Calibration Certificate

Invar rod (type, No.):

GPCL3 27690

No. of graduations measured:

5 - 344

Contract:

14-72-07

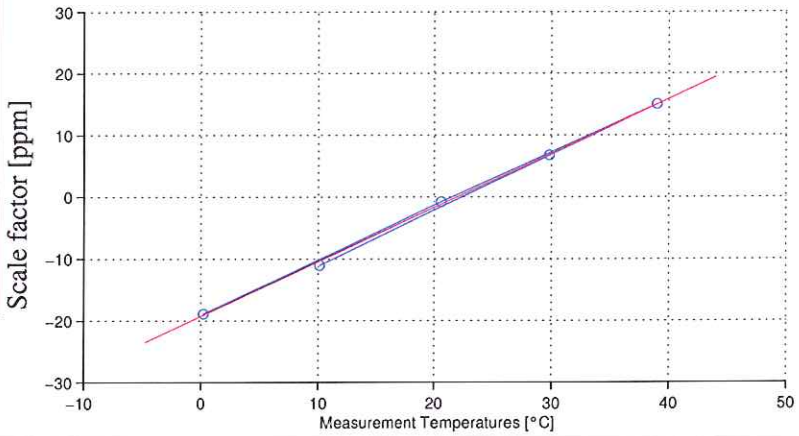
Date :

12.01.15

Determination of the coefficient of expansion

Horizontal calibration position

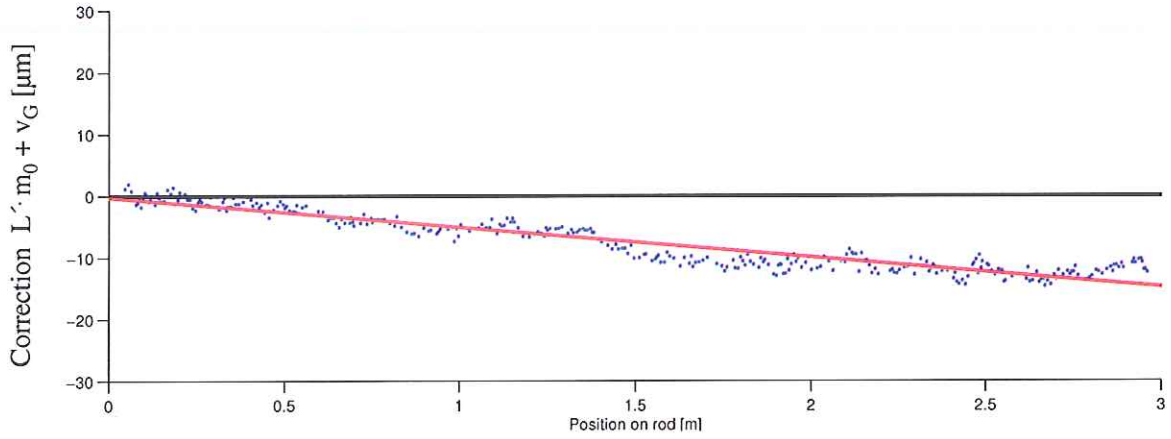
Measurement cycle: 30 → 0 → 20 → 40 → 10 [°C]



Coefficient of expansion:

α_T = 0.88 ± 0.02 *ppm/ °C* (k=1)

Determination of the scale factor **Vertical calibration position, middle 16 mm of scale**



Scale factor: m_0 = -4.85 ± 1.15 *ppm* at T_0 =19.8 °C (k=1)

Length adjustment from the vertical calibration (position of use)

$L = l^0 + L'[1 + (m_0 + \alpha_T(T - T_0)) \cdot 10^{-6}] + v_G$

l^0 = **-0.034 ± 0.007 mm**

v_G = **-0.000 mm** (k=1)

$l^0 = l_K^0 + v_K$

l_K^0 = **-0.016 ± 0.007 mm**

v_K = **-0.018 mm**

L'[m] = observed rod length v_G [m] = graduation correction

T[°C] = temperature

l^0 [m] = index correction (l_K^0[m] = index correction of reference bar, v_K[m] = reference bar correction)

Technical specialist: Sch. eyer Munich, 13.01.2015

Laboratory director: Institute director:

Geodätisches Prüflabor am Lehrstuhl für Geodäsie der TU München
Arcisstraße 21, 80290 München, Tel.: 089/289-22850, Fax: 089 /289-23967

Calibration Certificate

Number of Invar rod : 27690 Date : 12.01.15

Type of rod : GPCL3 Contract : 14-72-07

Positions of graduations measured : 5 - 344 (counting bar number from bottom)

Determination of the Scale Factor

Measurement Direction up Mean temp.: 19.8 °C Mean press.: 959.0 hPa

Scale factor : -4.88 ppm ± 1.15 ppm Average deviation of measurements : 1.55 µm

Measurement Direction down Mean temp.: 19.8 °C Mean press.: 959.0 hPa

Scale factor : -4.82 ppm ± 1.15 ppm Average deviation of measurements : 1.58 µm

Both directions averaged Mean temp.: 19.8 °C Mean press.: 959.0 hPa

Scale factor : -4.85 ppm ± 1.15 ppm Average deviation of measurements : 1.46 µm

The scale factor is calculated using the middle 16 mm of the visible bar code. If the visible width is smaller than that amount, the whole visible width is used.

Determination of the Index Correction

Measurement Direction up Correction : -0.017 mm ± 0.010 mm

Measurement Direction down Correction : -0.015 mm ± 0.010 mm

Both directions averaged Correction : -0.016 mm ± 0.007 mm

Reference bar correction Correction : -0.018 mm

The index correction is based on the lower edge of graduation bar No.66.825 [mm]Therfore this edge must theoretically have no scale factor correction. Because the scale factor is calculated using the graduation bar centers, a small correction for that reference bar will appear if its gauge is not exact.

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Number of Invar rod : 27690 Date : 12.01.15

Type of rod : GPCL3 Contract : 14-72-07

Positions of graduations measured : 5 - 344 (counting bar number from bottom)

Correction of Graduations

Correction of graduation bar centers is shown in [µm]

	0	1	2	3	4	5	6	7	8	9
0						1.4	2.2	1.1	0.3	-1.0
10	-0.8	-0.1	-1.4	-0.1	1.0	0.7	-0.4	-0.1	-0.8	1.1
20	0.4	-0.2	-0.0	1.8	1.2	2.2	-0.4	0.3	1.6	1.1
30	1.3	0.5	0.5	-0.8	-1.1	0.3	0.6	0.3	-0.2	-0.1
40	-0.1	1.2	-0.3	-0.6	-0.5	0.6	1.2	-0.7	-0.1	-0.0
50	1.4	0.4	0.5	0.9	1.7	1.3	0.4	0.9	0.2	0.7
60	-0.6	1.0	-1.3	-0.0	0.7	1.5	1.0	0.5	0.8	0.1
70	0.1	-0.0	1.1	-0.2	0.8	1.1	0.4	-0.3	0.4	-0.9
80	-0.5	-0.5	-1.3	-1.9	-0.6	-1.1	-1.1	-0.2	-0.9	-1.5
90	-0.9	0.6	-1.0	-0.0	-0.6	-0.2	-0.1	-0.2	-0.1	-0.0
100	-0.6	-0.9	0.6	-1.0	-1.8	-1.9	-1.9	-2.3	-0.9	-1.3
110	-1.1	-1.6	-1.2	-0.8	-0.3	-0.7	-0.4	-2.6	-0.5	-1.7
120	0.2	-0.4	-0.7	-0.2	-0.1	0.6	0.1	0.1	1.5	-0.7
130	0.8	0.6	0.7	1.9	1.3	2.0	1.4	0.4	-0.9	-0.9
140	-0.4	0.0	-0.1	-0.3	-0.5	0.9	0.5	0.8	0.8	0.9
150	1.2	0.2	0.9	0.4	0.6	1.0	1.2	1.0	1.1	1.3
160	0.8	0.8	-0.4	-0.6	-0.4	-1.2	-1.7	-0.9	-1.6	-1.5
170	-1.4	-2.2	-0.8	-2.9	-2.7	-2.1	-2.1	-3.0	-2.7	-2.4
180	-2.1	-3.2	-3.1	-1.5	-2.1	-2.3	-3.5	-2.1	-3.0	-1.8
190	-3.4	-2.7	-2.6	-2.3	-1.8	-2.7	-2.9	-3.7	-3.0	-1.9
200	-3.1	-3.1	-1.3	-1.9	-2.5	-0.7	-1.9	-2.2	-2.7	-1.1
210	-1.7	-1.3	-2.1	-3.6	-3.7	-2.0	-1.9	-1.9	-3.3	-3.3
220	-0.9	-2.7	-1.6	-0.1	-1.2	-0.6	-2.1	-1.3	-0.3	-0.4
230	-2.3	-2.0	-1.7	-0.1	-0.7	-2.1	-0.2	-0.5	-0.6	0.6
240	1.5	1.0	0.8	0.8	-2.0	1.1	-0.2	-0.0	-0.8	-2.0
250	-1.3	-2.1	-1.4	-1.2	-1.6	-1.7	-1.2	-0.4	-0.6	-0.5
260	1.0	-1.6	0.9	-0.3	0.5	-0.9	-0.4	0.2	-0.1	-1.2
270	-0.2	-0.4	-0.7	-0.6	-1.8	-0.8	-2.3	-2.6	-1.9	-2.6
280	-1.3	0.7	1.0	1.6	-0.6	2.4	0.3	1.4	1.0	0.8
290	-0.0	-0.5	0.3	0.2	-1.6	-1.4	-0.6	-0.3	-0.4	-0.9
300	1.0	-1.2	-1.0	0.4	-1.1	-0.7	-0.6	-1.7	-0.8	-1.4
310	0.2	-0.4	1.0	-0.3	0.3	1.0	0.5	1.0	1.0	1.9
320	0.4	-0.3	-0.1	0.2	0.6	1.5	1.4	1.0	1.8	2.3
330	1.6	2.6	2.6	2.3	3.0	2.3	3.2	3.8	3.2	3.9
340	4.0	3.5	2.3	2.4	1.9					

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Calibration of Invar Rods

Invar rods for precise levelling are examined on the comparators at the Geodetic Laboratory at the Chair of Geodesy of the Technical University in Munich. The distances between the single lines on the invar tape are tested with a laser interferometer. The lines are observed with an CCD-array camera. The observation process itself in these advanced comparators is therefore completely automated.

Determination of the Index correction of the graduation

The distance between the reference edge of the graduation and the support area of the rod is measured in the axis of the invar tape and compared with the default value.

It become specified

- the **index correction of the reference bar** l_K^0
  The reference edge of the reference bar is the only - by the manufacturer - used point which can be excerted to compare the graduation to the support area.

- the **reference bar correction** v_K
  In practice, not edges but bar centers are observed. The reference bar correction consists of any differences of the reference bar center from the reference edge, e.g. caused by a too wide/too narrow reference bar.

- the **index correction of the rod** l^0
  is the sum of index correction of the reference bar l_K^0 and the reference bar correction v_K. This is the correction value which has to be added to each rod reading.

For rods with two line graduations, the **offset between the graduations** k^0 is further determined.

Determination of the scale factor in vertical position

The position of all graduation bars is observed in both measurement directions.
The nominal and real position are compared and the results are related to a straight line. The gradient of this regression is the **scale factor** m_0 at the temperature of the measurement T_0.

Calibrating invar rods with line graduations the scale factor is determined for both scales separately.

A tabulated certificate of the **residuals of individual lines** is supplied on paper or disc.

Determination of the coefficient of expansion

For the evaluation of the coefficient of expansion the position of approx. 80 uniformly distributed lines (barcode rods) resp. all lines of the right graduation scale (line graduation rods)are observed at different temperatures on a horizontal comparator with an opto-electronic double-diode microscope. The respective scale factors depend on the temperatures, they are related to a regression line. Its gradient is the **coefficient of expansion** α_T.
Observations are accomplished in a cycle of $30 \rightarrow 0 \rightarrow 20 \rightarrow 40 \rightarrow 10$ [°C].
The ample differences of temperature between the single observations ensure, that malfunctions of the tension module and the influence of the friction between the invar tape and the housing of the rod can be detected.

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