UNCERTAINTY BUDGET FOR

COMMERCIAL GAGE BLOCK CALIBRATION

FOR

ACME Calibration – Hollywood, CA

NVLAP Lab Code – 200000-0

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AMMENDMENTS

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DISCLAIMER

SYMBOLS

c_i	Sensitivity Coefficients: represents the sensitivity of independent variable x_i.
$u(x_i)$	Standard uncertainty: "the uncertainty of x_i" reduced to 1σ.
$u_c(y)$	Combined uncertainty using the square root of the sum of squares method.
υ	Degrees of freedom.
υ_{eff}	Effective degrees of freedom using the Welch-Satterthwaite equation.

CLASSIFICATION CODES

A1 The uncertainty deduced from the analysis of the results of experimentation.
A2 The uncertainty deduced from the analysis of the results of Monte Carlo Simulation.

B1 The uncertainty deduced from evaluation by means other than the statistical analysis of a series of observations. Assumed probability distribution: Rectangular
B2 The uncertainty deduced from the results of calibration. Assumed probability distribution: Gaussian
B3 The uncertainty deduced from manufacture or calibration specifications. Assumed probability distribution: Gaussian
B4 The uncertainty deduced from the analysis of internal experimental results greater than 24 months in age. Assumed probability distribution: Gaussian
B5 The uncertainty deduced from the analysis of external experimental results. Assumed probability distribution: Gaussian
B6 The uncertainty is not able to be quantified. Information resides with another entity who may or may not have included the data in their expression of reference uncertainty. Assumed probability distribution: Gaussian
B7 The uncertainty is not able to be quantified. Assumed probability distribution: Rectangular

NOTES

1 Degrees of freedom for Type B uncertainties represented by a Gaussian distribution are assumed to be 99.
2 Degrees of freedom for Type B uncertainties represented by a rectangular distribution are assumed to be $1 \bullet 10^{200}$ or $1E^{+200}$.
3 Values are rounded up when the least significant digit (LSD) is greater than or equal to 5, and rounded down when the LSD is less than 5.
4 Expansion coefficients not equal to 2 are quantified from the utilization of the Student's t-distribution probability density function.
5 Sensitivity coefficients not identified are assumed to equal 1.

DEFINITIONS

Repeatability
Def – The variability (i.e. standard deviation) in measurement precision under replicate measurement conditions over a short period of time.

Reproducibility
Def – The variability (i.e. standard deviation) in measurement precision under reproducible conditions of measurement which may include, but are not limited to, one or more of the following conditions; day-to-day variability, operator-to-operator variability, system-to-system variability, and/or location-to-location variability.

Stability
Def – The run to run variability (i.e. standard deviation) estimated from a set of data collected from replicate trials or the run to run variability (i.e. standard deviation) estimated from a set of data collected from replicate calibration events.

Bias
Def – estimate of systematic error calculated by the difference between the mean of replicate indications, reported in calibration reports, and a reference quantity value.

Drift
Def – estimate of incremental change, or difference, in metrological properties over time or between calibration events.

Resolution
Def – smallest change in quantity being measured that causes a perceptible change in the corresponding indication.

Specification/Tolerance
Def – published accuracy specifications endorsed by a manufacturer or a reported tolerance specification endorsed by a calibration service provider.

Reference Standard Uncertainty
Def – estimated mean or reported value of uncertainty in measurement associated with the performance of calibration.

Reference Standard Stability
Def – estimated variability (i.e. standard deviation) of reference standard uncertainty associated with multiple calibration events.

REFERENCES

1 Guide to the Expression of Uncertainty in Measurement by JCGM; JCGM 100:2008
2 International Vocabulary of Metrology by JCGM; JCGM 200:2012
3 R205: Specific Requirements: Calibration Laboratory Accreditation Program by A2LA
4 G118: Guidance for Defining the Scope of Accreditation for Calibration Laboratories by A2LA
5 ILAC P14-01:2013: ILAC Policy for Uncertainty in Calibration by ILAC
6 NASA Measurement Uncertainty Analysis Principles and Methods
7 SEMATECH: Engineering Statistics Handbook by NIST
8 NPL Measurement Good Practice Guide No. 11 by Stephanie Bell
9 Distributions for Uncertainty Analysis by Dr. Howard T. Castrup
10 Error Distribution Variances and Other Statistics by Dr. Howard T. Castrup
11 Applying Measurement and Test Equipment Specifications by Susanne Castrup
12 How to Establish Manufacturing Specifications by Donald Wheeler
13 NIST Handbook 150:2006 Procedures and General Requirements by NVLAP
14 NIST Handbook 150-2F Calibration Laboratories Technical Guide for Dimensional Measurements by NVLAP
15 J.Res. NIST 102, 647 (1997) – Uncertainty and Dimensional Calibrations by Ted Doiron and John Stoup.
16 The Gage Block Handbook by Ted Doiron and John Beers
17 A2LA G103 – Guide for Estimation of Uncertainty of Dimensional Calibration and Testing Results by A2LA

SUMMARY OF RESULTS

Uncertainty Analysis: CMC (Calibration and Measurement Capability)

Measured Parameter or Device Calibrated	Range	Uncertainty (k=2)	Remarks
Standard Size Gage Blocks – Chrome-carbide	0.05 in to 4.0 in >4.0 in to 20 in	1.6 µin + 0.62L µin 1.9 µin + 0.56L µin	Commercial Grade Calibration

NOTES

1 CMC equation(s) derived from linear regression analysis.

UNCERTAINTY BUDGETS

Commercial Gage Block Calibration
Starrett CC Gage Block – ID# G-1
Range: 0.05 in to 4.0 in
Test Point: 0.1 in

Uncertainty Analysis: CMC (Calibration and Measurement Capability)

	Sensitivity Coefficient	Value	Unit	Type	Distribution	Divisor	Std Uncertainty	Degrees of Freedom	Significance Check
	(c_i)	(x_i)					$u(x_i)$	υ	
Repeatability	1	0.173	uin	A	Gaussian	1	0.1730	240	10.0%
Reproducibility	1	0.306	uin	A	Gaussian	1	0.3060	30	17.6%
Stability	1	0.244	uin	B	Gaussian	1	0.2440	10	14.0%
Drift	1	0.090	uin	B	Gaussian	1	0.0900	10	5.2%
Resolution	1	0.100	uin	B	Rectangular	√3	0.0577	1E+200	3.3%
Reference Standard	1	1.400	uin	B	Gaussian	2	0.7000	99	40.3%
Reference Std Stability	1	0.037	uin	B	Gaussian	2	0.0185	10	1.1%
Thermal Expansion	1	0.170	uin	B	Triangular	√6	0.0694	1E+200	4.0%
Thermal Gradients	1	0.037	uin	B	Triangular	√6	0.0151	1E+200	0.9%
Elastic Deformation	1	0.037	uin	B	Rectangular	√3	0.0214	1E+200	1.2%
Instrument Geometry	1	0.037	uin	B	Rectangular	√3	0.0214	1E+200	1.2%
Artifact Geometry	1	0.037	uin	B	Rectangular	√3	0.0214	1E+200	1.2%
							$u_c(y)$	υ_{eff}	
Combined Uncertainty (RSS method)							0.83	155.0	100.0%
Expansion Coefficienct (k)							2.000		
Expanded Uncertainty $[\ ku_c(y)\ ]$							1.7	uin	

Test Point: 4.0 in

Uncertainty Analysis: CMC (Calibration and Measurement Capability)

	Sensitivity Coefficient	Value	Unit	Type	Distribution	Divisor	Std Uncertainty	Degrees of Freedom	Significance Check
	(c_i)	(x_i)					$u(x_i)$	υ	
Repeatability	1	0.387	uin	A	Gaussian	1	0.3870	110	9.1%
Reproducibility	1	0.473	uin	A	Gaussian	1	0.4730	12	11.2%
Stability	1	0.458	uin	B	Gaussian	1	0.4580	4	10.8%
Drift	1	0.183	uin	B	Gaussian	1	0.1830	4	4.3%
Resolution	1	0.100	uin	B	Rectangular	√3	0.0577	1E+200	1.4%
Reference Standard	1	3.500	uin	B	Gaussian	2	1.7500	99	41.3%
Reference Std Stability	1	0.095	uin	B	Gaussian	2	0.0475	4	1.1%
Thermal Expansion	1	1.680	uin	B	Triangular	√6	0.6859	1E+200	16.2%
Thermal Gradients	1	0.122	uin	B	Triangular	√6	0.0498	1E+200	1.2%
Elastic Deformation	1	0.084	uin	B	Rectangular	√3	0.0485	1E+200	1.1%
Instrument Geometry	1	0.084	uin	B	Rectangular	√3	0.0485	1E+200	1.1%
Artifact Geometry	1	0.084	uin	B	Rectangular	√3	0.0485	1E+200	1.1%
							$u_c(y)$	υ_{eff}	
Combined Uncertainty (RSS method)							2.04	157.1	100.0%
Expansion Coefficienct (k)							2.000		
Expanded Uncertainty $[\ ku_c(y)\ ]$							4.1	uin	

UNCERTAINTY BUDGETS

Commercial Gage Block Calibration
Starrett Steel Gage Block – ID# GG-3
Range: 4.0 in to 20 in
Test Point: 4.0 in

Uncertainty Analysis: CMC (Calibration and Measurement Capability)

	Sensitivity Coefficient	Value	Unit	Type	Distribution	Divisor	Std Uncertainty	Degrees of Freedom	Significance Check
	(c_i)	(x_i)					$u(x_i)$	υ	
Repeatability	1	0.387	uin	A	Gaussian	1	0.3870	110	9.0%
Reproducibility	1	0.473	uin	A	Gaussian	1	0.4730	12	11.0%
Stability	1	0.465	uin	B	Gaussian	1	0.4650	4	10.8%
Drift	1	0.275	uin	B	Gaussian	1	0.2750	4	6.4%
Resolution	1	0.100	uin	B	Rectangular	√3	0.0577	1E+200	1.3%
Reference Standard	1	3.500	uin	B	Gaussian	2	1.7500	99	40.8%
Reference Std Stability	1	0.000	uin	B	Gaussian	2	0.0000	4	0.0%
Thermal Expansion	1	1.680	uin	B	Triangular	√6	0.6859	1E+200	16.0%
Thermal Gradients	1	0.122	uin	B	Triangular	√6	0.0498	1E+200	1.2%
Elastic Deformation	1	0.084	uin	B	Rectangular	√3	0.0485	1E+200	1.1%
Instrument Geometry	1	0.084	uin	B	Rectangular	√3	0.0485	1E+200	1.1%
Artifact Geometry	1	0.084	uin	B	Rectangular	√3	0.0485	1E+200	1.1%
							$u_c(y)$	υ_{eff}	
Combined Uncertainty (RSS method)							2.1	158.0	100.0%
Expansion Coefficienct (k)							2.000		
Expanded Uncertainty $[\ ku_c(y)\ ]$							4.1	uin	

Test Point: 20 in

Uncertainty Analysis: CMC (Calibration and Measurement Capability)

	Sensitivity Coefficient	Value	Unit	Type	Distribution	Divisor	Std Uncertainty	Degrees of Freedom	Significance Check
	(c_i)	(x_i)					$u(x_i)$	υ	
Repeatability	1	1.210	uin	A	Gaussian	1	1.2100	110	8.2%
Reproducibility	1	2.330	uin	A	Gaussian	1	2.3300	12	15.7%
Stability	1	2.148	uin	B	Gaussian	1	2.1480	4	14.5%
Drift	1	0.330	uin	B	Gaussian	1	0.3300	4	2.2%
Resolution	1	0.100	uin	B	Rectangular	√3	0.0577	1E+200	0.4%
Reference Standard	1	8.600	uin	B	Gaussian	2	4.3000	99	29.0%
Reference Std Stability	1	0.799	uin	B	Gaussian	2	0.3995	4	2.7%
Thermal Expansion	1	8.400	uin	B	Triangular	√6	3.4293	1E+200	23.1%
Thermal Gradients	1	0.440	uin	B	Triangular	√6	0.1796	1E+200	1.2%
Elastic Deformation	1	0.510	uin	B	Rectangular	√3	0.2944	1E+200	2.0%
Instrument Geometry	1	0.130	uin	B	Rectangular	√3	0.0751	1E+200	0.5%
Artifact Geometry	1	0.130	uin	B	Rectangular	√3	0.0751	1E+200	0.5%
							$u_c(y)$	υ_{eff}	
Combined Uncertainty (RSS method)							6.5	157.8	100.0%
Expansion Coefficienct (k)							2.000		
Expanded Uncertainty $[\ ku_c(y)\ ]$							13	uin	