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LABORATORY FOR PRODUCTION MEASUREMENT

Faculty of Mechanical Engineering

Smetanova 17, 2000 Maribor, Slovenia

SOP 6

CALIBRATION OF VERNIER CALLIPER GAUGES

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CONTENTS

1 INTRODUCTION

This procedure describes the steps taken when calibrating vernier calliper gauges of any dimension using the DIN 862 standard.

1.1 General aspects

Vernier calliper gauges are used to measure distances of either inside or outside measures or depths. Gauge blocks are used to calibrate the vernier calliper gauge.

2 MEASURING EQUIPMENT

Gauge blocks   -   ZEISS, 103 blocks

Coordinate measuring machine   -   ZEISS UMC 850

Gauge ring 50 mm   -   MITUTOYO

3 RECEIPT

The vernier calliper gauge is received from the customer and is visually checked for any obvious defects. Defects which are checked are corrosion; missing or worn parts of the scale (on classical scales); missing parts such as screws; and significant scratches or other defects which would impede use. The customer name, and type and serial number of the vernier calliper is also noted and is tagged on to the vernier calliper using a yellow identification sticker. The procedure for attaching this sticker is described in the paragraph 12.10.2. of the Quality manual.

The number of gauges is checked and compared with the accompanying documentation.

4 CLEANING

The measuring surfaces of the gauge blocks and the gauge measuring surfaces are cleaned using petroleum ether. Any grit or other particles are also cleaned from the scale. The surfaces are wiped afterwards using the tougher side of a chamois leather (or special synthetic cloth).

Minor damages on guides or measuring surfaces are repaired using special fine grindstone.

5 THERMAL STABILISATION

The temperature of the gauge is stabilised at 20 °C ± 1 °C for 5 hours.

6   CALIBRATION

6.1   Visual inspection

- Measuring surfaces are checked to see if there are any scratches which may impede calibration.

- Scale is checked:

  - Classical scale is checked for any marking points or numbers on the scale which may be missing or worn.

  - Dial scale is checked for the straightness of the pointer and its distance from the scale. The pointer must be of the same width as the lines on the scale. Lines of the scale must be oriented towards the centre of the dial scale. Resolution must be written on the scale (e. g. 0,01 mm)

  - Digital scale is checked for numerical legibility and for any scratches on the display. If the numbers are of poor resolution (checked at display value 88.88) the battery is changed and resolution is checked again. The numbers must be clearly visible in each measuring position.

6.2   Functional check

The gauge is tested for the full and smooth running of its specified distance. The air in guides is checked. The shown value should not change if the gauge is fixed used fixing screw.

6.2.1   Parallelism of Measuring Surfaces

The parallelism is checked by observing the air slot when measuring surfaces are in contact. It should not change if the gauge is fixed used fixing screw.

Zero position of the depth measuring bar is also checked.

Observed deviations are recorded in calibration report.

6.3   Measurement of deviations

Deviations of gauges with measuring range 0 - 150 mm are checked using gauge blocks of the dimensions stated in the Table 1.

Deviation of inside measure is checked at the value 50 mm using gauge ring (for all measuring ranges).

Deviations of gauges greater than 150 mm are checked using coordinate measuring machine according to the following procedure (for one measuring position) :
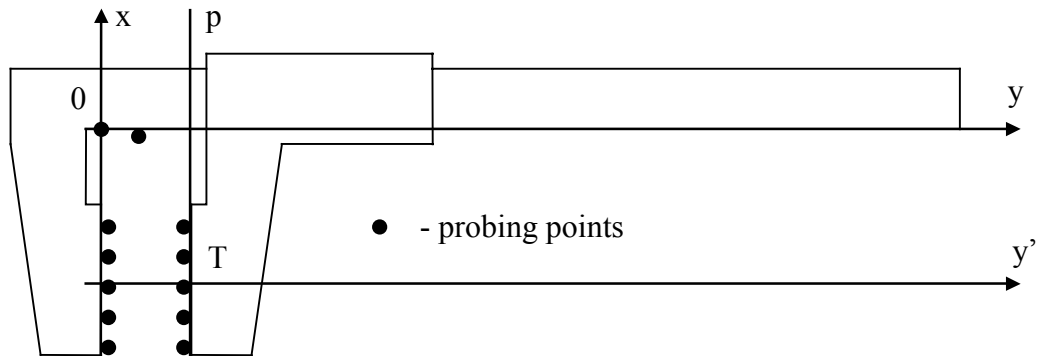
Figure 1: Measurement of deviations on the CMM

- first measurement deviation is checked by gauge block 40 mm using actual measurement force,

- five points are probed on the fix measuring surface and **x axes** is defined through these points (Fig. 1),

- one point is probed on the rule surface and **x coordinate** is set to 0 - y axes is defined (Fig. 1),

- y axes is moved for the half length of the measurement surface (y' in Fig. 1),

- zero point of the coordinate system is defined as intersection of x and y',

- the other four deviations (for measurement positions see Table 1) are measured by the CMM in the following way:

  - moving part of the gauge is moved into the measuremet position,

  - five points are probed on the moving measuring surface and the straight line **p** is calculated through these points (Fig. 1),

  - intersection of the line p with the y' axes is calculated (point T in Fig. 1),

  - distance of the point T from the zero point is calculated and compared with the set value on the gauge (measurement position); the deviation is calculated and recorded.

Table 1: Measurement positions for different measuring ranges

Measuring range (mm)	Measuremement positions (mm)				
0 - 150	0	40	70	100	125
0 - 200 (250)	40	41,3	100	131,4	180
0 - 300 (400)	40	41,3	131,4	200	281,2
0 - 500	40	131,4	281,2	380,5	481,1
0 - 750	40	131,4	281,2	481,1	700
0 - 1000	40	131,4	481,1	700	900

7   EVALUATION OF MEASURING RESULTS

The results of the readings taken for each gauge block (or measured by the CMM) are noted on a record sheet.

Example:

Gauge block (mm)	0	40	70	100	125
Deviation (μm)	+20	-20	0	-40	-20

8   DOCUMENTATION

The results from the calibrations are recorded according to instructions from Quality Manual.

9   PROTECTION

The measuring surfaces are oiled by special oil for instruments.

10   UNCERTAINTY

10.1   Mathematical model of the measurement

The deviation e (result of calibration) is given by the expression:

$$e = l_i \cdot (1+\alpha_m \cdot \theta_m) - l_e \cdot (1+\alpha_e \cdot \theta_e) + d_F \qquad (1)$$

where:

e -   deviation (result of calibration) at 20°C
l_i -   indicated value on the calliper gauge (reading)
α_m -   thermal expansion coefficient of the calliper gauge
θ_m -   deviation of the temperature of the calliper gauge
l_e -   calibrated length of the gauge block at 20°C or the value shown by the CMM
α_e -   thermal expansion coefficient of the gauge block (or the measuring system of the CMM)
θ_e -   deviation of the temperature of the gauge block (or the measuring system of the CMM)
d_F -   difference of the deformations caused by measuring force in measurement and in calibration (assumed to be 0)

If new quantities are defined as:

$\delta\theta = \theta_m - \theta_e$
$\delta\alpha = \alpha_m - \alpha_e$

then equation (1) gets the following form:

$$e = l_i \cdot (1 + \alpha_m \cdot \theta_e + \alpha_m \cdot \delta\theta) - l_e \cdot (1 + \alpha_m \cdot \theta_e - \delta\alpha \cdot \theta_e) + d_F \qquad (2)$$

10.2 Standard uncertainties of the estimations of the input values and combined standard uncertainty of measurement

Equation (10) in [2] gets in our case the following form:

$$u_c^2(e) = c_{li}^2 u^2(l_i) + c_{\alpha m}^2 u^2(\alpha_m) + c_{\theta e}^2 u^2(\theta_e) + c_{\delta\theta}^2 u^2(\delta\theta) + c_{le}^2 u^2(l_e) + c_{\delta\alpha}^2 u^2(\delta\alpha) + c_{dF}^2 u^2(d_F) \qquad (3)$$

where c_i are partial derivatives of the function (2):

$$c_{li} = \partial f/\partial l_i = 1 + \alpha_m \cdot \theta_e + \alpha_m \cdot \delta\theta \approx 1; \text{ if } \theta_{emax} = \pm 1 \text{ °C}$$
$$c_{\alpha m} = \partial f/\partial \alpha_m = \theta_e \cdot (l_i - l_e) \approx 100 \text{ μm°C if } \theta_{emax} = \pm 1°C \text{ and } (l_i - l_e)_{max} = 100 \text{ μm}$$
$$c_{\theta e} = \partial f/\partial \theta_e = \alpha_m \cdot (l_i - l_e) \approx 1{,}1 \cdot 10^{-3} \text{ μm°C}^{-1} \text{ if } \alpha_m = 11 \cdot 10^{-6} \text{ °C}^{-1}$$
$$c_{\delta\theta} = \partial f/\partial \delta\theta = \alpha_m \cdot l_i$$
$$c_{le} = \partial f/\partial l_e = -(1 + \alpha_m \cdot \theta_e + \delta\alpha \cdot \theta_e) \approx 1; \text{ if } \theta_{emax} = \pm 1 \text{ °C}$$
$$c_{\delta\alpha} = \partial f/\partial \delta\alpha = -l_e \cdot \theta_e \approx -l_i \cdot \theta_e$$
$$c_{dF} = \partial f/\partial d_F = 1$$

Calculation (estimation) of standard uncertainties of influence values is given in Table 1 for the equipment, methods and conditions used in our laboratory.

Table 1; Uncertainty budget

SOURCES OF UNCERTAINTY	standard uncertainty $u(x_i)$	$c_i \equiv df/dx_i$
1. *Uncertainty of the reading of the result $u(l_i)$* maximum errors are ±5 μm, at nonius 0,02 mm is ±13 μm (experiment), at nonius 0,05 is ±16 μm (experiment), and at nonius 0,1 mm is ±25 μm (estimated). The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $u(l_i) = (5μm)/\sqrt{3}$ for digital scale $u(l_i) = (13μm)/\sqrt{3}$ for nonius 0,02 mm $u(l_i) = (16μm)/\sqrt{3}$ for nonius 0,05 mm $u(l_i) = (25μm)/\sqrt{3}$ for nonius 0,1 mm	 2,9 μm 7,5 μm 9,5 μm 14,4 μm	 1

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2. *Uncertainty of the thermal expansion coefficient $u(\alpha_m)$* The bounds of $\pm 1 \cdot 10^{-6} {}^\circ C^{-1}$ are defined on experience basis. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $u(\alpha_m) = (1 \cdot 10^{-6} {}^\circ C^{-1}) / \sqrt{3}$	$0{,}58 \cdot 10^{-6} {}^\circ C^{-1}$	$100 \ \mu m {}^\circ C$
3. *Uncertainty of the gauge block (or CMM) temperature $u(\theta_e)$* The greatest temperature deviations in the room are $\pm 1 {}^\circ C$. We assume normal distribution and level of confidence at k = 2. Therefore: $u(\theta_e) = 1/2 {}^\circ C$	$0{,}5 {}^\circ C$	$1{,}1 \cdot 10^{-3}$ $\mu m {}^\circ C^{-1}$
4. *Uncertainty of temperature difference $u(\delta\theta)$* The greatest temperature difference is supposed to be $\pm 1 {}^\circ C$. We assume normal distribution and level of confidence at k = 2. Therefore: $u(\theta_m) = \frac{1}{2} {}^\circ C$	$0{,}5 {}^\circ C$	$-l_i \cdot \alpha_m$
5. *Uncertainty of the calibration of the standard $u(l_e)$ or uncertainty of the CMM result*		
5.1 *Vernier calliper gauges 0 - 150 mm* only one standard is used: the calibration certificate gives the expanded uncertainty: $U(l_e) = 0.1 \ \mu m + 1 \cdot 10^{-6} \cdot l$; k=2 standard uncertainty is therefore: $u_1(l_e) = U(l_e)/2$	$0.05 \ \mu m + 0.5 \cdot 10^{-6} \cdot l$	1
5.2 *Vernier calliper gauges greater than 150 mm (CMM is used)* For the measuring position in y axes (x-y plane on the table level at the left side of the table) uncertainty was evaluated experimentally using combination of gauge blocks Estimated standard uncertainty is: $u_2(l_e) = 1 \ \mu m + 1{,}5 \cdot 10^{-6} \cdot l$	$1 \ \mu m + 1{,}5 \cdot 10^{-6} \cdot l$	1

5.3 *Inside measure 50 mm* uncertainty of calibration of gauge ring is: $U(l_e)=0.5$ μm$+1\cdot10^{-6}\cdot l$; k=2 standard uncertainty is therefore: $u_1(l_e)=U(l_e)/2$	0.25 μm$+0{,}5\cdot10^{-6}\cdot l$	1
6. *Uncertainty of the thermal expansion coefficient difference u(δα)* The bounds of $\pm2\cdot10^{-6}°C^{-1}$ are defined on experience basis. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $u(\delta\alpha) = (2\cdot10^{-6\,°}C^{-1})\,/\sqrt{3}$	$1{,}2\cdot10^{-6}°C^{-1}$	$l_i\cdot\theta_e$
7. *Uncertainty of assumed difference between deformations caused by measurement force u(d_F)* Assumed difference of deformations is 0. In fact, different forces are applied in calibration and in measurement. The deviation caused by different forces is assumed to be maximum 3 ∝m. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $u(d_F) = 3$μm$/\sqrt{3}$	1,73 μm	1

10.3   Calculation of the combined uncertainty

10.3.1   Vernier callipers 0 - 150 mm

Constant part (independent from measured length):

$u_k{}^2 = 2{,}9^2 + 0{,}05^2 + 1{,}73^{2\,=}\,11{,}4$ μm^2

$u_k = 3{,}4$ μm

The part that depends on measured length ($u(l)$) consists of contributions No. 4, 5, and 6 (Table 1) and is calculated from the equation (3). Indicated value is assumed to be approximately the same as the length of the gauge block (measured length), expansion coefficient is assumed to be $12\cdot10^{-6}°C^{-1}$ (steel) and the temperature deviation is assumed to be 1°C (the greatest deviation in the room).

$u_l = 5{,}9\cdot10^{-6}\cdot l$

For the greatest measurement range 150 mm this value is:

$u_l = 0{,}9$ μm

Combined uncertainty for the length 150 mm is then:

$u_c = \sqrt{u_k{}^2 + u_l{}^2} = 3{,}5$ μm

After linearization we get:

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$u_c = 3,4 \ \mu m + 0,6 \cdot 10^{-6} \cdot l$

10.3.2 Vernier callipers greater than 150 mm

Constant part (independent from measured length):

$u_k^2 = 2,9^2 + 1^2 + 1,73^2 = 12,4 \ \mu m^2$

$u_k = 3,5 \ \mu m$

The part that depends on measured length (u(l)) is:

$u_l = 6,1 \cdot 10^{-6} \cdot l$

For the greatest measurement range 1000 mm this value is:

$u_l = 6,1 \ \mu m$

Combined uncertainty for the length 1000 mm is then:

$u_c = \sqrt{u_k^2 + u_l^2} = 7 \ \mu m$

After linearization we get:

$u_c = 3,5 \ \mu m + 3,5 \cdot 10^{-6} \cdot l$

10.3.3 Inside dimension

Combined standard uncertainty is the same as the uncertainty in 10.3.1.

10.4 Expanded uncertainty

According to EAL coverage factor k=2 is used for the calculation of the expanded uncertainty. The greatest calculated standard uncertainty is taken for all cases. The expanded uncertainty for all cases is:

$$U = 7 \ \mu m + 7 \cdot 10^{-6} \cdot l$$

Expanded uncertainty for vernier calipers with nonius 0,02 mm is:

$$U = 15,5 \ \mu m + 7 \cdot 10^{-6} \cdot l$$

Expanded uncertainty for vernier calipers with nonius 0,05 mm is:

$$U = 20 \ \mu m + 7 \cdot 10^{-6} \cdot l$$

Expanded uncertainty for vernier calipers with nonius 0,1 mm is:

$$U = 29 \ \mu m + 7 \cdot 10^{-6} \cdot l$$

11 TRACEABILITY

Measuring equipment used for calibration:

- gauge blocks ZEISS (0,5 - 100 mm) - calibrated by comparison using our reference set FRANK that is calibrated by primary standard

- gauge ring MITUTOYO - calibrated in LTM using ZEISS ULM and laser interferometer (calibrated in an accredited European laboratory)

- CMM ZEISS UMC 850 - calibrated for length measurements using long gauge blocks (KOBA and TESA and simulating actual measurement procedure described in 6.3.

12 LITERATURE

[1]   DIN 862, Meßschieber, Oct. 1983

[2]   ISO Guide to the Expression of Uncertainty in Measurement, Switzerland 1995

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Smetanova 17, 2000 Maribor, Slovenia

SOP 5

CALIBRATION OF MICROMETERS

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CONTENTS

1 INTRODUCTION

This procedure describes the steps taken when calibrating micrometers of any dimension using the DIN 863 standard.

1.1 General aspects

Micrometers are used to measure distances of either inside or outside measures, where attachments to the micrometer or special types of micrometer are used to measure inside dimensions. Ceramic gauge blocks and coordinate measuring machine are used to calibrate the micrometer.

2 MEASURING EQUIPMENT

Ceramic gauge blocks 2,5 - 25   -   MITUTOYO, 10 blocks

Steel gauge blocks 0,5 - 100 mm   -   KOBA, 122 blocks

Steel gauge blocks 125 - 500 mm   -   KOBA, 8 blocks

Steel gauge blocks 500 - 1000 mm   -   FRANK, 5 blocks

Optical Flat   -   TESA

Gauge rings 4 - 275 mm   -   MITUTOYO

3 RECEIPT

The micrometer is received from the customer and is visually checked for any obvious defects. Defects which are checked are corrosion, missing or worn parts of the scale (on classical scales); missing parts such as screws, and significant scratches or other defects which would impede use. The customer name, and type and serial number of the micrometer is also noted and is tagged on to the micrometer using a yellow identification sticker. The procedure for attaching this sticker is described in the paragraph 12.10.2. of the Quality manual.

The number of gauges is checked and compared with the accompanying documentation.

4 CLEANING

The measuring surfaces of the gauge blocks and the micrometer anvils are cleaned using petroleum ether. Any grit or other particles are also cleaned from the scale. The surfaces are wiped afterwards using the tougher side of a chamois leather (or special synthetic cloth).

5 THERMAL STABILISATION

The temperature of the micrometer is stabilised at 20 $^{\circ}$C ± 1 $^{\circ}$C for 5 hours.

6 CALIBRATION

6.1 Visual inspection

- Measuring surfaces are checked to see if there are any scratches, which may impede calibration.

- Scale is checked:

  ◊ Classical scale is checked for any marking lines or numbers on the scale, which may be missing or worn. The marking lines should be of the same width and have sharp edges.

  ◊ Digital scale is checked for numerical legibility and for any scratches on the display. If the numbers are of poor resolution (checked at display value 88.88) the battery is changed and resolution is checked again. The numbers must be clearly visible in each measuring position.

6.2 Functional check

The micrometer is tested for the full and smooth running of its specified distance. The lock nut is tested to see that is holds the micrometer spindle firmly at various positions.

6.2.1 Parallelism of Measuring Surfaces

The optical flat is placed between the two anvils, with the micrometer tightened in the normal way using the ratchet. The flat is given a small twist to check the grip of the anvils, and to remove any dust that may have settled on the surfaces. The number of interference lines or circles are counted on both measuring faces. The interference lines/circles that appear anywhere in the region less than 0.4 mm from the edge of the flat are ignored in the count. The numbers are added together and if the total is less than or equal to the values listed in the table below, the parallelism of measuring surfaces is in tolerance:

Measuring Range (mm)	Number of allowable interference lines or circles for parallelism according to DIN 863
00 to 25	$6 \approx 2$ μm
25 to 50	$6 \approx 2$ μm
50 to 75	$10 \approx 3$ μm
75 to 100	$10 \approx 3$ μm

In the case when parallelism is out of tolerances, the remark is written in the calibration report.

6.2.2   Flatness of Measuring Surfaces

The flatness of the micrometer anvils is inspected by means of the optical flat. The optical flat is placed between the two anvils following the procedure described in the previous section 6.2.2. If any interference lines are observed, the two outer lines are ignored and the other lines are counted. The table below shows the equivalent flatness corresponding to the number of lines counted:

Number of interference lines or circles according to DIN
$2 \approx 0.6 \ \mu m$

6.3   Measurement of deviations

6.3.1   Micrometers for measuring outside dimensions

6.3.1.1   Starting Point

The specified starting distance is checked:

- for the zero value (for micrometers of 0 - 25 mm) by tightening the micrometer (using the ratchet) until it tightens no further and then reading off the value, or;

- for values other than zero in the same way but with the use of a gauge block of appropriate dimension (e. g. for micrometer 50 - 75 mm starting point is checked using a gauge block 50 mm).

The deviation is stated in the calibration report.

6.3.1.2   Deviations in measuring positions

For micrometers of measuring range 0 - 25 mm the following gauge block dimensions are used:

2.5, 5.1, 7.7, 10.3, 12.9, 15.0, 17.6, 20.2, 22.8, 25 mm.

For micrometers of other measuring ranges the same gauge blocks are used, but each attached to a gauge block of a dimension that is equal to the lower measuring range limit.

The gauge block (or a combination of gauge blocks) is placed between the two anvils, with the micrometer tightened in the normal way using the ratchet so that the block is held firmly. The block is given a small twist to check the grip of the anvils, and to remove any dust that may have settled on the surfaces. The block is also placed in a position such that the anvils touch the centre of the gauge measuring faces.

If more than one gauge block is used, additional value of 0,2 μm is added to the sum of the gauge block lengths for each joint (experimentally evaluated).

6.3.2 Micrometers for measuring inside dimensions

6.3.2.1 Starting Point

The deviation in the starting point is checked using a gauge block of the dimension that is equal to the lower measuring range limit. The gauge block is put into special gauge block holder for checking inside dimensions (Fig. 1)
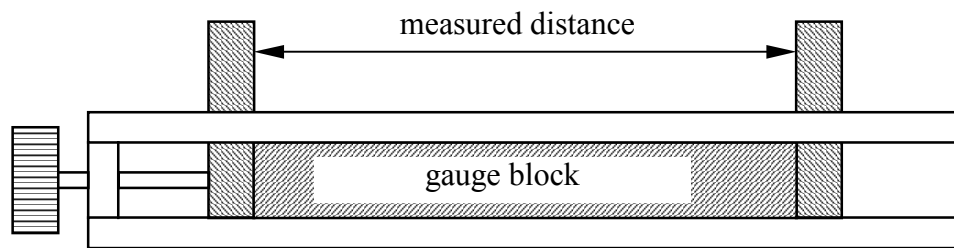

Figure 1: Gauge block holder for checking inside dimensions

The deviation is stated in the calibration report.

If more than one gauge block is used, additional value of 0,2 µm is added to the sum of the gauge block lengths for each joint (experimentally evaluated).

6.3.2.2 Deviations in measuring positions

The same gauge blocks are used as in 6.3.1.2, but they are put in the holder (Fig. 1). The micrometer is gently rotated in order to find the minimum distance.

6.3.3 Calibration of standard bars for micrometers

Standard bars for micrometers are calibrated in the same way and with the same device as long gauge blocks. The procedure and uncertainty is described in SOP 16.

6.3.4 Three point micrometers for measuring inside diameters

6.3.4.1 Starting Point

The deviation in the starting point is checked using a gauge ring of the dimension that is equal to the lower measuring range limit.

The deviation is stated in the calibration report.

6.3.4.2 Deviations in measuring positions

Two gauge rings are used for checking deviations. One diameter is approximately at the middle of the measuring range and the other is approximately at the upper limit of the measuring range.

Measurement is repeated in three different positions (the gauge ring is rotated twice for 120°) and the mean value is stated in the calibration report.

7   EVALUATION OF MEASURING RESULTS

The results of the readings taken for each gauge block (gauge ring) are noted on a record sheet. If the micrometer reading for a given distance is different to the value indicated on the gauge block this difference is recorded.

Example:

Gauge block (mm)	2.5	5.1	7.7	10.3	12.9	15.0	17.6	20.2	22.8	25
Deviation (μm)	+1	-1	0	-1	+2	0	+2	-1	+1	-1

8   DOCUMENTATION

The results from the calibrations are recorded according to instructions from Quality Manual.

9   PROTECTION

The micrometer is oiled by special oil for instruments.

10   UNCERTAINTY

10.1   Mathematical model of the measurement

The deviation e (result of calibration) is given by the expression:

$$e = l_i \cdot (1 + \alpha_m \cdot \theta_m) - l_e \cdot (1 + \alpha_e \cdot \theta_e) + d_F \qquad (1)$$

where:

e -   deviation (result of calibration) at 20 °C
l_i -   indicated value on the micrometer (reading)
α_m -   thermal expansion coefficient of the micrometer
θ_m -   deviation of the temperature of the micrometer
l_e -   calibrated length of the gauge block (or gauge block combination) or gauge ring at 20 °C
α_e -   thermal expansion coefficient of the gauge block(s) (or ring)
θ_e -   deviation of the temperature of the gauge block
d_F -   difference of the deformations caused by measuring force in measurement and in calibration (assumed to be 0)

If new quantities are defined as:

$\delta\theta = \theta_m - \theta_e$
$\delta\alpha = \alpha_m - \alpha_e$

then equation (1) gets the following form:

$$e = l_i \cdot (1 + \alpha_m \cdot \theta_e + \alpha_m \cdot \delta\theta) - l_e \cdot (1 + \alpha_m \cdot \theta_e - \delta\alpha \cdot \theta_e) + d_F \tag{2}$$

10.2   Standard uncertainties of the estimations of the input values and combined standard uncertainty of measurement

Equation (10) in [2] gets in our case the following form:

$$u_c^2(e) = c_{li}^2 u^2(l_i) + c_{\alpha m}^2 u^2(\alpha_m) + c_{\theta e}^2 u^2(\theta_e) + c_{\delta\theta}^2 u^2(\delta\theta) + c_{le}^2 u^2(l_e) + c_{\delta\alpha}^2 u^2(\delta\alpha) + c_{dF}^2 u^2(d_F) \tag{3}$$

where c_i are partial derivatives of the function (2):

$$c_{li} = \partial f / \partial l_i = 1 + \alpha_m \cdot \theta_e + \alpha_m \cdot \delta\theta \approx 1; \text{ if } \theta_{emax} = \pm 1 \ ^\circ\text{C}$$

$$c_{\alpha m} = \partial f / \partial \alpha_m = \theta_e \cdot (l_i - l_e) + l_i \cdot \delta\theta$$

$$c_{\theta e} = \partial f / \partial \theta_e = \alpha_m \cdot (l_i - l_e) \approx 2{,}2 \cdot 10^{-4} \ \mu\text{m}^\circ\text{C}^{-1} \text{ if } \alpha_m = 11 \cdot 10^{-6} \ ^\circ\text{C}^{-1}$$

$$c_{\delta\theta} = \partial f / \partial \delta\theta = \alpha_m \cdot l_i$$

$$c_{le} = \partial f / \partial l_e = -(1 + \alpha_m \cdot \theta_e + \delta\alpha \cdot \theta_e) \approx 1; \text{ if } \theta_{emax} = \pm 1 \ ^\circ\text{C}$$

$$c_{\delta\alpha} = \partial f / \partial \delta\alpha = -l_e \cdot \theta_e \approx -l_i \cdot \theta_e$$

$$c_{dF} = \partial f / \partial d_F = 1$$

Calculation (estimation) of standard uncertainties of influence values is given in Table 1 for the equipment, methods and conditions used in our laboratory.

Table 1: Uncertainty budget

SOURCES OF UNCERTAINTY	standard uncertainty $u(x_i)$	$c_i = df/dx_i$
1. *Uncertainty of the reading of the result $u(l_i)$* maximum error for digital scale is ±1 µm and for classical scale ±2 µm. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $u(l_i) = (1\mu m) / \sqrt{3}$; for digital scale $u(l_i) = (2\mu m) / \sqrt{3}$; for classical scale	 0,57 µm 1,15 µm	 1 1

2. *Uncertainty of the thermal expansion coefficient u(α_m)* The bounds of $\pm 1 \cdot 10^{-6} °C^{-1}$ are defined on experience basis. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $u(\alpha_m) = (1 \cdot 10^{-6} °C^{-1}) / \sqrt{3}$	$0,58 \cdot 10^{-6} °C^{-1}$	$20\ \mu m °C + l_i \cdot \delta\theta$
3. *Uncertainty of the gauge block temperature u(θ_e)* The greatest temperature deviations in the room are $\pm 1°C$. We assume normal distribution and level of confidence at $k = 2$. Therefore: $u(\theta_e) = 1/2 °C$	$0,5\ °C$	$2,2 \cdot 10^{-4}\ \mu m °C^{-1}$
4. *Uncertainty of temperature difference u($\delta\theta$)* The greatest temperature difference is supposed to be $\pm 0,2°C$. We assume normal distribution and level of confidence at $k = 2$. Therefore: $u(\delta\theta) = 0,2/2 °C$	$0,1\ °C$	$l_i \cdot \alpha_m$
5. *Uncertainty of the calibration of the standard u(l_e)*		
5.1 *Outside micrometers 0-25 mm* only one standard is used: the calibration certificate gives the expanded uncertainty: $U(l_e) = 0.1\ \mu m + 1 \cdot 10^{-6} \cdot l$; $k=2$ standard uncertainty is therefore: $u_1(l_e) = U(l_e)/2$	$0,05 \mu m + 0.5 \cdot 10^{-6} \cdot l$	1
5.2 *Outside micrometers with starting point > 0* two or three standards are used the uncertainty for two standards is: $u(l_e) = \sqrt{u(l_{e1})^2 + u(l_{e2})^2 + u(con)^2}$ where: $u(l_{e1})$, $u(l_{e2})$ - uncertainties of standards $u(con)$ - uncertainty of the connection $u(l_{e1}) = u(l_{e2}) = 0,05\ \mu m + 0,5 \cdot 10^{-6} \cdot l$; $u(con) = 0,1\ \mu m$ standard uncertainty for two gauge blocks is: $u_2(l_e) = 0.12\ \mu m + 0,71 \cdot 10^{-6} \cdot l$	$0,12 \mu m + 0,71 \cdot 10^{-6} l$	1
standard uncertainty for three gauge blocks is: $u_3(l_e) = 0.17\ \mu m + 0,87 \cdot 10^{-6} \cdot l$	$0,70 \mu m + 0,87 \cdot 10^{-6} l$	1

5.3 Inside micrometers (using 2 gauge blocks) the uncertainty for two standards is: $$u(l_e) = \sqrt{u(l_{e1})^2 + u(l_{e2})^2 + 3 \cdot u(con)^2}$$ where: $u(l_{e1})$, $u(l_{e2})$ - uncertainties of standards $u(con)$ - uncertainty of the connection $u(l_{e1})=u(l_{e2})=0.05$ μm$+0{,}5 \cdot 10^{-6} \cdot l$; $u(con)=0{,}1$ μm standard uncertainty for two gauge blocks is: $u_2(l_e) = 0.19$ μm$+0{,}71 \cdot 10^{-6} \cdot l$	$0{,}17$ μm$+0{,}71 \cdot 10^{-6} \cdot l$	1
5.4 Three point inside micrometers uncertainty of calibration of gauge ring is: $U(l_e)=0{,}5$ μm$+1 \cdot 10^{-6} \cdot l$; $k=2$ standard uncertainty is therefore: $u_1(l_e)=U(l_e)/2$	$0{,}25$ μm$+0{,}5 \cdot 10^{-6} \cdot l$	1
6. *Uncertainty of the thermal expansion coefficient difference $u(\delta\alpha)$* The bounds of $\pm 2 \cdot 10^{-6}{}^\circ C^{-1}$ are defined on experience basis. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $$u(\delta\alpha) = (2 \cdot 10^{-6}{}^\circ C^{-1}) / \sqrt{3}$$	$1{,}2 \cdot 10^{-6}{}^\circ C^{-1}$	$-l_i \cdot \theta_e$
7. *Uncertainty of assumed difference between deformations caused by measurement force $u(d_F)$* Assumed difference of deformations is 0. In fact, different forces are applied in calibration and in measurement. The deviation caused by different forces is assumed to be maximum $0{,}5$ μm. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $$u(d_F) = 0{,}5\mu m / \sqrt{3}$$	$0{,}3$ μm	1

10.3   Calculation of the combined uncertainty

10.3.1   Outside micrometers 0 - 25 mm (digital scale)

Constant part (independent from measured length):

$u_k^2 = 0{,}57^2 + 0{,}05^2 + 0{,}3^2 = 0{,}42$ μm^2

$u_k = 0{,}65$ μm

The part that depends on measured length (u(l)) consists of contributions No. 4, 5, 6 (Table 1) and is calculated from the equation (2). Indicated value is assumed to be

approximately the same as the length of the gauge block (measured length), expansion coefficient is assumed to be $12 \cdot 10^{-6}$ °C^{-1} (steel) and the temperature deviation is assumed to be 1 °C (the greatest deviation in the room).

$u_l = 1{,}86 \cdot 10^{-6} \cdot l$

$u_c = 0{,}65 \ \mu m + 1{,}86 \cdot 10^{-6} \cdot l$

10.3.2 Calibrations using 2 or 3 gauge blocks (digital scale)

Since calibration uncertainty of gauge blocks is much smaller than other components, no significant differences in combined uncertainty appear (on the 3rd decimal place). Therefore, it is assumed that the combined uncertainty is equal for all cases

10.3.3 Inside three point micrometers (digital scale)

Constant part (independent from measured length):

$u_k^2 = 0{,}57^2 + 0{,}5^2 + 0{,}3^2 = 0{,}48 \ \mu m^2$

$u_k = 0{,}7 \ \mu m$

The part that depends on measured length (u(l)) is:

$u_l = 1{,}86 \cdot 10^{-6} \cdot l$

$u_c = 0{,}7 \ \mu m + 1{,}86 \cdot 10^{-6} \cdot l$

10.3.4 Micrometers with classical scale

Constant part (independent from measured length):

$u_k^2 = 1{,}15^2 + 0{,}05^2 + 0{,}3^2 = 1{,}41 \ \mu m^2$

$u_k = 1{,}19 \ \mu m$

The part that depends on measured length (u(l)) is:

$u_l = 1{,}86 \cdot 10^{-6} \cdot l$

$u_c = 0{,}65 \ \mu m + 1{,}86 \cdot 10^{-6} \cdot l$

10.4 Expanded uncertainty

According to EAL coverage factor k=2 is used for the calculation of the expanded uncertainty. The greatest calculated standard uncertainty is taken for all cases (digital scale). The expanded uncertainty for all cases is:

$$U = 1{,}5 \ \mu m + 4 \cdot 10^{-6} \cdot l$$

Expanded uncertainty for classical scale is for all cases:

$$U = 2{,}4 \ \mu m + 4 \cdot 10^{-6} \cdot l$$

11 TRACEABILITY

Measuring equipment used for calibration:

- ceramic gauge blocks MITUTOYO - calibrated by comparison using our reference set FRANK that is calibrated by primary standard,

- gauge blocks KOBA (0,5 - 100 mm) - calibrated by comparison using our reference set FRANK that is calibrated by primary standard,

- long gauge blocks KOBA (125 - 500 mm) and TESA (600 - 1000 mm) - calibrated by comparison in DKD or other accredited or national European laboratory

- gauge rings MITUTOYO - calibrated in LTM using ZEISS ULM and laser interferometer (calibrated in an accredited European laboratory)

- optical flat TESA - calibrated in an accredited European laboratory

12 LITERATURE

[1]   DIN 863, Meßschrauben, Oct. 1983

[2]   ISO Guide to the Expression of Uncertainty in Measurement, Switzerland 1995

LABORATORY FOR PRODUCTION MEASUREMENT

Faculty of Mechanical Engineering

Smetanova 17, 2000 Maribor, Slovenia

SOP 8

CALIBRATION OF DIAL GAUGES

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Changes made

AMENDMENT		REMOVED			ADDED		
No.	Date	Section	Page	Issue No.	Section	Page	Issue No.
Present issue E-1 is equal to the issue No. 3 dated September 1998.							

CONTENTS

1 INTRODUCTION

This procedure describes the steps taken when calibrating dial gauges with measuring range up to 50 mm using the DIN 878 standard.

1.1 General aspects

Dial gauges are calibrated on a special device for calibration of dial gauges. The resolution of the device is 0,001 mm. Dial gauges with measuring range greater than 10 mm are calibrated using gauge blocks in addition to the device.

2 MEASURING EQUIPMENT

Device for calibration of dial gauges - MAHR 865 E (MILITRON display)

Gauge blocks - KOBA, 122 blocks

3 RECEIPT

The dial gauge is received from the customer and is visually checked for any obvious defects. Defects, which are checked are corrosion; missing or worn parts of the scale (on classical scales); missing parts such as screws; and significant scratches or other defects which would impede use. The customer name, and type and serial number of the dial gauge is also noted and is tagged on to the dial gauge using a yellow identification sticker. The procedure for attaching this sticker is described in the paragraph 12.10.2. of the Quality manual.

The number of gauges is checked and compared with the accompanying documentation.

4 CLEANING

The measuring surfaces of the calibration device, gauge blocks and the gauge measuring surfaces are cleaned using petroleum ether. Any grit or other particles are also cleaned from the scale. The surfaces are wiped afterwards using the tougher side of a chamois leather (or special synthetic cloth). The moving shaft is also cleaned if necessary.

5 THERMAL STABILISATION

The temperature of the gauge is stabilised at 20 $^{\circ}$C ± 1 $^{\circ}$C for 5 hours.

6   CALIBRATION

6.1   Visual inspection

- Measuring surfaces are checked to see if there are any scratches which may impede calibration.

- Scale is checked:
  - Dial scale is checked for the straightness of the pointer and its distance from the scale. The pointer must be of the same width as the lines on the scale. Lines of the scale must be oriented towards the centre of the dial scale. Resolution must be written on the scale (e. g.→ ‖ ← 0,01 mm)
  - Digital scale is checked for numerical legibility and for any scratches on the display. If the numbers are of poor resolution (checked at display value 88.88) the battery is changed and resolution is checked again. The numbers must be clearly visible in each measuring position.

6.2   Functional check

The gauge is tested for the full and smooth running of its specified distance.

6.3   Fixing the gauge into the calibration device

The moving part of the calibration device (probe) should be in the lower position. The gauge is fixed in such a way that the pointer is below zero position.

6.4   Adjustment of zero position

- the probe of the calibration device (which is in contact with the probe of the gauge) is lifted to the position where the pointer of the gauge is exactly in the zero position (the line indicating zero position is covered by the pointer, or a digital display shows 0,00(0) mm).

- display of the calibration device is reset (set to 0,000 mm).

6.5   Measurement of deviations

- the measuring range is divided into ten (10) equal increments - ten measuring positions are defined in addition to zero point.

- the probe of the calibration device is lifted to the first measuring position (positive direction of approaching measuring position); the exact value (e.g. 1,000 mm) should be shown on the display of the device. The deviation from the exact value is read from the dial gauge and is recorded.

- the same procedure is used for other 9 measuring positions.

If the measuring range is greater than 10 mm, gauge blocks of different dimensions (depend on measuring range) are put between the probe of the device and the probe of the dial gauge.

Example: *A dial gauge with the measuring range 30 mm is calibrated*
Measuring positions: 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, 30 mm
Measurement of deviations:
1st position (3 mm) -   *probe of the device is lifted to 3,000 mm*
2nd position (6 mm) -   *probe of the device is lifted to 6,000 mm*
3rd position (9 mm) -   *probe of the device is lifted to 9,000 mm*
4th position (12 mm) -   *probe of the device is in position 9,000 mm and 3 mm gauge block is put between the probes*
5th position (15 mm) -   *probe of the device is in position 9,000 mm and 6 mm gauge block is put between the probes*
6th position (18 mm) -   *probe of the device is in position 9,000 mm and 9 mm gauge block is put between the probes*
etc...

A value 0,1 μm (experimentally evaluated contact error between the probe and the gauge block) is added to the length of the gauge block.

- after the last deviation is recorded, the probe of the device is lifted for approximately ten scale divisions above the maximum value on the scale and then moved down to the last measuring position (negative direction of approaching measuring position). The deviation of the value indicated by the gauge is recorded again.

- the probe is moved down to other 10 measuring positions (negative direction) and the deviations are recorded.

- the measurement is finished when the last deviation (in zero position) is recorded.

6.6   Measurement of repeatability

The probe of the device is positioned five times in a measuring position (does not matter in which one) in such a way that the display of the device always shows the same value. Values shown by the dial gauge are recorded.

7   EVALUATION OF MEASURING RESULTS

7.1   Measurement of deviations

The graph is drawn for positive and for negative direction of measurement as it is shown in Figure 1.
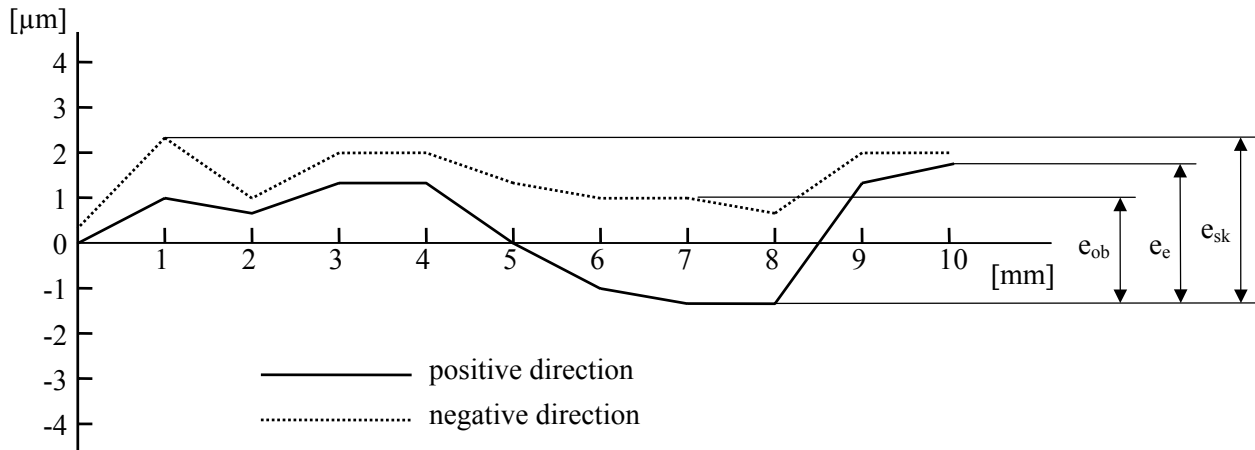
Figure 1: Deviation graph of a dial gauge 0 - 10 mm with characteristic deviations

The following values (Figure 1) are calculated in addition to deviations in each measuring position:

e_{sk} - overall deviation (the difference between the two extreme deviations (for both directions together)

e_e - the greatest difference between two extreme deviations for one direction (positive or negative; depends on which one is bigger)

e_{ob} - the greatest difference between the deviation in positive direction and in negative direction in one measuring position

7.2   Repeatability

Repeatability is the difference between the greatest and the smallest indicated value of the measurement described in 6.6. It is also stated in the calibration certificate.

8   DOCUMENTATION

The results from the calibrations are recorded according to instructions from Quality Manual.

9   PROTECTION

The measuring surface is oiled by special oil for instruments.

10   UNCERTAINTY

10.1   Mathematical model of the measurement

The deviation e (result of calibration) is given by the expression:

$$e = l_i \cdot (1 + \alpha_m \cdot \theta_m) - l_e \cdot (1 + \alpha_e \cdot \theta_e) \tag{1}$$

where:

e - deviation (result of calibration) at 20°C

l_i - indicated value on the dial gauge (reading)

α_m - thermal expansion coefficient of the dial gauge mechanism

θ_m - deviation of the temperature of the dial gauge

l_e - indicated value on the calibration device (plus length of a gauge block where applicable)

α_e - thermal expansion coefficient of the measurement system of the calibration device

θ_e - deviation of the temperature of the measurement system of the calibration device

If new quantities are defined as:

$\delta\theta = \theta_m - \theta_e$

$\delta\alpha = \alpha_m - \alpha_e$

then equation (1) gets the following form:

$$e = l_i \cdot (1 + \alpha_m \cdot \theta_e + \alpha_m \cdot \delta\theta) - l_e \cdot (1 + \alpha_m \cdot \theta_e - \delta\alpha \cdot \theta_e) \tag{2}$$

10.2 Standard uncertainties of the estimations of the input values and combined standard uncertainty of measurement

Equation (10) in [3] gets in our case the following form:

$$u_c^2(e) = c_{li}^2 u^2(l_i) + c_{\alpha m}^2 u^2(\alpha_m) + c_{\theta e}^2 u^2(\theta_e) + c_{\delta\theta}^2 u^2(\delta\theta) + c_{le}^2 u^2(l_e) + c_{\delta\alpha}^2 u^2(\delta\alpha) \tag{3}$$

where c_i are partial derivatives of the function (2):

$c_{li} = \partial f / \partial l_i = 1 + \alpha_m \cdot \theta_e + \alpha_m \cdot \delta\theta \approx 1$; if $\theta_{emax} = \pm 1$ °C

$c_{\alpha m} = \partial f / \partial \alpha_m = \theta_e \cdot (l_i - l_e) \approx 50$ μm°C if $\theta_{emax} = \pm 1$°C and $(l_i - l_e)_{max} = 50$ μm

$c_{\theta e} = \partial f / \partial \theta_e = \alpha_m \cdot (l_i - l_e) \approx 5{,}5 \cdot 10^{-4}$ μm°C^{-1} if $\alpha_m = 11 \cdot 10^{-6}$ °C^{-1}

$c_{\delta\theta} = \partial f / \partial \delta\theta = \alpha_m \cdot l_i$

$c_{le} = \partial f / \partial l_e = -(1 + \alpha_m \cdot \theta_e + \delta\alpha \cdot \theta_e) \approx 1$; if $\theta_{emax} = \pm 1$ °C

$c_{\delta\alpha} = \partial f / \partial \delta\alpha = -l_e \cdot \theta_e \approx -l_i \cdot \theta_e$

Calculation (estimation) of standard uncertainties of influence values is given in Table 1 for the equipment, methods and conditions used in our laboratory.

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Table 1: Uncertainty budget

SOURCES OF UNCERTAINTY	standard uncertainty $u(x_i)$	$c_i \equiv df/dx_i$
1. Uncertainty of the reading of the result $u(l_i)$		
1.1 Mechanical indication with pointer (resol. 0,01 mm) maximum errors are ± 2 μm. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $u(l_i) = (2 \mu m) / \sqrt{3}$	1,15 μm	1
1.2 Digital indication with two decimal places maximum errors are ± 5 μm. Therefore: $u(l_i) = (5 \mu m) / \sqrt{3}$	2,9 μm	1
1.3 Digital indication with three decimal places maximum errors are $\pm 0,5$ μm. Therefore: $u(l_i) = (0,5 \mu m) / \sqrt{3}$	0,29 μm	1
2. Uncertainty of the thermal expansion coefficient $u(\alpha_m)$ The bounds of $\pm 1 \cdot 10^{-6} °C^{-1}$ are defined on experience basis. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $u(\alpha_m) = (1 \cdot 10^{-6} °C^{-1}) / \sqrt{3}$	$0,58 \cdot 10^{6}$ °C^{-1}	50 μm°C
3. Uncertainty of the temperature deviation $u(\theta_e)$ The greatest temperature deviations in the room are $\pm 1°C$. We assume normal distribution and level of confidence at k = 2. Therefore: $u(\theta_e) = 1/2°C$	0,5°C	$5,5 \cdot 10^{-4}$ μm°C^{-1}
4. Uncertainty of temperature difference $u(\delta\theta)$ The greatest temperature difference is supposed to be $\pm 0,2°C$. We assume normal distribution and level of confidence at k = 2. Therefore: $u(\delta\theta) = 0,2/2°C$	0,1 °C	$l_i \cdot \alpha_m$
5. Uncertainty of indication of the device $u(l_e)$		
5.1 Dial gauges 0 - 10 mm (no gauge block used) only uncertainty of calibration influences the result; the calibration certificate gives the expanded uncertainty: $U(l_e) = 0.6$ μm $+ 2,5 \cdot 10^{-6} \cdot l$; k=2 standard uncertainty is therefore: $u_1(l_e) = U(l_e)/2$	0.3 μm$+1,25 \cdot 10^{-6} \cdot l$	1

5.2 Dial gauges with measuring range greater than 10 mm Gauge blocks are used in addition to the device. The uncertainty is influenced by the device (5.1), the uncertainty of calibration of gauge blocks and the uncertainty of calculated contact error between the probe and the gauge block. Standard uncertainty of calibration of the gauge blocks is: $u(gb) = 0.025 \ \mu m + 0{,}25 \cdot 10^{-6} \cdot l$ Standard uncertainty of calculated contact error is: $u(a) = 0{,}03 \ \mu m$ $u_2(l_e) = \sqrt{u_1(l_e)^2 + u(gb)^2 + u(a)^2}$	$0{,}3 \ \mu m + 1{,}27 \cdot 10^{-6} \cdot l$	1
6. *Uncertainty of the thermal expansion coefficient difference u(δα)* The bounds of $\pm 2 \cdot 10^{-6} \, °C^{-1}$ are defined on experience basis. The uncertainty is assumed to be represented by a rectangular distribution. Therefore: $u(\delta\alpha) = (2 \cdot 10^{-6} \, °C^{-1}) / \sqrt{3}$	$1{,}2 \cdot 10^{-6} \, °C^{-1}$	$-l_i \cdot \theta_e$

10.3   Calculation of the combined uncertainty

10.3.1   Dial gauges with mechanical indication (pointer) and resolution 0,01 mm

Constant part (independent from measured length):

$u_k{}^2 = 1{,}15^2 + 0{,}3^2 = 1{,}41 \ \mu m^2$

$u_k = 1{,}18 \ \mu m$

The part that depends on measured length (u(l)) consists of contributions No. 2, 3, and 4 (Table 1) and is calculated from the equation (2). Indicated value is assumed to be approximately the same as the measured length, expansion coefficient is assumed to be $12 \cdot 10^{-6} \, °C^{-1}$ (steel) and the temperature deviation is assumed to be 1 °C (the greatest deviation in the room).

$u_l = 2{,}1 \cdot 10^{-6} \cdot l$

$u_c = 1{,}18 \ \mu m + 2{,}1 \cdot 10^{-6} \cdot l$

10.3.2   Dial gauges with digital indication and resolution 0,01 mm

Constant part (independent from measured length):

$u_k{}^2 = 2{,}9^2 + 0{,}3^2 = 8{,}5 \ \mu m^2$

$u_k = 2{,}9 \ \mu m$

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The part that depends on measured length (u(l)) is:

$u_l = 2{,}1 \cdot 10^{-6} \cdot l$

$u_c = 2{,}9 \ \mu m + 2{,}1 \cdot 10^{-6} \cdot l$

10.3.3 Dial gauges with digital indication and resolution 0,001 mm

Constant part (independent from measured length):

$u_k{}^2 = 0{,}29^2 + 0{,}3^{2\ =}\ 0{,}17 \ \mu m^2$

$u_k = 0{,}42 \ \mu m$

The part that depends on measured length (u(l)) is:

$u_l = 2{,}1 \cdot 10^{-6} \cdot l$

$u_c = 0{,}42 \ \mu m + 2{,}1 \cdot 10^{-6} \cdot l$

10.4 Expanded uncertainty

According to EAL coverage factor k=2 is used for the calculation of the expanded uncertainty. The expanded uncertainty for dial gauges with mechanical indication (pointer) and resolution 0,01 mm is:

$$U = 2{,}5 \ \mu m + 4{,}5 \cdot 10^{-6} \cdot l$$

The expanded uncertainty for dial gauges with digital indication and resolution 0,01 mm is:

$$U = 6 \ \mu m + 4{,}5 \cdot 10^{-6} \cdot l$$

The best expanded uncertainty for dial gauges with resolution 0,001 mm is:

$$U = 0{,}9 \ \mu m + 4{,}5 \cdot 10^{-6} \cdot l$$

11 TRACEABILITY

Measuring equipment used for calibration:

- gauge blocks KOBA (0,5 - 100 mm) - calibrated by comparison using our reference set FRANK that is calibrated by primary standard

- calibration device MAHR 856E - calibrated by gauge blocks KOBA (0,5 - 100 mm) and inductive probe MAHR, that is also calibrated using gauge blocks KOBA

12   LITERATURE

[1]   DIN 878, Meßuhren, Oct. 1983

[2]   DIN 879, Feinzeiger, Oct. 1983

[3]   ISO Guide to the Expression of Uncertainty in Measurement, Switzerland 1995