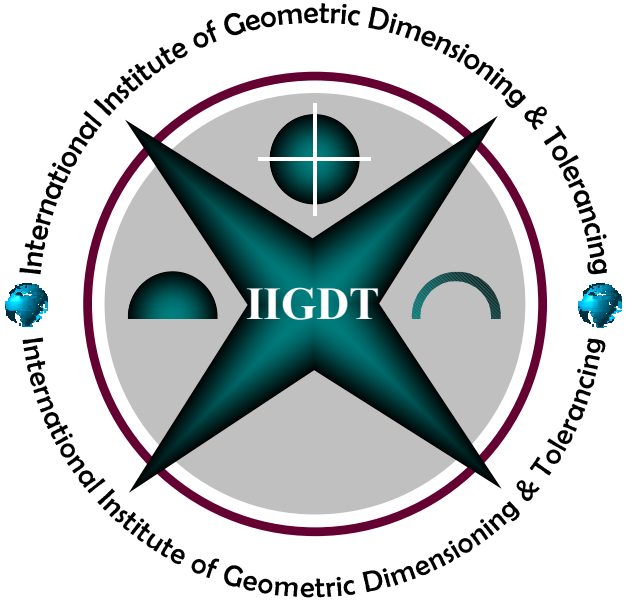
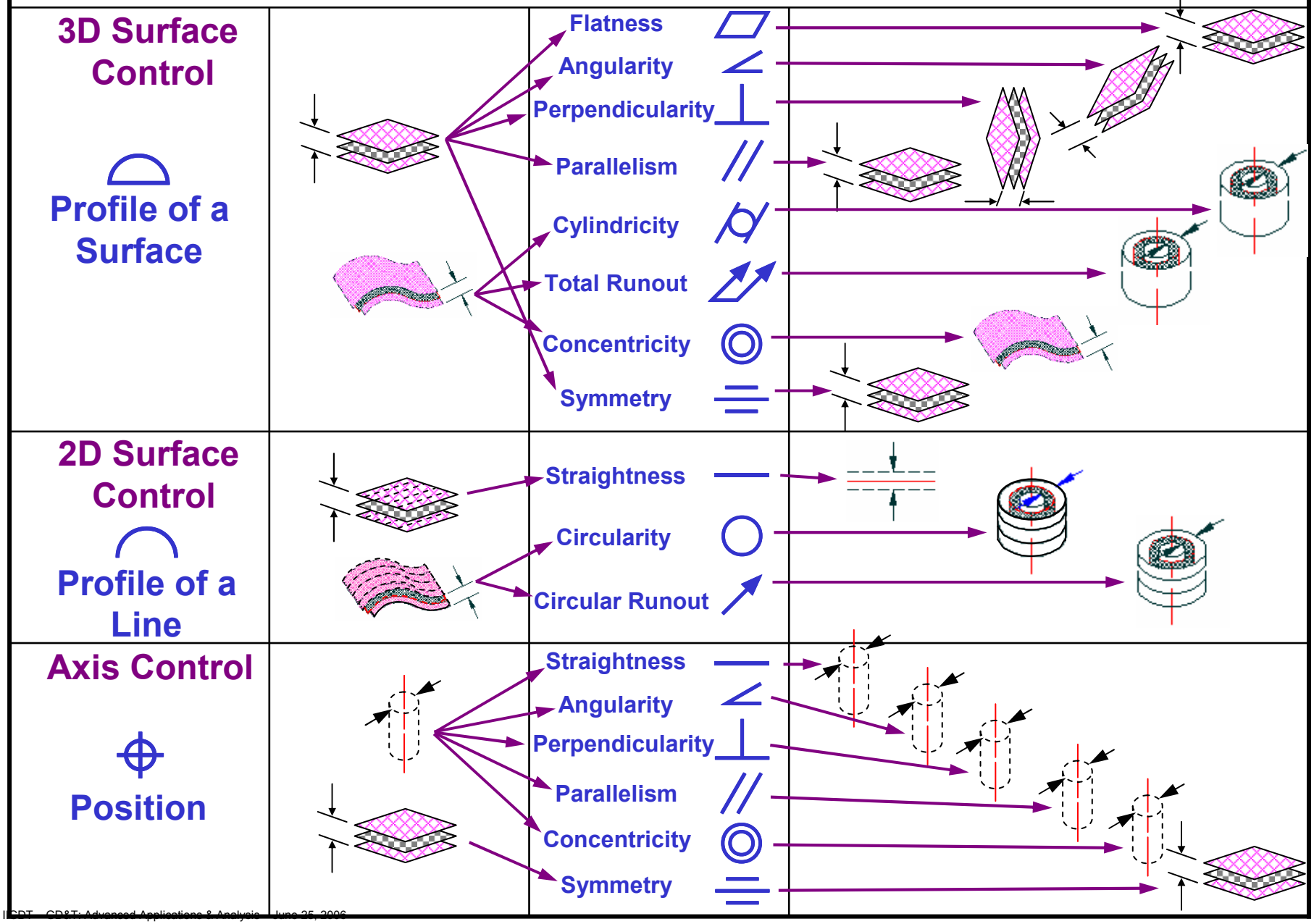
International Institute of GD&T



GD&T & Measurement Uncertainty

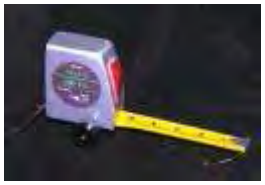
International Institute of GD&T
2 Loring Road, Hopkins, MN 55305
www.iigdt.com

Global Simplification of GD&T



Measurement

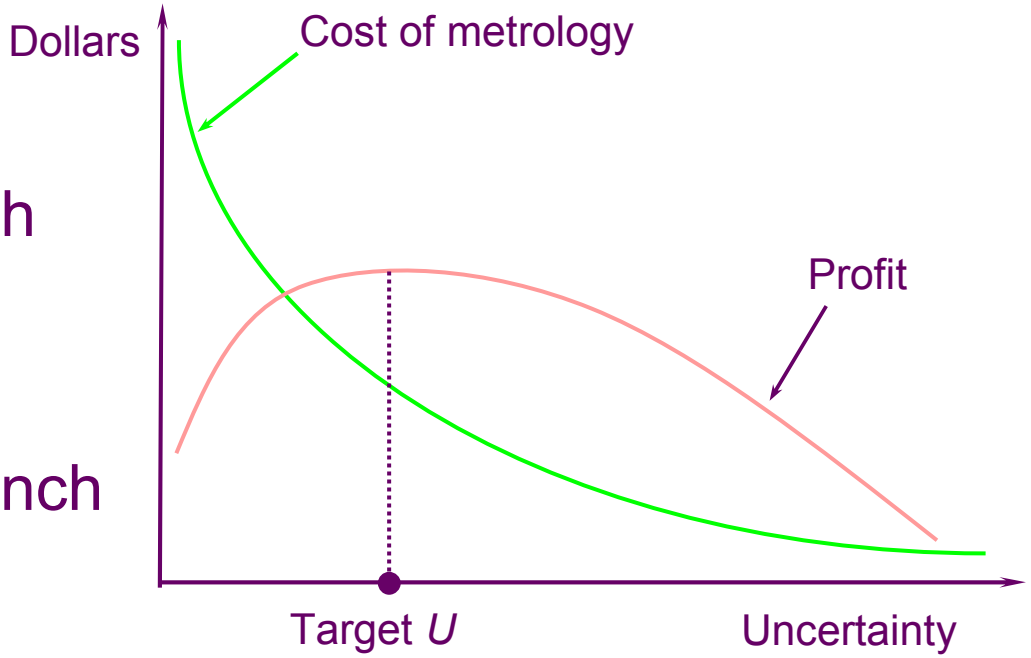
Eyeball: $L=L_{est} \pm 1$ inch



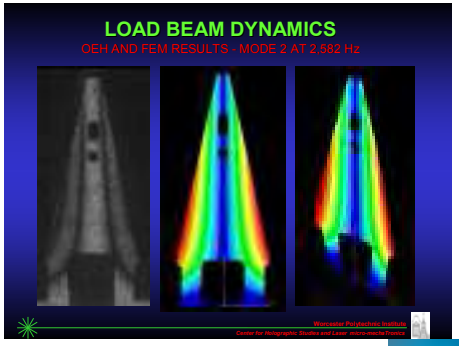
Tape: $L=L_{est} \pm 1/16$ inch

Micrometer: $L=L_{est} \pm 0.001$inch

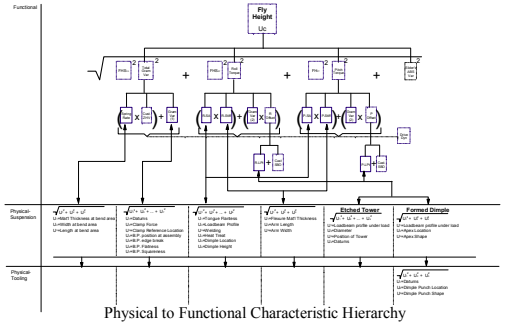
Gage block comparator: $L=L_{est} \pm 1$ microinch



Coordinate Measuring Machines

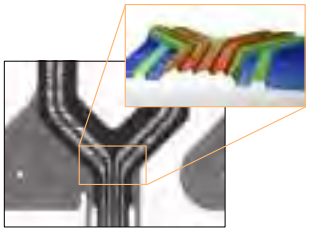


3D Measurement

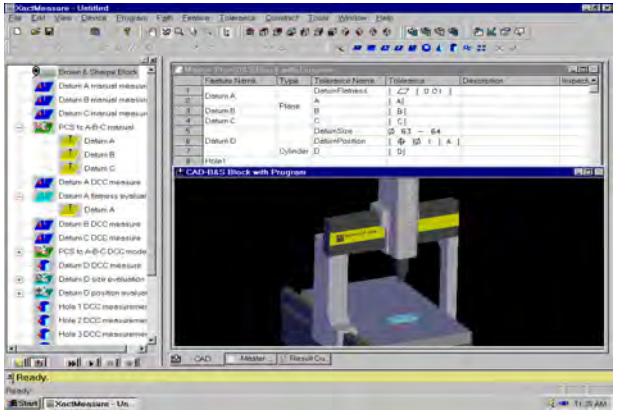


Physical to Functional Characteristic Hierarchy

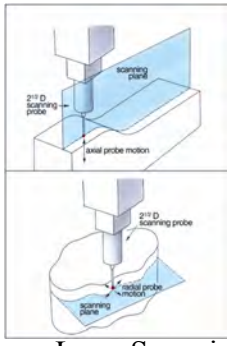
Micro-Scale CMM (Contact)



3D Analysis



Other Meas. Systems



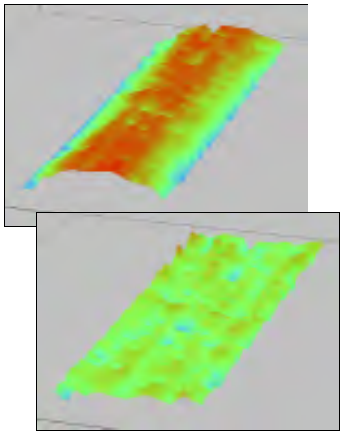
Open-Loop Scanning

Micro-Scale CMM (Non-Contact)

Contact CMM's

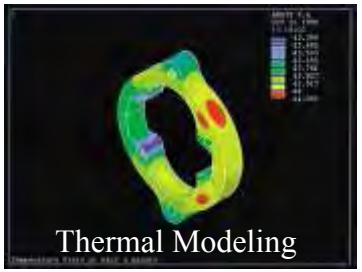
Non-Contact CMM's

Geometric Error Analysis



Surface Analysis

- Correlating Physical Measurements to Functional Parameters
  - -Input for FEA Models and Experimental Validation
- 3D Characterization of Tooling & Product Components
  - -Standardized Software for Programming Efficiency & Analysis)
  - -Extraction of Surface Roughness, Waviness, Form
- Maintaining Commodity Plans with Key Measurement Suppliers
  - CMMs, Vision Systems, Laser Sensors



Thermal Modeling

ASME B89 Committee on "Metrology"

Comprised of "7" Divisions:

- B89.1 – Length
- B89.2 – Angles
- B89.3 – Geometry
- B89.4 – Coordinate Measuring Technology
- B89.5 – General Principles and Definitions
- B89.6 – Environment
- B89.7 – Measurement Uncertainty

B89.7 – Measurement Uncertainty

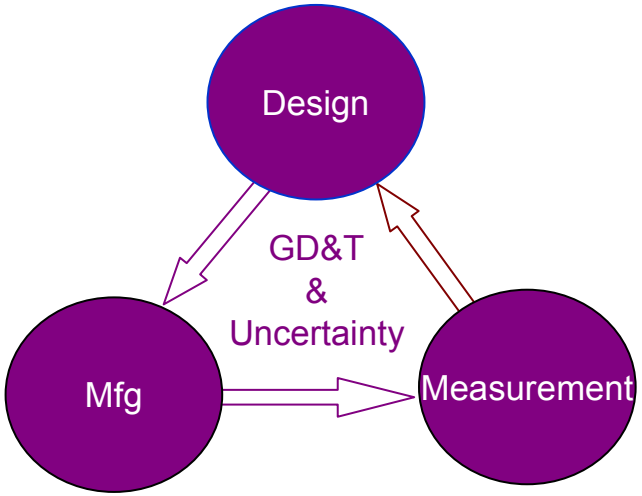
"Motivations"

- Need for a uniform approach (GUM) to the treatment of uncertainty in ASME B89 document
- Need for simplified guidance documents as GUM moves into industrial arena
- General dissatisfaction with quality of existing written standards produced by ISO

ASME Y14.5M–1994

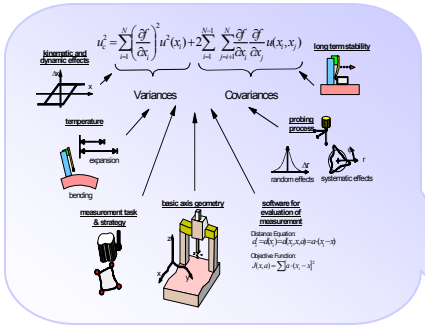
ASME Y14.5.1M–1994

GUM

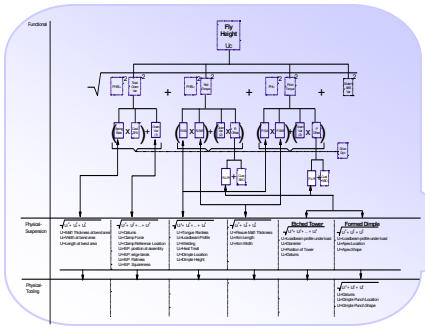


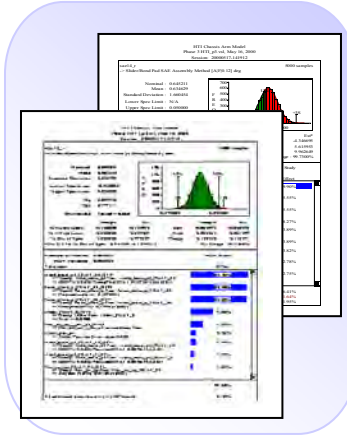
ASME B89.7 Committee "Measurement Uncertainty"

- B89.7.1 - Guidelines for B89 Doc's
- B89.7.2 - Inspection Planning
- B89.7.3 - Decision Rules
- B89.7.4 - General Principles
- B89.7.5 - Communications
- B89.7.6 - Uncertainty Considerations in Tolerancing
- B89.7.7 - Advanced Uncertainty Concepts
- B89.7.8 - Traceability



"Quality Transformation"





Scientific Approach

Uncertainty Management

Physical-to-Functional Hierarchies

Dimensional Management

Design of Experiments

Reliability Analysis

Regression Analysis

ANOVA

Fishbone Diagrams

Control Charts

Cp, Cpk

Gage R&R

Repeatability

Histograms

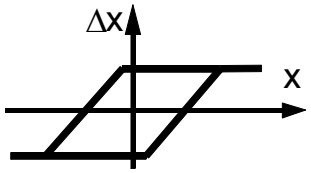
Transformation

Current Approach

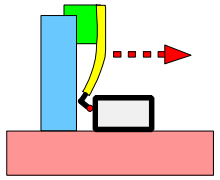
Analytic Solutions

$$u_c^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j)$$

kinematic and dynamic effects



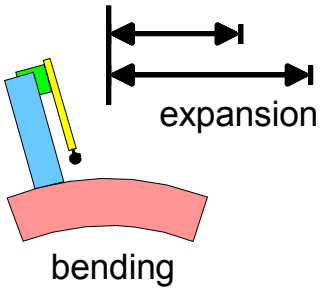
long term stability



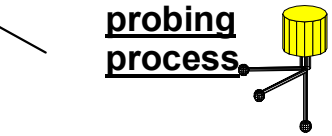
Variances

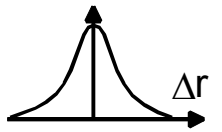
Covariances

temperature

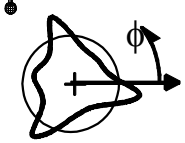


probing process



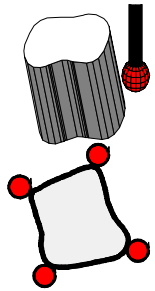


random effects

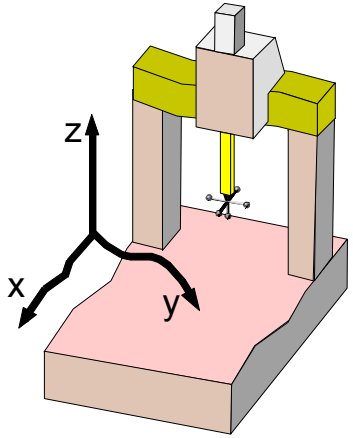


systematic effects

measurement task & strategy



basic axis geometry



software for evaluation of measurement

Distance Equation:

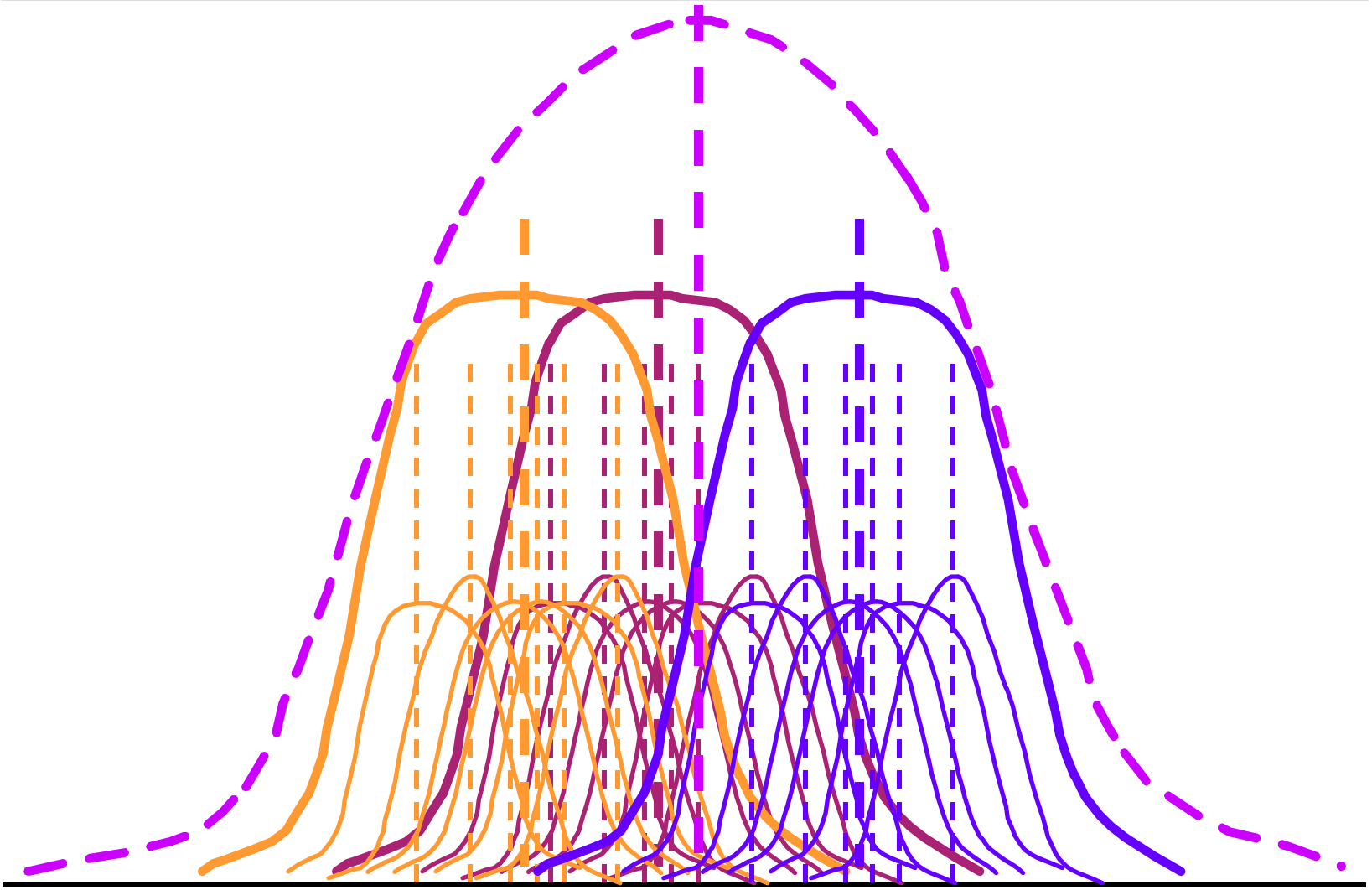
$$d_i = d(x_i) = d(x_i, x, a) = a \cdot (x_i - x)$$

Objective Function:

$$J(x, a) = \sum \left[a \cdot (x_i - x \right]^2$$

Graphic courtesy of Dr. Trapet - PTB

U_{95} Estimates Distribution of Multiple Measurement Systems Over a Period of Time



Sources of Error / Contributors to Measurement Uncertainty

1. Environment
2. Reference Element for Measurement Equipment
3. Measurement Equipment
4. Measurement Setup
5. Software & Calculations
6. Metrologist / Operator
7. Measurement Object
8. Definition of the Characteristic
9. Measuring Procedure
10. Physical Constants & Conversion Factors

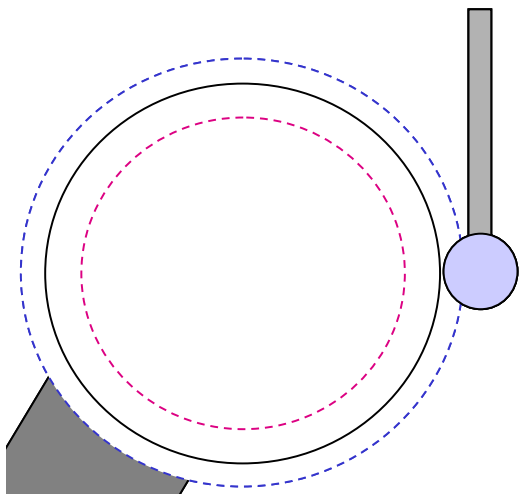
Sources of Error…

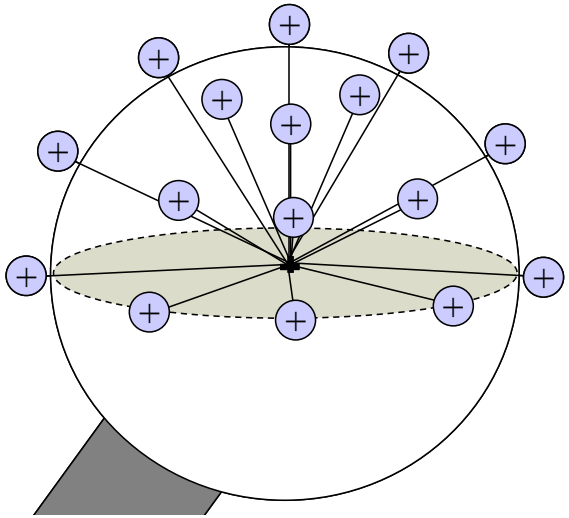
1. Environment for the measurement
   - Temperature: absolute temperature, time variance, spatial variance
   - Vibration/noise
   - Humidity
   - Contamination
   - Illumination
   - Ambient pressure
   - Air composition
   - Air flow
   - Gravity
   - Transients in the power supply
   - Pressured air (e.g. air bearings)
   - Heat radiation

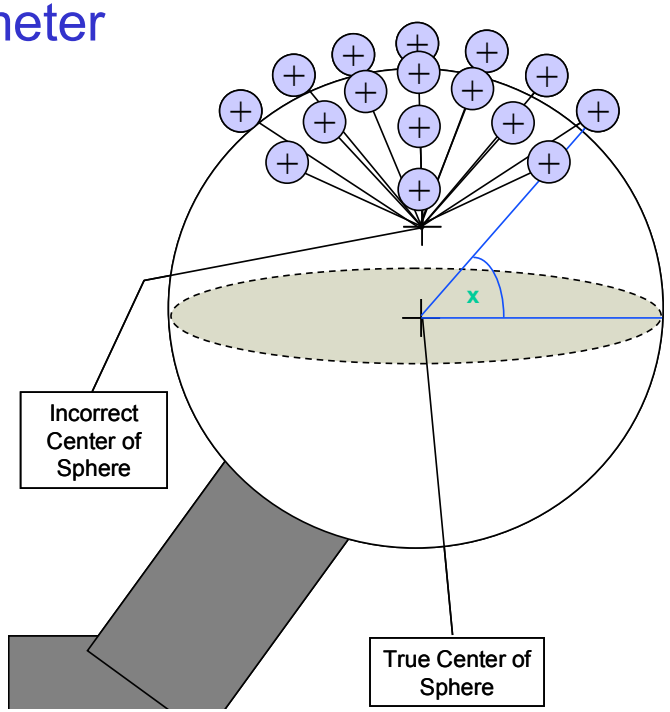
Sources of Error…

2. Reference element of measurement equipment

- Uncertainty of the calibration
- Stability
- Scale mark quality
- Temperature expansion coefficient
- Physical principle: line scale, optical digital scale, magnetic digital scale, spindle, rack & pinion, interferometer







Sources of Error…

3. Measurement equipment
   - Interpretation system
   - Magnification-electrical or mechanical - error wavelength!!
   - Zero-point stability
   - Force stability/absolute force
   - Hysteresis
   - Guides/slide-ways
   - Temperature expansion
   - Parallaxes
   - Time since last calibration
   - Responds characteristic
   - Interpolation system - error wavelength
   - Interpolation resolution

Sources of Error…

4. Measurement setup (excl. the placement and clamping of the workpiece)
   - Cosine errors
   - Abbe principle
   - Temperature sensitivity
   - Stiffness/rigidity
   - Tip radius
   - Form deviation of tip
   - Stiffness of the probe system
   - Optical aperture
   - Interaction between workpiece and setup
   - Warming up

Sources of Error…

5. Software and calculations
    - Rounding/Quantification
    - Algorithms
    - Implementation of algorithms
    - Number of significant digits in the computation
    - Sampling
    - Filtering
    - Correction of algorithm/Certification of algorithm
    - Interpolation extrapolation

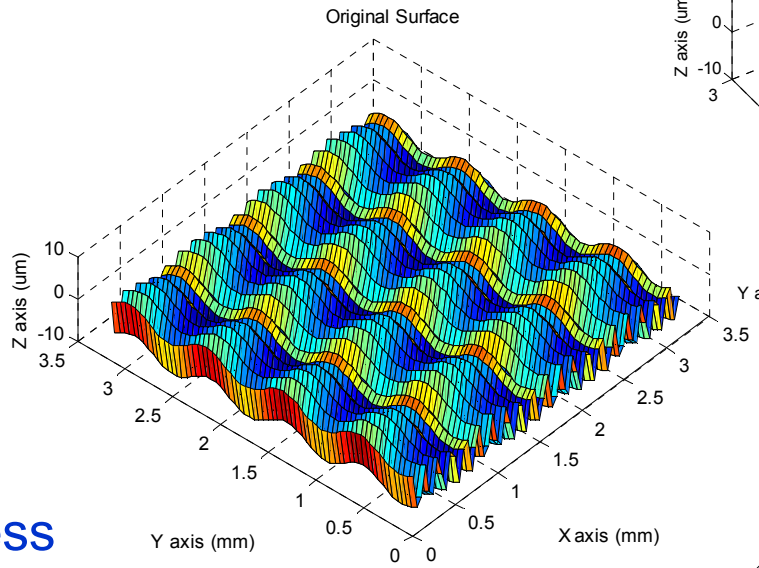
Sources of Error…

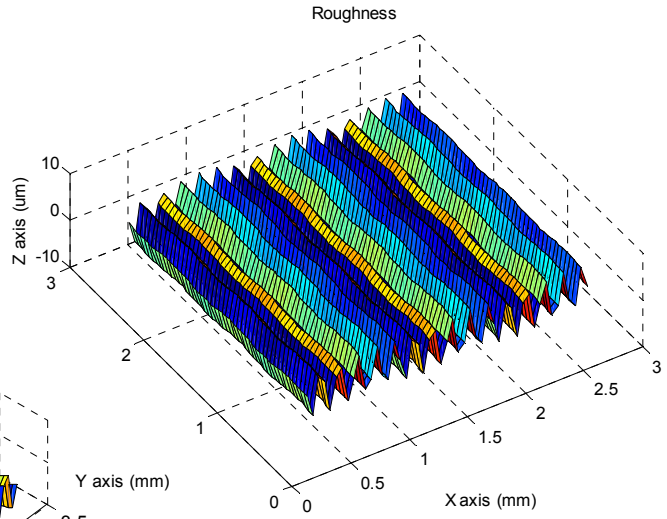
6. Metrologist –operator
   - Education
   - Experience
   - Training
   - Physical disadvantages/ability
   - Knowledge
   - Honest

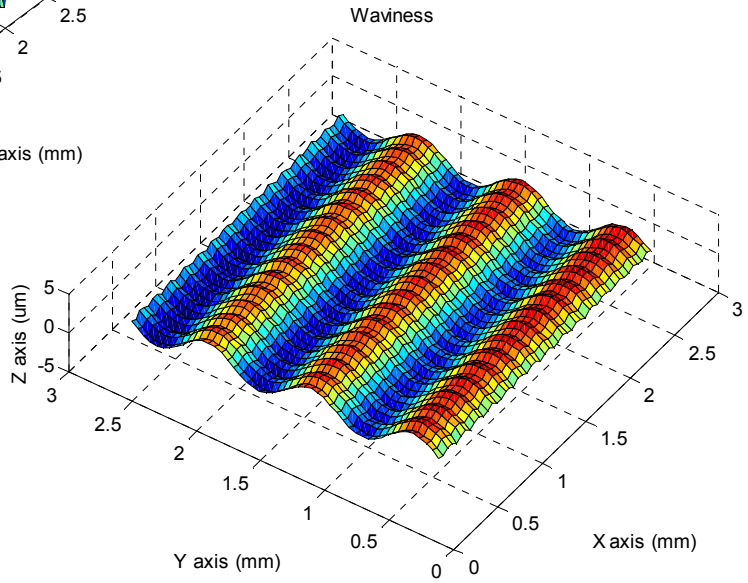
Sources of Error…

7. Measurement Workpiece or Measuring Instrument

- Surface Roughness, Waviness, & Form
- Temperature expansion coefficient
- Weight
- Size
- Shape
- Magnetism
- Cleanliness
- Internal stress
- Creep characteristics





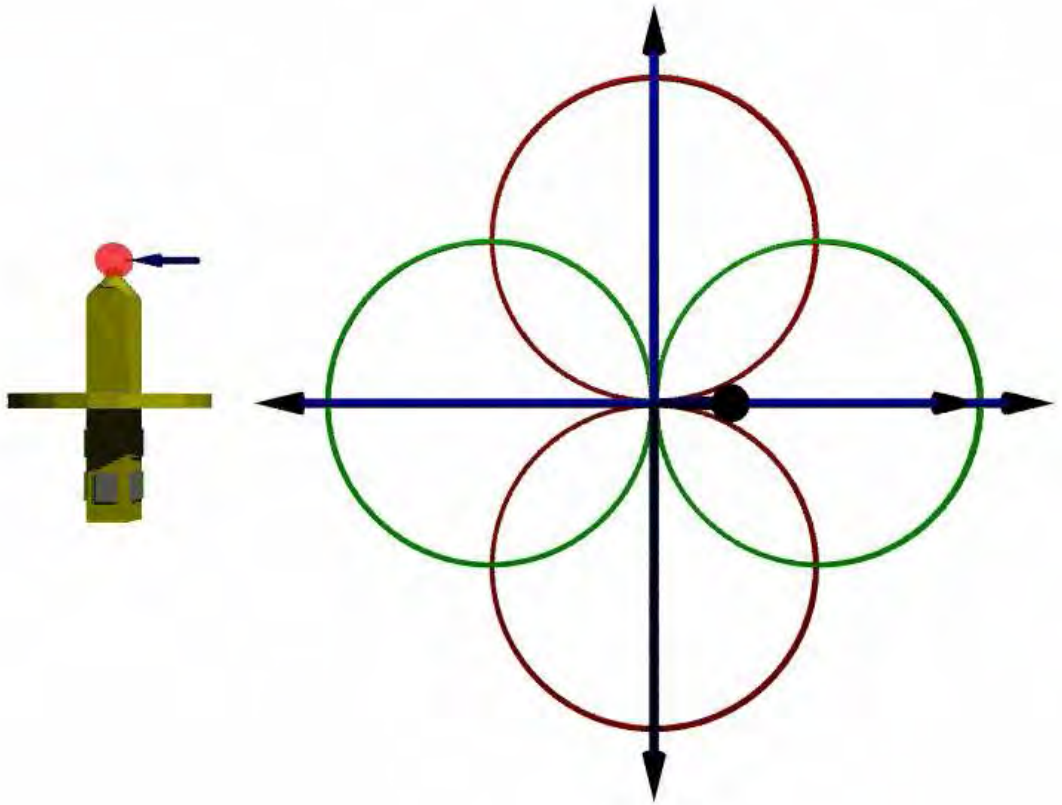


Sources of Error…

8. Definition of the Characteristic
   - Toleranced feature
   - Reference system
   - Degree of freedom
   - Distance
   - Angle

Sources of Error…

9. Measuring procedure
    - Number of measurements
    - Order of measurements
    - Duration of measurements
    - Choice of principle of measurement
    - Reference standard
    - Alignment
    - Clamping
    - Fixturing
    - Number of points
    - Probing principle
    - Drift check



Sources of Error.

10. Physical constants and conversion factors

- Lacking knowledge of the correct physical values of e.g. material properties (workpiece, measuring instrument, ambient air, etc.)

Business Drivers to Support a Decision to Invest into Aggressive GD&T Training

1. Increased Business due to Increased Capability
2. Increased Profit with Reduced or Eliminated Returns
3. Increased Recognition as a Leading Edge Supplier/Customer
4. Increased Customer Satisfaction Based on Improved Conditions
5. Increased Yield / Reduced Inspection (reduced scrap and rework)
6. Unambiguous and Understood Engineering Requirements
7. Better ability to predict and control processes