The Value of a Measurement is in the Application of its Result

Applied Metrology 101

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Metrology

Metrology (met´ rol u jee) n. 1 The science or study of measurement.

Applied Metrology:

Making measurement useful.

Applied Metrology 101

- The pursuit of knowledge.
  - The goal.
- Question everything.
  - The measurand.
- The investigation.
  - The measurement
- The implications.
  - The application and uncertainty.

The Pursuit of Knowledge

"To measure is to know.“

- Lord Kelvin (1824-1907)

First and Foremost:

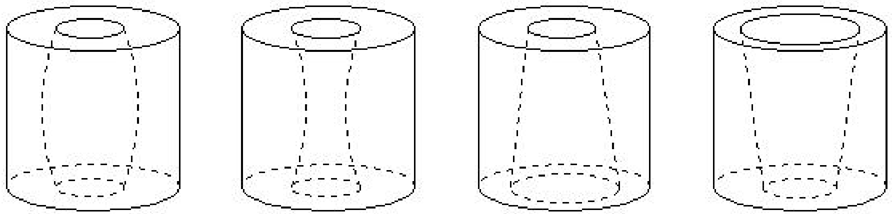
What is your reason for measuring?

Question Everything

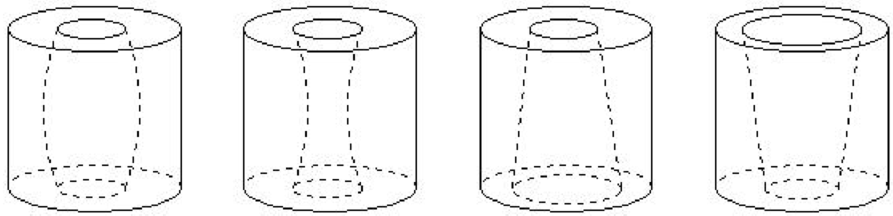
- What do you want to know about your process or product?
- Defining the measurand:
  - Be specific.
  - Do you require an answer that is numerical, graphical or both?
  - To what degree do you need to know this?
    - Be practical here, there are tradeoffs!!!

The Measurand

- Be specific
  - The better that you can define a functional measurand the more useful the results will be.
  - Example:
    - Honing Stroke adjustment.

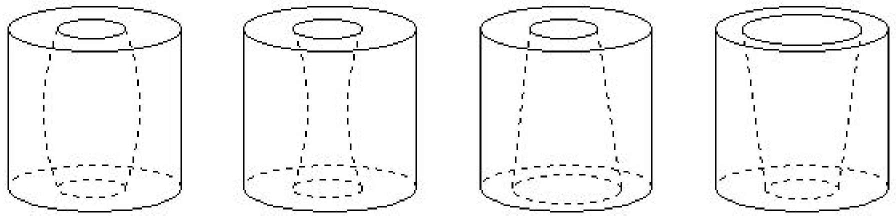


The Measurand



- This isn't necessarily "Cylindricity"!!!
  - Cylindricity also incorporates "Roundness" and "Centerline Deviations".
  - This is a linear/parabolic variation in diameter!!!

The Measurand

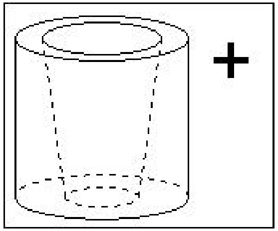


- Be very careful concerning language!
  - Often, instrument manufacturers will define their own terms:
    - Parallelism
    - Taper
    - Diameter Variation

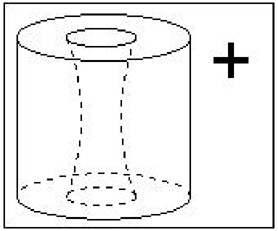
The Measurand

- Given a very specific definition (and defined conventions) a numerical results may be adequate.

  – Positive/Negative Taper
    - Based on linear regression



  – Positive Negative Hourglass
    - Based on parabolic regression



The Investigation

- Upon defining the measurand, we need to select the right equipment and make the measurement.
  - This is analogous to the detective pulling out his kit and dusting for fingerprints.

"Surface finish is the fingerprint of the manufacturing process"

– *David Whitehouse*

The Measurement

- At some point you are going to have to make the commitment and acquire a result.
  - Up to this point, things have been rather theoretical.

- Measurement is based on a <u>system</u> or <u>process</u>, not just a gage.
  - The result is from the system!!!

The Measurement

- The Measurement System
  - Gage (and the condition thereof)
    - Attributes: tip radius, data points, math, etc.
  - Calibration/Traceability (or the lack thereof)
  - Operator (skill level)
  - Procedures (and the following thereof)
  - Environment
    - Temperature, cleanliness, vibration, etc.
  - Workpiece
    - Temperature, Cleanliness, fixturing, etc.

The Measurement

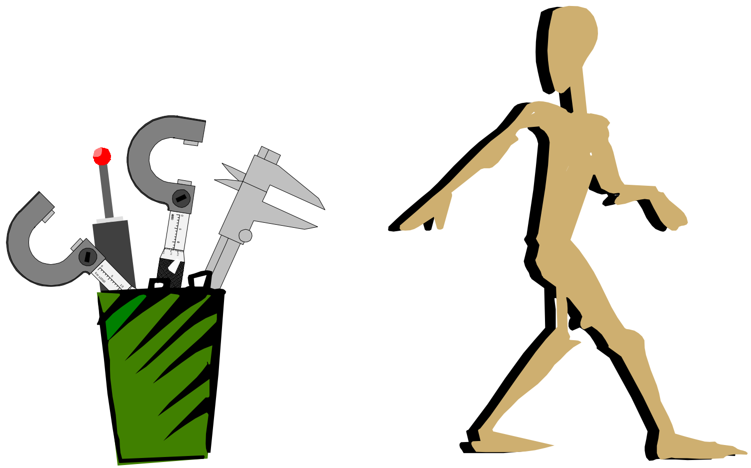
- The measurement system provides some numerical/graphical result.
  – Does the result have the necessary "traceability" information
    - **Operator, Date, Time, Calibration Info, <u>units</u>, Part/Serial Numbers, etc.**
    - Results should be able to "Stand Alone".
    - Does the Mars Climate Orbiter ring any bells!?!
    - This isn't rocket science!

The Implications

- Commonly heard:

“If the results aren’t what I wanted…

…it must be the gage’s fault!”



The Implications

- Measurement results have some inherent uncertainty.
  - The measured result is only an estimate of the “true” or “correct” value.

- Uncertainty:

“How far from the truth can my result be.”

Measurement Uncertainty

- Traditionally, we dealt with "*accuracy*" and "*repeatability*".
  - Accuracy:

    Are we targeted?
  - Repeatability:

    Do we get the same value again & again

- "*Uncertainty*" encompasses these ideas in a more comprehensive manner.

Measurement Uncertainty

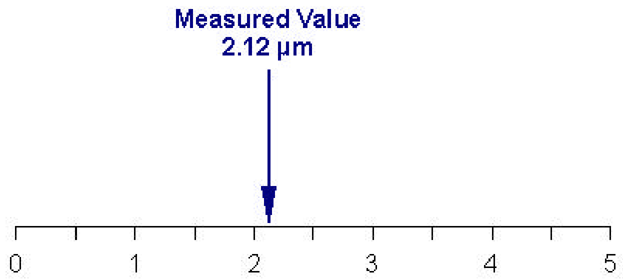
- Many are intimidated by the concept of uncertainty…

  … it's not that difficult.

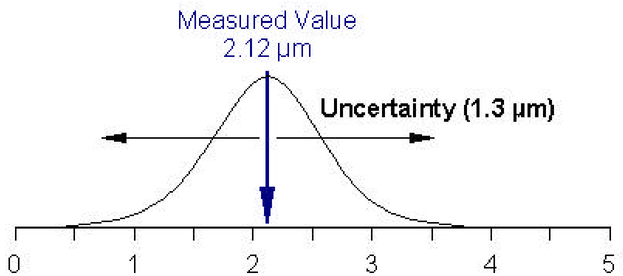
- Measurement uncertainty is trying to predict where the true value is given my measured value.
  - It relates the "measurement" to the true value of the "measurand".

Measurement Uncertainty

- Given my result:



- Where might the true value lie? (2.12 +/- 1.3)

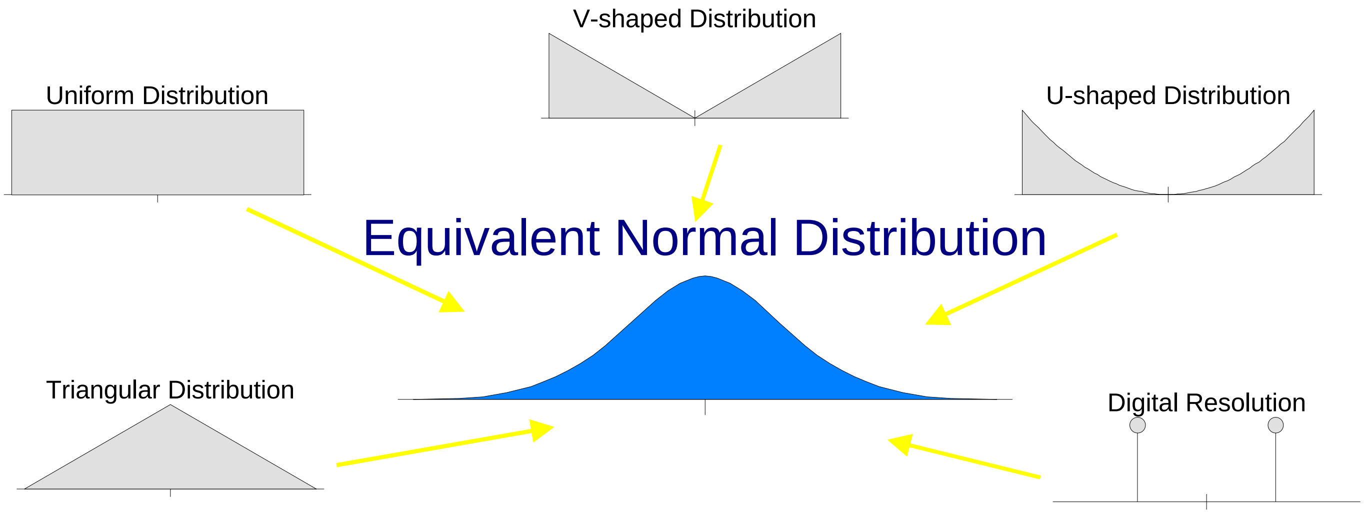


Measurement Uncertainty

- Consider the Contributors (FMEA-style)
  - What are the elements of the measurement system that can make it be wrong?
  - Determine how each can affect the result and express it as a standard deviation.
  - Combine the standard deviations to get the distribution.
    - Uncertainty is typically expressed as +/- 2 standard deviations of this distribution.

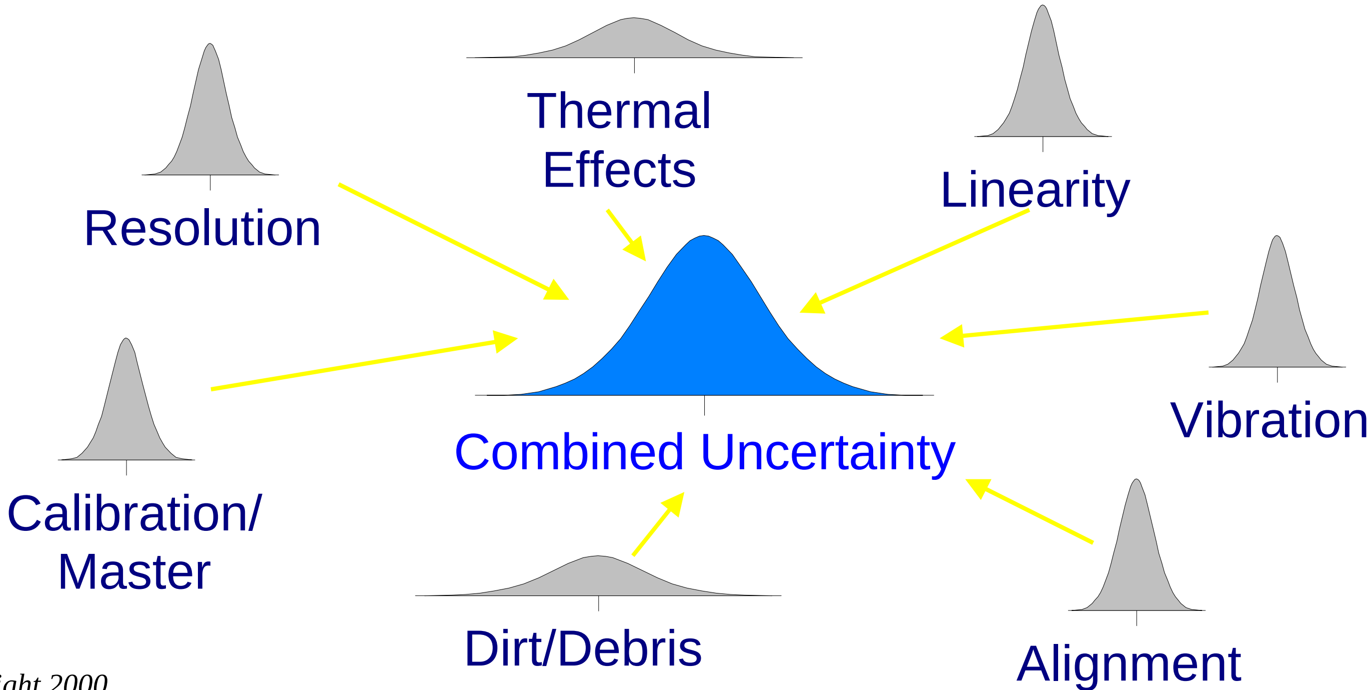
Measurement Uncertainty

- Each contributor can be approximated as normal distribution of errors
  - Even if the errors themselves are normally distributed.



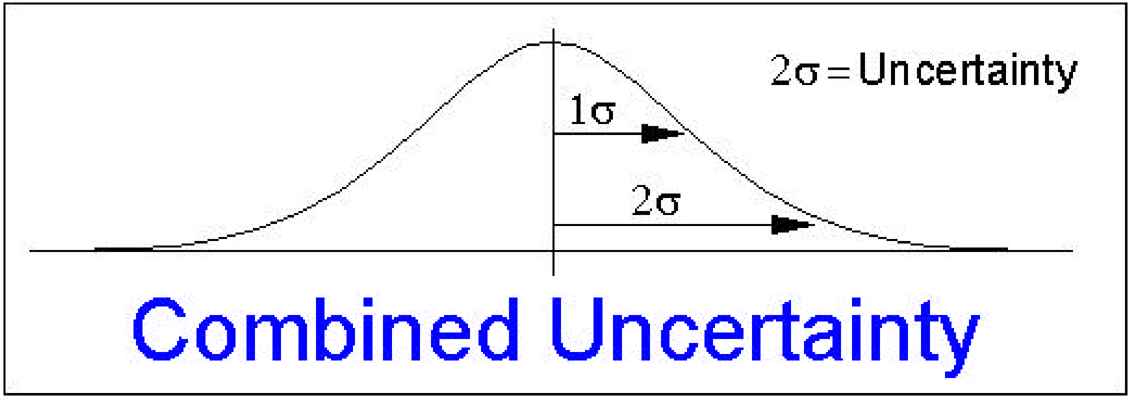
Measurement Uncertainty

- Once you have a distribution for all contributors you simply “pool” them.



Measurement Uncertainty

- Measurement Uncertainty is typically expressed as a *"2 Standard Deviation"* value.
  - The "2" is the "coverage factor"
    - (95% confidence)



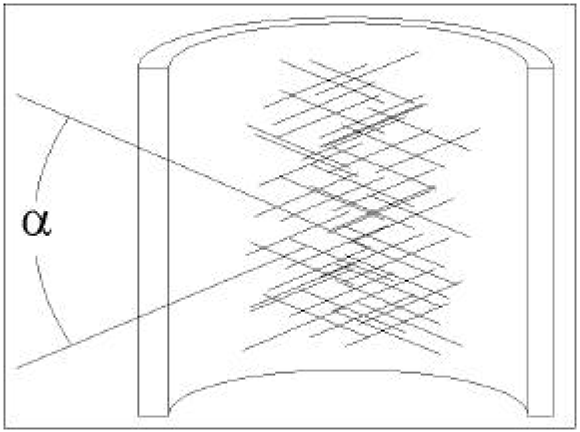
The Implications (continued)

- When a measured result is reported, there must be an associated uncertainty. This dictates the <u>action</u>.

- Applications:
  - Determining *when* to adjust the process
  - Pre-shipment or Receiving inspection
  - Customer/Supplier Disputes
  - Correlation problems

Example: Cross-hatch Angle

- The Goal:
  - Does the cross-hatch angle meet the specification (45° +/- 5°)? Should the process be adjusted?
- The measurand
  - The included angle based on the predominant valleys as shown in the Figure.



Example: Cross-hatch Angle

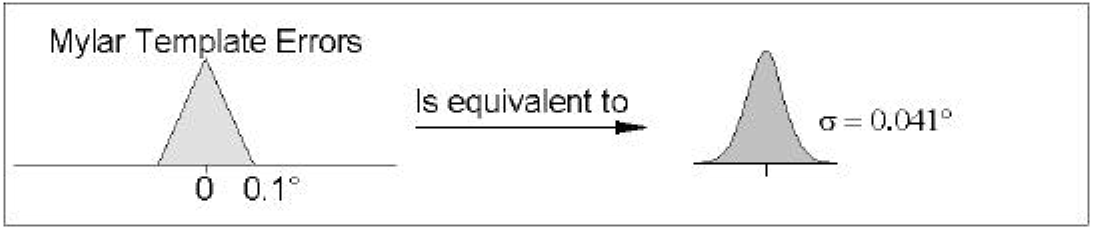
- The Measurement
  - Method selection:
    - Mylar Template; visual assessment
  - Measured value was 47.5°
- The implications.
  - Need to know the uncertainty before acting on the result.

Example: Cross-hatch Angle

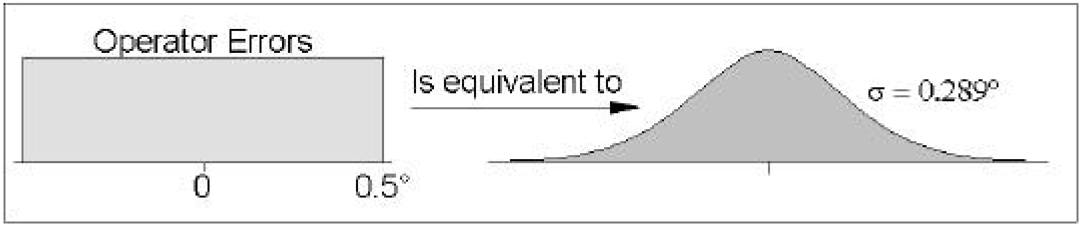
- The implications (continued)
  - Estimate the uncertainty
- Primary Contributors:
  - Printed Mylar Template:
    - Printing good to within 0.1 degrees
    - Assume triangular distribution
  - Manual Interpretation
    - Operator, lighting, etc. good to within 0.5 degrees
    - Assume uniform distribution

Example: Cross-hatch Angle

- Uncertainty Estimation
  - Mylar Template:



  - Operator



Example: Cross-hatch Angle

Combining the contributions

$$s_{combined} = \sqrt{s_{mylar}^2 + s_{operator}^2}$$

$$s_{combined} = \sqrt{0.041^2 + 0.289^2} = 0.292^\circ$$

Expanding the uncertainty

$$U_{95} = k \cdot s_{combined} = 2 \cdot 0.292 = 0.584^\circ$$

Example: Crosshatch Angle

- The measured cross-hatch angle is:

  47.5° +/- 0.6°

  – Given our estimated uncertainty the true value should lie between

  46.9° - 48.1°

- Reminder: The spec is 45.0° +/- 5°

Summary

- Metrology is a tool for understanding.
  - A tool is only effective if it is applied properly.
- Understand the elements of measurement
  - Goal (Question)
  - Measurand (Result to be Determined)
  - Measurement (The Process)
  - Implications (Uncertainty)