Fundamental Concepts for Developing Measurement Uncertainty Estimates

Short Course

PJLA

Trainer:
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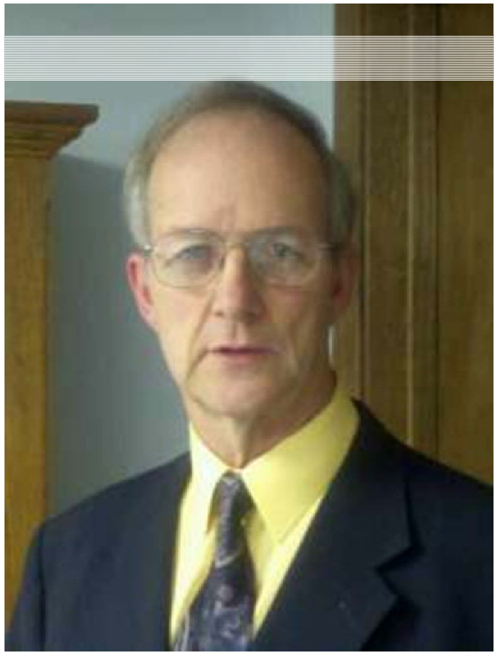
Introducing PJLA

Formed in 1999, PJLA is an ILAC MRA Signatory. As such it is an internationally recognized accrediting body providing accreditation services to calibration and testing laboratories in many countries throughout the world now including Great Britain.

In addition to this free short course on Measurement Uncertainty Fundamentals, PJLA routinely offers customer and public training programs on a variety of topics related to the ISO/IEC 17025:2017 standard and its implementation.

The PJLA website includes a schedule of upcoming training plus recordings of instructional webinars on a variety of topics related to ISO/IEC 17025:2017 standard

Todays training is intended to provide you with useful fundamental knowledge of measurement uncertainty and the methods used to estimate the uncertainty of calibration or testing results.



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Schedule of Activity

Todays training will be approximately 2 hours in duration with a 15 minute break at the midpoint.

A question and answer period will follow the second hour

There will be 7 interactive quizzes during the course of the training.

A poll of possible answers will be displayed. You are to select what you believe to be the correct answer.

After you have had a chance to make your selection, the correct answer will be given with discussion as necessary for clarification.

Todays presentation will be recorded and available on the PJLA website for review or download.

A certificate of completion will be issued by email to all participants several days after the training is completed.

The “GUM”

JCGM 100:2008

Evaluation of Measurement Data - Guide to the Expression of Uncertainty in Measurement

https://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

The "VIM"

JCGM 200:2012

International Vocabulary of Metrology – Basic and General Concepts and Associated Terms

https://www.bipm.org/utils/common/documents/jcgm/JCGM_200_2012.pdf

Requirements from Standards and References

Measurement Uncertainty requirements in ISO/IEC 17025:2017

Measurement Uncertainty requirements in ILAC P14

Measurement Uncertainty requirements in JCGM 100:2008 "the GUM"

Measurement Uncertainty requirements in PJLA PL-3

Standards and Reference Requirements

ISO/IEC 17025:2017

7.6.1 Laboratories shall identify the contributions to measurement uncertainty. When evaluating measurement uncertainty, all contributions which are of significance, including those arising from sampling, shall be taken into account using appropriate methods of analysis.

Question #1

Quiz Question 1:

When evaluating the uncertainty of measurement results, what uncertainty sources must be included in the analysis?

1) *All that can be easily identified*
2) *All that are of significance*
3) *All that are identified in ISO/IEC 17025:2017*
4) *Customer requested sources listed on the purchase order*

Interactive Quiz #1 Answer Sheet

<u>Quiz Question 1:</u>

When evaluating the uncertainty of measurement results, what uncertainty sources must be included in the analysis?

All that are of significance

ISO/IEC 17025:2017

7.6.1 Laboratories shall identify the contributions to measurement uncertainty. When evaluating measurement uncertainty, all contributions which are ***<u>of significance</u>***, including those arising from sampling, shall be taken into account using appropriate methods of analysis.

Note: PJLA PL-3 requires that your uncertainty procedure must contain a "significance test".

Standards and Reference Requirements

ISO/IEC 17025:2017

7.6.1 Laboratories shall identify the contributions to measurement uncertainty. When evaluating measurement uncertainty, all contributions which are of significance, including those arising from sampling, shall be taken into account using appropriate methods of analysis.

7.6.2 A laboratory performing calibrations, including of its own equipment, shall evaluate the measurement uncertainty for all calibrations.

7.6.3 A laboratory performing testing shall evaluate measurement uncertainty. Where the test method precludes rigorous evaluation of measurement uncertainty, an estimation shall be made based on an understanding of the theoretical principles or practical experience of the performance of the method.

Standards and Reference Requirements

ISO/IEC 17025:2017

7.6.3 NOTE 1 In those cases where a well-recognized test method specifies limits to the values of the major sources of measurement uncertainty and specifies the form of presentation of the calculated results, the laboratory is considered to have satisfied 7.6.3 by following the test method and reporting instructions.

- All elements of the test and components of the equipment are potential sources of uncertainty
- Detailed specification of the test apparatus is provided
- Specific instructions are given for performance of the test
- Stated limits to the values of the major sources of measurement uncertainty are typically based on the statistical analysis of data from tests within the applicable range of the test method.

Standards and Reference Requirements

ISO/IEC 17025:2017

7.6.3 NOTE 2 For a particular method where the measurement uncertainty of the results has been established and verified, there is no need to evaluate measurement uncertainty for each result if the laboratory can demonstrate that the identified critical influencing factors are under control.

Be aware that NOTE 2 applies to testing laboratories only!

Section 7.6.2 requires calibration laboratories to … "*evaluate measurement uncertainty for all calibrations*"

7.6.3 NOTE 3 For further information, see ISO/IEC Guide 98-3, ISO 21748 and the ISO 5725 series.

Question #2

Quiz Question 2: True or False

For a calibration laboratory, there is no need to evaluate measurement uncertainty for each calibration result if the laboratory estimated it once and can demonstrate that the identified critical influencing factors are under control.

1) *True*
2) *False*

Interactive Quiz #2 Answer Sheet

Quiz Question 2: True or False

For a calibration laboratory, there is no need to evaluate measurement uncertainty for each calibration result if the laboratory estimated it once and can demonstrate that the identified critical influencing factors are under control.

FALSE

ISO/IEC 17025:2017

Found in 7.6.3 A laboratory performing testing …

NOTE 2 For a particular method where the measurement uncertainty of the results has been established and verified, there is no need to evaluate measurement uncertainty for each result if the laboratory can demonstrate that the identified critical influencing factors are under control.

Be aware that NOTE 2 applies to testing laboratories only!

Standards and Reference Requirements

ILAC P14

Uncertainty resulting from repeatability must be included in the estimate

Regardless of the reporting option chosen, if the UUT will be used to perform further calibrations the uncertainty must always be reported

Uncertainty and CMC must be both estimated by the same method

The uncertainty must never be reported as less than the CMC for the ability of the laboratory to perform the calibration

The uncertainty shall never be reported at more than 2 significant digits (*PJLA PL-3 specifies the method, a calculator is available*)

Standards and Reference Requirements

JCGM 100:2008 Evaluation of measurement data - Guide to the expression of uncertainty in measurement “the GUM”

All contributors of significance must be taken into account

All contributors must be evaluated using appropriate mathematical and statistical techniques

Repeatability is represented by the experimental standard deviation of the mean

The best approximation of the actual value of the measured value is the average of repeated readings

Type A analysis is when the result is obtained from the statistical analysis of a series of readings

Type B analysis is when the result is obtained by any other method

Standards and Reference Requirements

PJLA PL-3 Example policy of an Accrediting Body

Uncertainty analysis is to be documented in an uncertainty "budget".

This is typically the process of identifying uncertainty components, quantifying those components, combining those components, then expanding those components.

The laboratory must define the manner in which uncertainty is accounted for when making statements of compliance with specifications. (*Now imbedded in the ISO/IEC 17025:2017 Standard as the "Decision Rule".)*

Uncertainty for calibrations performed and CMC as it appears on the scope of accreditation must be estimated by the same method.

Measurement Uncertainty Concepts

What is Measurement Uncertainty?

What are the Sources of Measurement Uncertainty?

- Limitations in the data defining the measurement
- Limitations in the capability of the measuring equipment

Accounting for Measurement Uncertainty when Making Statements of Conformity

Measurement Uncertainty Calculation Development

Measurement Uncertainty requirements related to calibration laboratories

Measurement Uncertainty requirements related to testing laboratories

Review examples of Measurement Uncertainty estimation for calibration and testing laboratories

What is Measurement Uncertainty

It is the extent to which a measurement result may differ from the actual or true value of the parameter being measured.

Note: Measurement uncertainty is not a measurement error!

Measurement uncertainty tends to result from limitations of the measurement and test equipment and lack of detail and clarity in defining the measurement and measurement process.

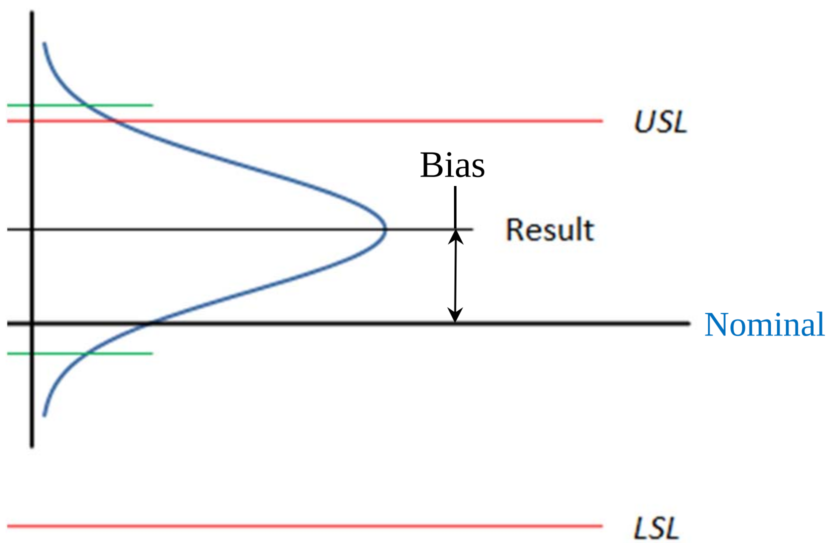
A measurement result may be affected by both random variation and systematic variation in the measurement system.

Random variation results in measurement uncertainty.

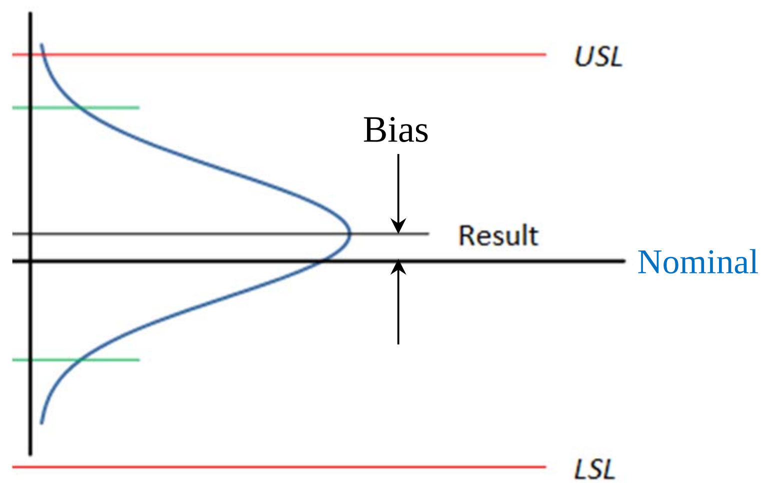
Systematic variation typically results in measurement bias which affects compliance with specification.

What is Measurement Uncertainty

- **Random variation** in the measurement process: Produces variation between individual measured values.
- **Systematic variation** in the measurement process: Produces bias between expected values and measured values.
- Standard deviations are the same. The means are different



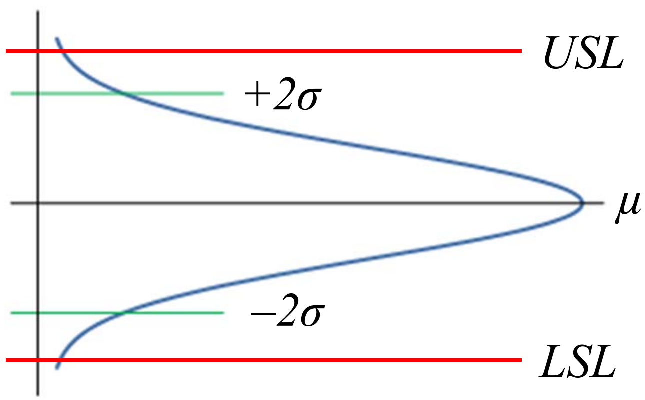
Dispersion results from random variation



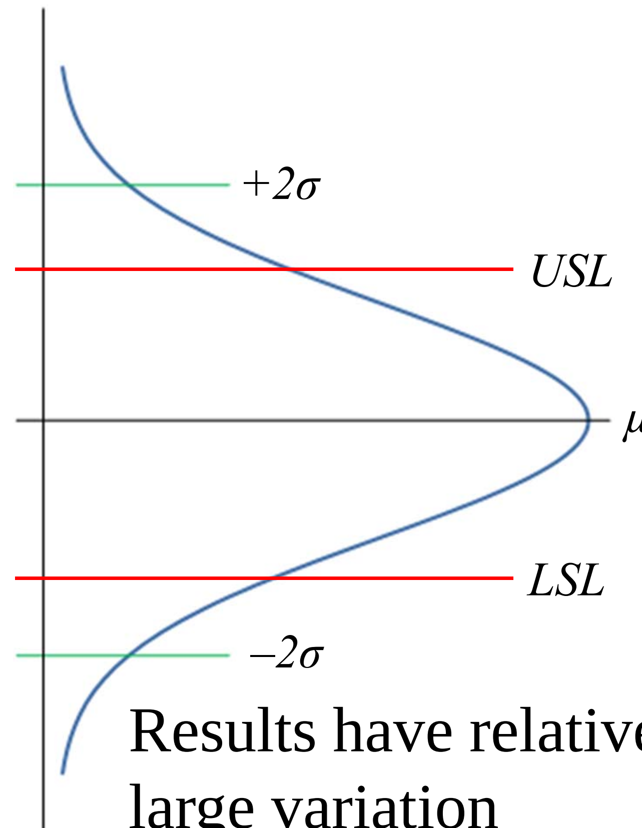
Bias results from Systematic variation

What is Measurement Uncertainty

- Both distributions shown below are normal with the same mean but different standard deviations
- Both are fully defined by their mean and standard deviation



Results have relatively small variation



Results have relatively large variation

Interactive Quiz #3 Answer Sheet

Quiz Question 3:

When performing system analysis, there are 2 common types of variation, random and systematic.

Which one is responsible for the dispersion of uncertainty values?
#1 *Random*

Which one is responsible for the bias of uncertainty values?
#2 Systematic

Which type has the potential to reduce the risk of false acceptance and improve compliance with specification?
#2 Systematic

Examples of M&TE Limitations

Limited resolution: Resolution may range from very fine (an instrument can resolve or discriminate between items with very small differences e.g. a micrometer with 0.025 mm resolution) to very course (an instrument can only resolve or discriminate between items with relatively large differences e.g. a yardstick with 3 mm resolution).

The instrument and the UUT both expand beyond their calibrated length due to the temperature exceeding the standard temperature of 20 °C.

Low RH and nonstandard temperature result in accelerated evaporation of the distilled water used to calibrate a pipette.

The weight of a precision mass must be adjusted based on the local value of g where it will be used compared to the local value of g at the location of calibration.

Examples of Data Limitations

A test procedure defines the manner by which a test is to be performed.

Where time is critical to the outcome of a test result, resolution of the timing device affects the extent to which the result is uncertain.

The dimensional definition of an apparatus for performing the test has liberal tolerances which may result in large variation between otherwise similar pieces of equipment.

In some instances, published test procedures contain the acceptance criteria and describe the sampling method by which they were determined. The method was statistical but important statistical parameters are not clearly stated or defined.

Accounting for Measurement Uncertainty when making Statements of Compliance

ISO/IEC 17025:2017

7.8.6.1 When a statement of conformity to a specification or standard is provided, the laboratory shall document the decision rule employed, taking into account the level of risk (such as false accept and false reject and statistical assumptions) associated with the decision rule employed, and apply the decision rule.

- The decision rule must be mutually agreed to and documented
- False acceptance and other types of risk must be taken into account along with statistical assumptions
- The decision rule must be applied in making the compliance statement

Example Decision Rule and Compliance Statement

A valid decision rule would be as follows:

"*A test result will be considered as in compliance if the risk of false acceptance does not exceed 5% with the uncertainty estimated at an approximate 95% confidence level with k =2*"

A corresponding and valid compliance statement is as follows:

"*The false acceptance risk associated with the test results is 4.2% and is considered to be in compliance based on the decision rule agreed to and stated on this test report*"

Application of the decision rule would require that the risk of false acceptance be calculated and if it is not greater than 5%, the results are stated as being in compliance.

If on the other hand the risk of false acceptance exceeds 5%, the result is stated as being in noncompliance.

Question #4

Quiz Question 4:

What is a decision rule?

1) *It is a rule used by both parties to determine if the measurement uncertainty has been properly estimated and applied to the results*
2) *It is a rule agreed to by the customer and the laboratory defining how uncertainty is accounted for when making a statement of compliance with a specification.*
3) *It is a rule recommended by the calibration service provider and acceptance by the customer is mandatory in order to establish traceability of the calibration results*

Interactive Quiz #4 Answer Sheet

Quiz Question 4:

What is a decision rule?

What it is: It is a rule agreed to by the customer and the laboratory defining how uncertainty is accounted for when making a statement of compliance with a specification.

How it's used: Uncertainty is applied to the measurement result according to the decision rule and the compliance decision is made.

ISO/IEC 17025:2017

7.8.6.1 When a statement of conformity to a specification or standard is provided, the laboratory shall document the decision rule employed, taking into account the level of risk (such as false accept and false reject and statistical assumptions) associated with the decision rule employed, and apply the decision rule.

Hour 2 begins in 15 minutes

Uncertainty Included In Test Method

Designation: D 6184 – 98 (Reapproved 2005)

ASTM D 6184 – 98 Standard Test Method for Oil Separation from Lubricating Grease (Conical Sieve Method)

Compliance of Test Results with Performance Specification:

Uncertainty Included In Test Method

Repeatability: The difference between two test results, obtained by the same operator with the same apparatus under constant specified operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values only in 1 case in 20:

Repeatability: % oil separation = $1.151 \times (M)^{0.5}$

Reproducibility: The difference between two single and independent results by two different operators working in different laboratories on identical test material would. in the long run, in the normal and correct operation of the test method, exceed the following values only in 1 case in 20:

Reproducibility: % oil separation = $1.517 \times (M)^{0.5}$

Note: In both cases M is the mean of two tests or determinations

What does this mean?

Uncertainty Included In Test Method

Here's what it means:

A trained laboratory technician performing the tests

- ✓ in accordance with the prescribed method (consistently following the procedure)
- ✓ under the prescribed conditions (environmental conditions such as temperature, barometric pressure, local value of g etc. are within the acceptable limits)
- ✓ using specified equipment (not substituting equipment which may perform differently than the equipment specified)
- ✓ in a continued state of known performance capability (in a state of current calibration or verification)

can evaluate its results against the stated acceptance criteria and can then report acceptance or rejection against the stated acceptance criteria with a 95% confidence level.

Question #5

Quiz Question 5:

Are the following definitions of Repeatability and Reproducibility correct?

Repeatability: Multiple test performed by the same operator using the same equipment.

Reproducibility: Multiple test performed by the two different operators in different laboratories.

Interactive Quiz #5 Answer Sheet

Quiz Question 5:

Are the following definitions of Repeatability and Reproducibility correct? ***YES***

Repeatability: Multiple test performed by the same operator using the same equipment.

HLA comment: Typically reveals the results of random variation

Reproducibility: Multiple test performed by the two different operators in different laboratories.

HLA comment: Typically reveals the results of systematic variation

***ASTM D 6184 – 98** Standard Test Method for Oil Separation from Lubricating Grease (Conical Sieve Method)

Found on Page 3 of 4

Uncertainty Included In Test Method

Acceptance criteria are developed by in depth statistical analysis of sample results from multiple laboratories performing the same test multiple times.

Sample data obtained from multiple laboratories performing the same test multiple times, permits the determination of the mean (μ) of the distribution of sample averages. (i.e. the experimental standard deviation of the mean) and the standard deviation. This is used to establish acceptance criteria with a probability of 19 times out of 20 or 95%.

Uncertainty is present due to variation of equipment, operator skill and reproducibility but the manner by which the acceptance criteria is determined includes the uncertainty in the method of the analysis and therefore does not require further analysis.

Uncertainty Included In Test Method

Summary of Test Method 4.1

The weighed sample is placed in a cone-shaped, wire cloth sieve, suspended in a beaker, then heated under static conditions tor the specified time and temperature.

Unless otherwise required by the grease specification, the sample is tested at standard conditions of 100 °C +/- 0.5 °C for 30 +/- 0.25 hr. The separated oil is weighed and reported as a percentage of the mass of the starting test sample.

The sample is weighed on a balance

It is heated to a specified temperature

It is maintained at the specified temperature for a specified time

The sample is visually examined to detect non-homogeneity such as oil separation, phase changes or gross contamination.

Uncertainty Included In Test Method

Detailed dimensions with tolerances are provided for the cone and the wire mesh material of which it is constructed.

A target dimension is provided to insure that the amount of sample material in the sieve is approximately the same for each test.

The sample is visually examined to detect non-homogeneity such as oil separation, phase changes or gross contamination.

The balance must have a 250 g capacity with 0.01 g resolution.

The sample is heated to a 100 °C +/- 0.5 °C.

The sample is maintained at the specified temperature for 30 hours +/- 15 minutes.

These potential variations were present during the statistical analysis which developed the acceptance criteria. As a result, further evaluation of measurement uncertainty is not required.

Micrometer Calibration Uncertainty Budget

A micrometer calibration typically has 6 significant sources of uncertainty:

1) Uncertainty of the standard
2) Uncertainty due to non-repeatability
3) Uncertainty due to limited resolution
4) Uncertainty due to non-standard temperature
5) Uncertainty of the temperature measurement device
6) Uncertainty due to differential temperature

Question #6

Quiz Question 6:

When preparing an uncertainty estimate of test or calibration results, where is the uncertainty of the standard or standards found?

1) On the purchase order for calibration services
2) On the invoice for the unique calibration performed
3) On the calibration certificate or test report
4) The customer is responsible for estimating the uncertainty based on there specification

Interactive Quiz #6 Answer Sheet

Quiz Question 6:

When preparing an uncertainty estimate of test or calibration results, where is the uncertainty of the standard or standards found?

#3 On the calibration certificate or test report

Source: ISO/IEC 17025:2017 7.8.4.1 a) the measurement uncertainty of the measurement result

A calibration certificate should also include the confidence interval and the coverage factor "k" (*Source: ILAC P14*) and the decision rule if a statement of compliance has been requested (*Source: ISO/IEC 17025:2017 7.1.3 … the decision rule shall be clearly defined*).

Additional requirements for calibration certificates are found in 7.8.1, 7.8.2 and 7.8.4, however not all of these are used in making a compliance statement.

Micrometer Calibration Uncertainty Budget

Given information

1) **The uncertainty of the standard:** 0.278 µm with “k” = 2

2) **The uncertainty due to non-repeatability:**

5 sample results:

1) 127.0025 mm
2) 127.0000 mm
3) 127.0000 mm
4) 127.0025 mm
5) 127.0000 mm

127.0010 mm	Average 127.0010 mm
1.3693 µm	Sample Standard Deviation 1.3693 µm
0.6124 µm	Experimental Standard Deviation of the Mean

Micrometer Calibration Uncertainty Budget

Given information

3) **The uncertainty due to limited resolution**

The resolution of the micrometer is 2.50 µm

4) **The uncertainty due to non-standard temperature:**

The calibration was performed at 19 °C

Coefficient of linear thermal expansion = 12 µm/m/°C

$$\left|12*1.075 - 12*0.925\right| = Effective\ CTE = \frac{1.80\ \mu m}{m°C}$$

5) **The uncertainty of the temperature measurement device:**

0.39 °C with “k” = 2

6) **Uncertainty due to differential temperature:**

0.25°C

Micrometer Calibration Uncertainty Budget

Uncertainty of the standard:

Found on the calibration certificate

It results from a type B analysis

The D of F is 1000 (This is an arbitrarily determined number)

The distribution type is $\text{Normal}_{\text{Exp}}$

The divisor is k (typically this is 2)

The standard uncertainty is the uncertainty divided by k

The C of S (Coefficient of Sensitivity) is 1 since there are no correlations with other sources

The variance "V" is the (standard uncertainty times the C of S)^2

Micrometer Calibration Uncertainty Budget

Uncertainty due to non-repeatability:

The experimental standard deviation of the mean determined from a sample of 5 measurements $\hat{\sigma}_{\bar{x}} = s/\sqrt{n}$

It results from a type A analysis

The D of F is the sample size minus 1 *(n-1)* (Note: not arbitrary)

The distribution type is $\text{Normal}_{\text{Std}}$

The divisor is k (typically this is 2)

The standard uncertainty is the uncertainty divided by k

The C of S (Coefficient of Sensitivity) is 1 since there are no correlations with other sources

The variance "V" is the (standard uncertainty times the C of S)^2

Micrometer Calibration Uncertainty Budget

Uncertainty due to limited resolution:

The “Half Interval” of the resolution is the resolution divided by 2.

In this example the resolution is 2.50 µm therefore the half interval is 1.25 µm.

It results from a type B analysis

The D of F is 1000

The distribution type is “Rectangular” or “Uniform”

The divisor is $\sqrt{3}$ or 1.732

The standard uncertainty is the uncertainty divided by 1.732

The C of S (Coefficient of Sensitivity) is 1 since there are no correlations with other sources

The variance “V” is the (standard uncertainty times the C of S)^2

Micrometer Calibration Uncertainty Budget

Uncertainty due to non-standard temperature:

Standard temperature is typically 20 °C

The spreadsheet is programmed to calculate the dimensional effect of non-standard temperature.

It results from a type B analysis

The D of F is 1000

The distribution type is "U shaped"

The divisor is $\sqrt{2}$ or 1.414

The standard uncertainty is the uncertainty divided by 1.414

The C of S (Coefficient of Sensitivity) is 1 since there are no correlations with other sources

The variance "V" is the (standard uncertainty times the C of S)^2

Micrometer Calibration Uncertainty Budget

Uncertainty of the temperature measurement device:

Found on the calibration certificate

It results from a type B analysis

The D of F is 1000 (This is an arbitrarily determined number)

The distribution type is $\text{Normal}_{\text{Exp}}$

The divisor is k (typically this is 2)

The standard uncertainty is the uncertainty divided by k

The C of S (Coefficient of Sensitivity) is 1 since there are no correlations with other sources

The variance “V” is the (standard uncertainty times the C of S)^2

Micrometer Calibration Uncertainty Budget

Uncertainty due to differential temperature:

Differential temperature results from the temperature of the unit being calibrated and the device used to perform the calibration.

It results from a type B analysis

The D of F is 1000 (This is an arbitrarily determined number)

The distribution type is $\text{Normal}_{\text{Exp}}$

The divisor is $\sqrt{3}$ or 1.732

The standard uncertainty is the uncertainty divided by k

The C of S (Coefficient of Sensitivity) is 1 since there are no correlations with other sources

The variance "V" is the (standard uncertainty times the C of S)^2

Micrometer Calibration Uncertainty Budget

Solving for the expanded uncertainty:

Once the variance has been determined for each of the sources of uncertainty, the expanded uncertainty “U” can be calculated using the RSS “Root Sum of Squares method (see the formula below)

$$U = 2\sqrt{\sum_{i=1}^{6}\left(u_i * CofS_i\right)^2}$$

$$U = 2\sqrt{\left(V_1 + V_2 + V_3 + V_4 + V_5 + V_6\right)}$$

Question #7

Quiz Question 7:

Part 1: *What is the divisor for a Normal expanded distribution?*

Part 2: *What is the divisor for a Rectangular or Uniform distribution?*

Part 3: *What is the divisor for a Triangular distribution?*

Part 4: *What is the divisor for a U-shaped distribution?*

Interactive Quiz #7 Answer Sheet

Quiz Question 7:

What is the divisor for a Normal expanded distribution?

"k" typically 2. Found on the Calibration Certificate or Test Report

What is the divisor for a Rectangular or Uniform distribution?

$\sqrt{3}$ *or 1.372*

What is the divisor for a Triangular distribution?

$\sqrt{6}$ *or 2.449*

What is the divisor for a U-shaped distribution?

$\sqrt{2}$ *or 1.414*

Micrometer Calibration Uncertainty Budget

Edison Calibration Laboratory, Inc.

Mitutoyo 125 mm to 150 mm Caliper Type Micrometer with 2.50 µm Resolution

Heating & Cooling System is Boundary Driven (U shaped distribution)

Uncertainty Budget

Source	Description		Unc Estimate (µm)	D of F	Analysis Type	Distribution Type	Divisor	Std Unc (µm)	C of S	Var (µin^2)
C_1	Uncertainty of Standard		0.278	1000	B	NorExp	2	0.14	1.00	1.93E-02
C_2	Repeatability		0.612	4	A	NorStd	1	0.61	1.11	4.63E-01
C_3	Resolution *(Half interval)*		1.250	1000	B	Rect	1.73205	0.72	1.00	5.21E-01
C_4	Non-Standard Temp	19.0 °C	0.225	1000	B	NorExp	2	0.11	1.00	1.27E-02
C_5	Unc of Thermometer		0.390	1000	B	U	1.4142	0.28	1.00	7.61E-02
C_6	Differential Temp		0.250	1000	B	Rect	1.73205	0.14	1.00	2.08E-02
	CTE of Standard (µm)		12.0 µm/m/°C							
	CTE of UUT (µm)		12.0 µm/m/°C							
	Effective CTE (µm)		1.8 µm/m/°C							
Sum of the Variances			1.1							
Combined Standard Uncertainty (u_c)			1.05							
Expanded Uncertainty ($U=k*u_c$)		k=2	2.11							

Standard Description: Grade AA Gage Block

Enter calibration magnitude below: 125.0000 mm

Uncertainty SI Units: 2.2 µm

Date: 10-Mar-20

Test Result Uncertainty Budget

An uncertainty budget for a test result, (e.g. Dimensional Inspection) will be very similar to the above budget for calibration of a micrometer.

- Uncertainty of any standards used: *Always included*
- Uncertainty due to non-repeatability and limited resolution: *Typically not included unless the item being tested reports a test result*
- Uncertainty due to environmental effects: *When applicable*
- C of S (Coefficient of Sensitivity): *If a correlation exits between 2 functions then use either the partial derivative of one function with respect to the other or the result of numerical analysis*
- The variance is the (standard uncertainty times the C of S)^2

I know that you believe you understand what you think you heard , but I'm not sure you realize that what you think you heard is not what I said.

Time for Questions

End of Measurement Uncertainty Training