Calibration of a gauge block of nominal length 50 mm

The calibration of the grade 0 gauge block (ISO 3650) of 50 mm nominal length is carried out by comparison using a comparator and a calibrated gauge block of the same nominal length and the same material as reference standard. The difference in central length is determined in vertical position of the two gauge blocks using two length indicators contacting the upper and lower measuring faces.

The actual length of the gauge block to be calibrated is related to the actual length of the reference standard by the equation

$l_X' = l_S' + \delta l$

with δl being the measured length difference. l_X blocks under the measurement conditions, in particular at a temperature which on account of the uncertainty in the measurement of laboratory temperature may not be identical with the reference temperature for length measurements.

Model Equation:

$$l_X = l_S + \delta l_D + \delta l + \delta l_C - L * (\alpha_{av} * \delta t + \delta\alpha * \Delta t_{av} + u_{at}) - \delta l_V$$

List of Quantities:

Quantity	Unit	Definition
l_X	mm	length of the gauge block to be calibrated
l_S	mm	length of the reference gauge block at the reference temperature of t_0=20 °C according to its calibration certificate
δl_D	mm	Change of the length of the reference gauge block since its last calibration due to drift
δl	mm	observed difference in length between the unknown and the reference gauge block
δl_C	mm	correction for non-linearity and offset of the comparator
L	mm	nominal length of the gauge blocks under consideration
α_{av}	K^{-1}	average of the thermal expansion coefficients of the unknown and the reference gauge block
δt	K	difference in temperature between the unknown the reference gauge block
$\delta\alpha$	K^{-1}	difference in the thermal expansion coefficients between the unknown and the reference gauge block
Δt_{av}	K	deviation of the average temperature of the unknown and the standard gauge block from the reference temperature
u_{at}		coorection for second order terms of ($\delta\alpha * \Delta t_{av}$)
δl_V	mm	correction for non-central contacting of the measuring faces of the unknown gauge block

l_S:

Type B normal distribution
Value: 50.000020 mm
Expanded Uncertainty: $30 \cdot 10^{-6}$ mm
Coverage Factor: 2.0

REFERENCE STANDARD: The length of the reference gauge block together with the associated expanded uncertainty of measurement is given in the calibration certificate of a set of gauge blocks as 50,000 02 mm ±30 nm (coverage factor k=2).

δl_D: Type B triangular distribution
Value: 0 mm
Halfwidth of Limits: $30 \cdot 10^{-6}$ mm

DRIFT OF THE STANDARD: The temporal drift of the length of the reference gauge block is estimated from previous calibrations to be zero with limits ±30 nm. General experience with gauge blocks of this type suggest that the zero drift is the most probable value and that a triangular probability distribution can be assumed.

δl: Type A
Method of observation: Direct
Number of observations: 5

No.	Observation
1	$-100 \cdot 10^{-6}$ mm
2	$-90 \cdot 10^{-6}$ mm
3	$-85 \cdot 10^{-6}$ mm
4	$-95 \cdot 10^{-6}$ mm
5	$-100 \cdot 10^{-6}$ mm

Arithmetic Mean: $-94.000 \cdot 10^{-6}$ mm
Pooled Standard Deviation: $12 \cdot 10^{-6}$ mm
Pooled Degrees of Freedom: 9
Standard Uncertainty: $4.749 \cdot 10^{-6}$ mm

MEASUREMENTS: A pooled estimate of standard deviation of 15 nm derived from previous measurements is used for the evaluation of the repeatability. The following observations are made for the difference between the unknown gauge block and the reference standard, the comparator being reset using the reference standard before each reading.

δl_C: Type B rectangular distribution
Value: 0 mm
Halfwidth of Limits: $32 \cdot 10^{-6}$ mm

COMPARATOR: The comparator has been verified to meet the specifications stated in EAL-G21. From this it can be ascertained that for length differences D up to ±10 µm corrections to the indicated length difference are within the limits ±(30 nm + 0,02 * abs(D)). Taking into account the tolerances of the grade 0 gauge block to be calibrated and the grade K reference gauge block the maximum length difference will be within ±1 µm leading to the limits of ±32 nm for non-linearity and offset corrections of the comparator used.

L: Constant
Value: 50 mm

Nominal length of the gauge block to be calibrated.

α_{av}: Type B rectangular distribution
Value: $11.5 \cdot 10^{-6}$ K^{-1}
Halfwidth of Limits: $1 \cdot 10^{-6}$ K^{-1}

TEMPERATURE CORRECTION: Based on the calibration certificate of the reference gauge block and the manufacturer's data for the gauge block to be calibrated the linear thermal expansion coefficient of the steel gauge blocks is assumed to be within the interval $(11{,}5 \pm 1{,}0) \times 10^{-6}$ $°C^{-1}$.

δt: Type B rectangular distribution
Value: 0 K
Halfwidth of Limits: 0.05 K

TEMPERATURE CORRECTION: Before calibration care is taken to ensure that the gauge blocks assume ambient temperature of the measuring room. The remaining difference in temperature between the standard and the gauge block to be calibrated is estimated to be within ±0,05 K.

$\delta\alpha$: Type B triangular distribution
Value: 0.0 K^{-1}
Halfwidth of Limits: $2{\cdot}10^{-6}$ K^{-1}

TEMPERATURE CORRECTION: Combining the two rectangular distributions the difference in linear thermal expansion coefficient is triangularly distributed within the limits ±2E-6 $°C^{-1}$.

Δt_{av}: Type B rectangular distribution
Value: 0 K
Halfwidth of Limits: 0.5 K

TEMPERATURE CORRECTION: The deviation of the mean temperature of measurement from the reference temperature t_0 = 20 °C is estimated to be within ±0,5 °C.

u_{at}: Type B normal distribution
Value: 0
Expanded Uncertainty: $0.236{\cdot}10^{-6}$
Coverage Factor: 1.0

TEMPERATURE CORRECTION: The best estimates of the difference in linear expansion coefficients ($\delta\alpha$) and the deviations of the mean temperature from the reference temperature (Δt_{av}) are zero. Therefore second order terms have to be taken into account in the evaluation of their uncertainty contribution resulting in the product of standard uncertainties associated with the factors of the product term ($\delta\alpha \times \Delta t_{av}$) in the model equation. The final standard uncertainty is $u(\delta\alpha \times \Delta t_{av}) = 0{,}236{\cdot}10^{-6}$.

δl_V: Type B rectangular distribution
Value: 0 mm
Halfwidth of Limits: $6.7{\cdot}10^{-6}$ mm

VARATION IN LENGTH: For gauge blocks of grade 0 the variation in length determined from measurements at the centre and the four corners has to be within ±0,12 mm (ISO 3650). Assuming that this variation occurs on the measuring faces along the short edge of length 9 mm and that the central length is measured inside a circle of radius 0,5 mm the correction due to central misalignment of the contacting point is estimated to be within ±6,7 nm.

Uncertainty Budgets:

l_X: length of the gauge block to be calibrated

Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
l_S	50.00002000 mm	$15.00 \cdot 10^{-6}$ mm	normal	1.0	$15 \cdot 10^{-6}$ mm	19.3 %
δl_D	0.0 mm	$12.25 \cdot 10^{-6}$ mm	triangular	1.0	$12 \cdot 10^{-6}$ mm	12.8 %
δl	$-94.000 \cdot 10^{-6}$ mm	$4.749 \cdot 10^{-6}$ mm	normal	1.0	$4.7 \cdot 10^{-6}$ mm	1.9 %
δl_C	0.0 mm	$18.48 \cdot 10^{-6}$ mm	rectangular	1.0	$18 \cdot 10^{-6}$ mm	29.2 %
L	50.0 mm					
α_{av}	$11.5000 \cdot 10^{-6}$ K^{-1}	$577.4 \cdot 10^{-9}$ K^{-1}	rectangular	0.0	0.0 mm	0.0 %
δt	0.0 K	0.02887 K	rectangular	$-580 \cdot 10^{-6}$	$-17 \cdot 10^{-6}$ mm	23.6 %
$\delta\alpha$	0.0 K^{-1}	$816.5 \cdot 10^{-9}$ K^{-1}	triangular	0.0	0.0 mm	0.0 %
Δt_{av}	0.0 K	0.2887 K	rectangular	0.0	0.0 mm	0.0 %
u_{at}	0.0	$236.0 \cdot 10^{-9}$	normal	-50	$-12 \cdot 10^{-6}$ mm	11.9 %
δl_V	0.0 mm	$3.868 \cdot 10^{-6}$ mm	rectangular	-1.0	$-3.9 \cdot 10^{-6}$ mm	1.3 %
l_X	49.99992600 mm	$34.18 \cdot 10^{-6}$ mm				

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
l_X	49.999926 mm	$68 \cdot 10^{-6}$ mm	2.00	95% (t-table 95.45%)