded uncertainty is:

$$U = \sqrt{(0{,}2\ \mu m)^2 + (2{,}8 \cdot 10^{-6} \cdot L)^2}\ ; k = 2$$

10.A UNCERTAINTY OF THE SCANNING PROCEDURE

10.1.A Mathematical model of measurement

Since the measurement is repeated 10 times, the final result is calculated as an arithmetic mean of 10 measurements:

$$D = \frac{1}{10}\sum_{i=1}^{10} D_i \quad (3)$$

$$D_i = D_c - L(\bar{\alpha} \cdot \delta T + \delta\alpha \cdot \bar{\theta}) - p_n \quad (4)$$

where:

- D – calibration result (calibrated diameter) at 20 °C
- D_i – single measurement result at 20 °C
- D_c – diameter calculated by the CMM from measurement points
- L – nominal diameter (with no uncertainty)
- $\bar{\alpha}$ – average temperature expansion coefficient of the calibrated ring and the CMM measurement system
- δT – difference between the temperatures of the calibrated ring and the CMM measurement system
- $\delta\alpha$ – difference between the temperature expansion coefficients of the calibrated ring and the CMM measurement system
- $\bar{\theta}$ – average temperature deviation of the calibrated ring and the CMM measurement system from 20 °C
- p_n – random error of the actual diameter due to roundness deviation of the calibrated ring

10.2.A Standard uncertainty of a single measurement $u(D_i)$

Equation for calculating total standard uncertainty from [1] is in our case:

$$u_c^2(D_i) = c_{Dc}^2 u^2(D_c) + c_\alpha^2 u^2(\bar{\alpha}) + c_{\delta T}^2 u^2(\delta T) + c_{\delta\alpha}^2 u^2(\delta\alpha) + c_\theta^2 u^2(\bar{\theta}) + c_{pn}^2 u^2(p_n) \quad (5)$$

where c_i are partial derivatives of the function f (4)

$c_{Dc} = \partial f / \partial D_c = 1$

$c_\alpha = \partial f / \partial \bar{\alpha} = -L \cdot \delta T$

$c_{\delta T} = \partial f / \partial \delta T = -L \cdot \bar{\alpha}$

$c_{\delta\alpha} = \partial f / \partial \delta\alpha = -L \cdot \bar{\theta}$

$c_\theta = \partial f / \partial \bar{\theta} = -L \cdot \delta\alpha$

$c_{pn} = \partial f / \partial p_n = 1$

Standard uncertainties of the input quantities are evaluated (estimated) for the used measurement standard, calibration procedure, and assumed measurement conditions. When calculating CMC, “ideal” ring with zero roundness deviation is presumed. The uncertainty of an actual calibration considering the roundness deviation of the calibrated ring is evaluated by applying and Excel application »Negotovost SOP13.xlsx« (stored in the folder “»4-Sistem kakovosti/SOP/SOP13-Premer nastavnih obročev”).

a) Uncertainty of the calculated diameter $u(D_c)$

Standard uncertainty is evaluated in the procedure SOP 11 (experimental). We made a comparison between standard rings 14 mm and 50 mm. In the correction of measuring results to the calibrated value we considered the calibrated values of rings diameter (14 mm and 50 mm; two-point measurement; see 10.2 a) and also the roundness deviation (comparative diameter is an average value of the ring diameter). Roundness values are shown in Figure 5:

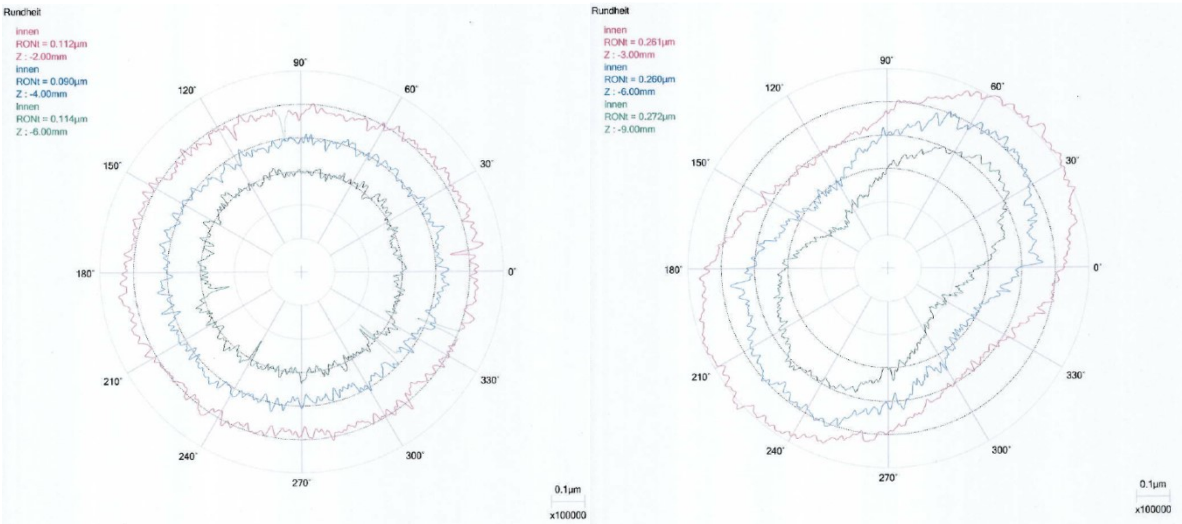

Figure 5: Roundness of standard ring 14 mm (0,1133 µm) –left and standard ring 50 mm (0,361 µm) – right

Standard uncertainty influenced by roundness at calibration of rings 2 mm up to 120 mm diameters is estimated by:

u= 0,15 µm

Average uncertainty is:

$$u = \sqrt{0{,}2\ \mu\text{m}^2 + 0{,}15\mu\text{m}^2} = 0{,}25\ \mu\text{m}$$

Because of roundness deviation 0,975 µm at 150 mm ring, the standard measurement uncertainty influenced by roundness deviation is

u = 0,6 µm

In calibration of rings with diameters 125 mm to 300 mm, the uncertainty budget is

u = 0,7 µm.

b) Uncertainty of the average temperature expansion $u(\overline{\alpha})$

The interval $\pm 1\cdot 10^{-6}$ °C^{-1} is defined based of the data from a handbook (for steel). Standard uncertainty at the supposed rectangular distribution is:

$$u(\alpha_m) = (1 \cdot 10^{-6}°\text{C}^{-1})\sqrt{3} = 0{,}58 \cdot 10^{-6}°\text{C}^{-1}$$

c) Uncertainty of the temperature difference $u(\delta T)$

The rings are fixed on the same base plate and the temperature of the plate is measured. The temperature of the plate during the measurement is limited to (20±0,5) °C (see chapter 6.3.A). The difference interval of 0,1 °C is supposed. Standard uncertainty at the supposed normal distribution is:

$u(\delta T)$ = 0,1/2 °C = 0,05 °C

d) Uncertainty of the temperature expansion coefficient difference $u(\delta\alpha)$

Since the temperature expansion is not corrected, the difference between the temperature expansion of the CMM measurement system (producer's specification: $\alpha = 8\cdot10^{-6}$ °C^{-1}) and the calibrated ring (steel; $\alpha = 10{,}5\cdot10^{-6}$ °C^{-1}) $I_{\delta\alpha} = 2{,}5\cdot10^{-6}$ °C^{-1} is supposed as the deviation interval. Standard uncertainty at the supposed rectangular distribution is:

$u(\delta\alpha) = 2{,}5\cdot10^{-6}$ °C$^{-1}/\sqrt{3} = 1{,}44\cdot10^{-6}$ °C^{-1}

e) Uncertainty of the average temperature deviation from 20 °C $u(\bar{\theta})$

The temperature expansion is not corrected, but the allowed temperature deviation during the calibration is limited to (20±0,5) °C. Standard uncertainty at the supposed rectangular distribution is:

$u(\theta_m)$ = 0,2 °C $/\sqrt{3}$= = 0,12 °C

f) Uncertainty of the actual ring diameter due to the roundness deviation of the calibrated ring $u(p_n)$

Actual ring diameter is different in different directions (it could be bigger or smaller than the mean diameter reported in the calibration certificate), Therefore, the deviation of an actual diameter is considered to be a random error. It is not taken into account in the CMC evaluation, since an "ideal" roundness of the calibrated ring is presumed. However, the measurement uncertainty reported in the calibration certificate includes the roundness deviation contribution. It is assumed that the deviation interval of an actual diameter (in any chosen direction) is:

$$I_D = D_{sr} \pm o_{kr}$$

vhere:

D_{sr} - calibrated mean diameter

o_{kr} - measured roundness deviation ($r_{max} - r_{min}$)

Standard uncertainty is then:

$$u(p_n) = o_{kr}/\sqrt{3}$$

This uncertainty contribution is evaluated by using the Excel application »Negotovost-SOP 13« stored in the folder »4-Sistem kakovosti/SOP/SOP 13«.

Table 2: Uncertainty budget for the scanning procedure

Quantity X_i	Estimated value x_i	Standard uncertainty $u(x_i)$	Distribution	Sensitivity coefficient c_i	Uncertainty contribution $u_i(y) = c_i \cdot u(x_i)$
D_c	(2 to 120) mm (125 to 300) mm	0,25 µm 0,7 µm	Normal	1	0,25 µm 0,7 µm
$\overline{\alpha}$	$9{,}5\cdot10^{-6}$ °C^{-1}	$0{,}58\cdot10^{-6}$ °C^{-1}	Rectangular	0,1 °C·L	$0{,}06\cdot10^{-6}\cdot L$
δT	0 °C	0,05 °C	Normal	$9{,}5\cdot10^{-6}$ °C$^{-1}\cdot L$	$0{,}47\cdot10^{-6}\cdot L$
$\delta\alpha$	$2{,}5\cdot10^{-6}$ °C^{-1}	$1{,}44\cdot10^{-6}$ °C^{-1}	Rectangular	0,5 °C·L	$0{,}72\cdot10^{-6}\cdot L$
$\overline{\theta}$	0 °C	0,29 °C	Rectangular	$2{,}5\cdot10^{-6}$ °C$^{-1}\cdot L$	$0{,}72\cdot10^{-6}\cdot L$
p_n	0 mm	0 µm	Rectangular	1	0 µm
				Total :	$\sqrt{(0{,}25\ \mu m)^2 + (1{,}12\cdot10^{-6}\cdot L)^2}$ $\sqrt{(0{,}7\ \mu m)^2 + (1{,}12\cdot10^{-6}\cdot L)^2}$

10.3.A Standard uncertainty of the calibration result *u*(*D*)

Since the result is calculated as an arithmetic mean of 10 measurements, standard uncertainty *u(D)* can be evaluated as follows (according to GUM):

$$u(D) = \frac{u(D_i)}{\sqrt{10}}$$

Calculated standard uncertainty for diameters 2 mm to 120 mm is:

$$u = \sqrt{(0{,}08\ \mu m)^2 + (0{,}35\cdot10^{-6}\cdot L)^2}$$

Calculated standard uncertainty for diameters 125 mm to 300 mm is:

$$u = \sqrt{(0{,}22\ \mu m)^2 + (0{,}35\cdot10^{-6}\cdot L)^2}$$

Due to the uncertainty of the evaluation procedure and insufficient proves of competence by means of intercomparisons, the uncertainty for diameters 2 mm to 120 mm is increased to:

$$u = \sqrt{(0{,}1\ \mu m)^2 + (1{,}4\cdot10^{-6}\cdot L)^2}$$

for diameters 125 mm to 300 mm the uncertainty is increased to::

$$u = \sqrt{(0{,}3\ \mu m)^2 + (1{,}4\cdot10^{-6}\cdot L)^2}$$

10.4.A Expanded uncertainty

According to EA coverage factor k = 2 is used for the calculation of the expanded uncertainty. The best calibration and measurement capabilities (CMCs) expressed as expanded uncertainties are:

for diameters 2 mm to 120 mm the expanded uncertainty is:

$$U = \sqrt{(0{,}2\ \mu m)^2 + (2{,}8 \cdot 10^{-6} \cdot L)^2}$$

for diameters 125 mm do 300 mm the expanded uncertainty is:

$$U = \sqrt{(0{,}6\ \mu m)^2 + (2{,}8 \cdot 10^{-6} \cdot L)^2}$$

11 TRACEABILITY

The device for performing calibrations:

- CMM ZEISS UMC 850 – performance test with long gauge blocks (KOBA) in LTM.
- Standard rings ø 14 mm (ZEISS), ø 50 mm (ZEISS), ø 150 mm (MITUTOYO), calibrated in an European national metrology institute

12 LITERATURE

[1] EA 4/02 M: 2013: Evaluation of the Uncertainty of Measurement in Calibration

[2] EURAMET cg-6, Extent of Calibration for Cylindrical Diameter Standards, 2011