The Role of Standardization for Industrial Metrology

Dr. Henrik S. Nielsen
HN Metrology Consulting
Chairman, ISO TC 213:
"Geometrical Product Specifications"

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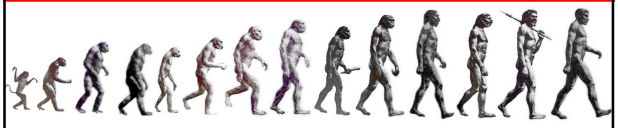
The Evolution of GPS



- GPS has followed the development of accuracy needs in industry:
  - From measuring on the drawing
  - to dimensional tolerancing
  - and hybrid tolerancing
    - Geometrical tolerances used as Band-Aids on dimensional tolerancing
  - To pure geometrical tolerancing
    - All tolerance zones are locked to a functionally correct datum system

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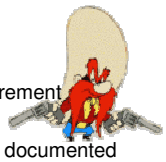
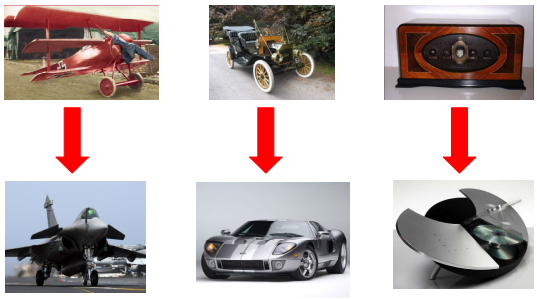
In The Good Ole Days...

- Transition from craft to industry
  - Emerging need for interchangeable parts
- Design and manufacturing close together
  - Easy communication
- Large dimensional tolerances
  - Compared to the form capability
  - Form could be ignored during measurement
- Tribal knowledge
  - Many important requirements are not documented

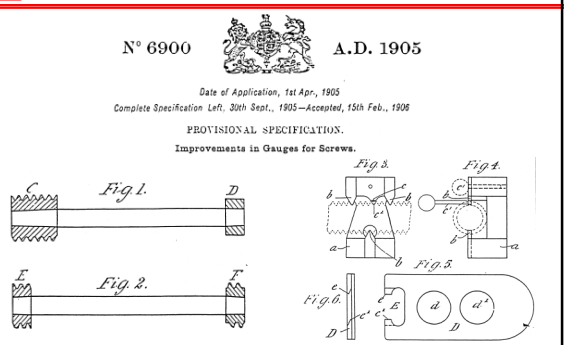


1880

The Evolution of Products



Taylor's Patent



N° 6900 A.D. 1905

Date of Application, 1st Apr., 1905
Complete Specification Left, 30th Sept., 1905—Accepted, 15th Feb., 1906

PROVISIONAL SPECIFICATION.

Improvements in Gauges for Screws.

Fig. 1. Fig. 2. Fig. 3. Fig. 4. Fig. 5. Fig. 6.

1905

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The First Geometrical Tolerances

- Not measurement requirements, but fit requirements
- Defines simultaneous requirements to several features
  - Can reference a datum system
  - Ensures correct position of features after assembly
- Requirements expressed as zones
  - Zones can be positioned with datums

1940

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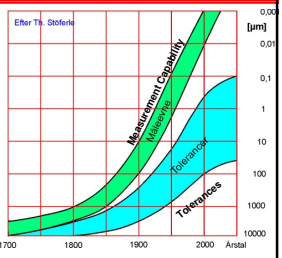
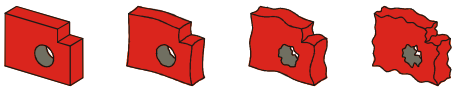
Why Do We Need More Precise Tolerance Definitions?

- Tolerances are reduced by a factor of 10 every 50 years
- Form and geometry errors are not reduced
  - Thus become larger and larger compared to the tolerances



1900 1940 1980 2010



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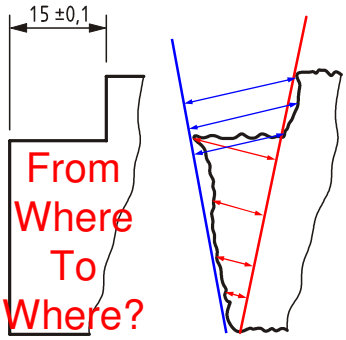
Step Height



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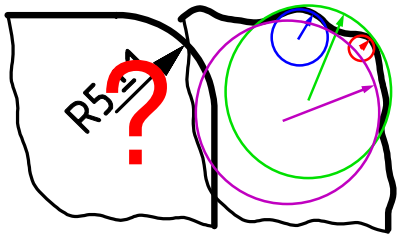
Radius



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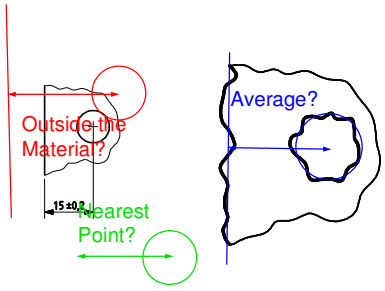
Distance



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No Coordinate System

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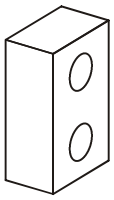
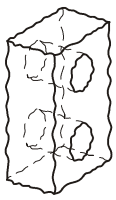
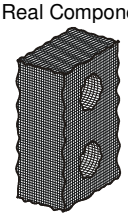
The Three Worlds

CAD Nominal Model	Specification Skin Model	Verification Real Component
		
Perfect Geometry No Angular Deviations	Geometrical Deviations Angular Deviations	Sampling

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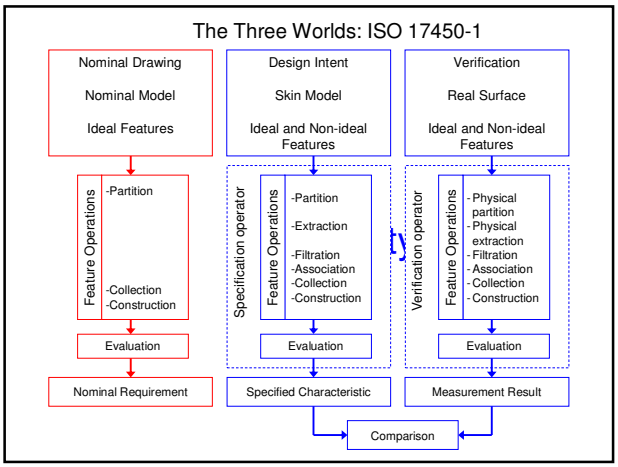

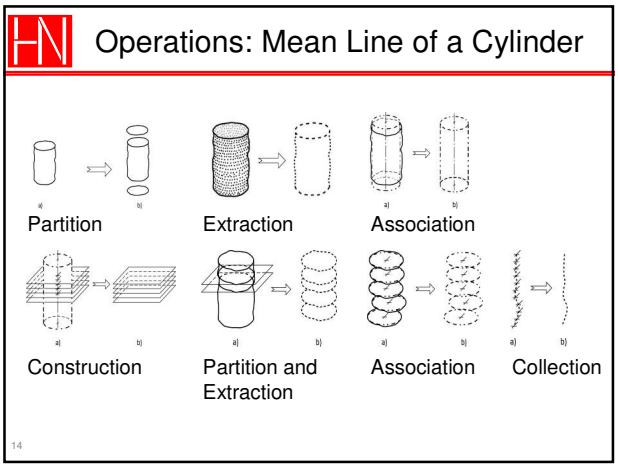

Operators and operations

- An operator is an ordered set of operations
- A specification operator acts on the skin model
  - Defines the “true” measurement value
  - Defines together with a numerical value a requirement to the component
- A verification operator acts on the real component
  - Defines the actual measured value

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The Duality Principle

- A GPS specification defines a specification operator independently of measurement procedures and measurement equipment
- The GPS specification is realized in a verification operator that is independent of the specification
  - The intent is that the verification mirrors the specification
  - Measurement uncertainty is used to evaluate of the verification is suitable

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The GPS Matrix System

Fundamental GPS Standards

Global GPS Standards
GPS or related standards that covers or have influence on several or all GPS chains of standards

General GPS Matrix (Chains of Standards)

1. Linear Size	11. Orientation
2. Linear Distance	12. Location
3. Radial Distance	13. Circular Runout
4. Arc length	14. Total Runout
5. Angular Size	15. Datums
6. Angular Distance	16. Roughness
7. Form of a Line (Unrelated)	17. Waviness
8. Form of a Line (Related)	18. Primary Profile
9. Form of a Surface (Unrelated)	19. Surface Imperfections
10. Form of a Surface (Related)	20. Edges

Complementary GPS Matrix
Process Specific Chains of Standards
Machine Element Specific Chains of Standards

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General GPS Standards Chains of Standards

- Chain link 1-3 are necessary to define an unabiguous specification
- Chain link 5-7 defines the verification (the measured value)

Chain Link						
1	2	3	4	5	6	7
Drawing Indication - Code	Tolerance Definition – Theoretical definition of the characteristic	Definition of the characteristic on the real workpiece Specification operator	Comparison of the defined and the measured characteristic	Measured value of the characteristic for the real workpiece Verification operator	Definition of metrological characteristics for measuring equipment	Calibration and verification of metrological characteristics for measuring equipment
Specification of GPS Characteristics				Verification of GPS Characteristics		

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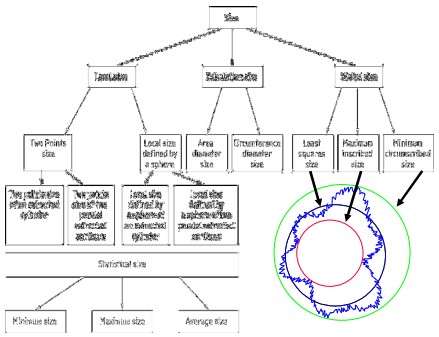
The GPS Language is Precise



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GPS is a Toolbox

- Everybody needs some of the tools
- Nobody needs all of the tools
- Somebody needs each tool
- A plumber and a carpenter need different tools
- Caterpillar (heavy equipment) needs different tools than nanotechnology
- ISO TC 213 aims to provide the tools for everybody's needs
  - But does not expect anybody to know or use all of the tools

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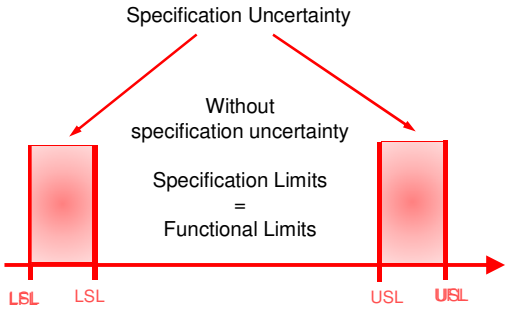
Translating Micrometers into Euros

Optimizing the economics of production and verification



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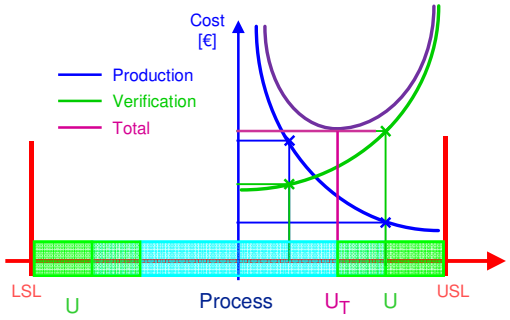
Translating Micrometers into Euros

Optimizing the economics of production and verification



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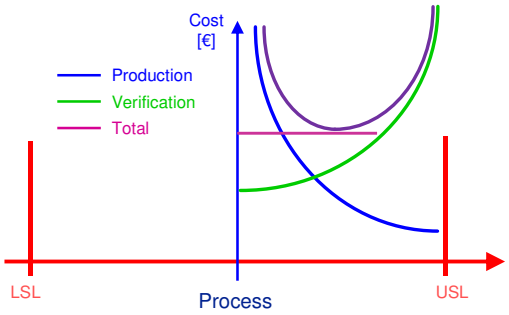
Translating Micrometers into Euros

When the specification uncertainty returns…



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GPS is:

- A language that allows precise expressions of functional requirements
  - Smaller grey areas
  - Larger tolerances
  - Better communication with suppliers
  - More room for manufacturing
  - Cheaper products

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Decision Rules

- The party proving conformance or non conformance has to count the measurement uncertainty against himself
  - Suppliers have to subtract their uncertainty from the specification to prove conformance
  - Customers have to add their uncertainty to the specification to prove non conformance

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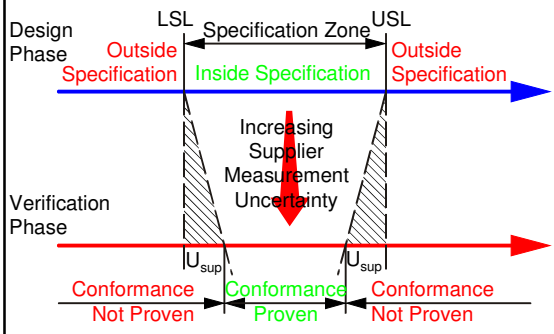
Proving Conformance
Supplier Measurement



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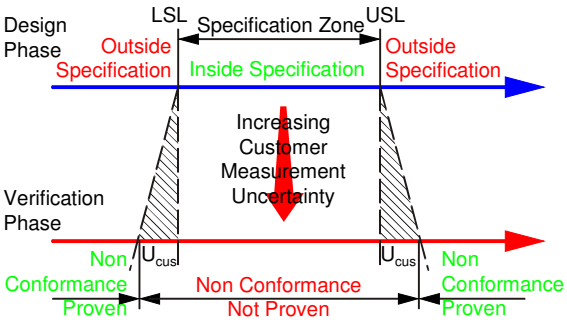
Proving Non Conformance
Customer Measurement – Incoming Inspection



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Standard Trend: Specifying Metrological Characteristics

- Measurement equipment specifications used to be based on arbitrary tests
  - Designed to be easy and inexpensive to carry out
  - Not to fit into an uncertainty budget
- GUM created a need for users to be able to estimate the uncertainty of measurements
  - And the uncertainty components from measurement equipment
- Measurement equipment standards are changing to define metrological characteristics

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Metrological Characteristic

- Characteristic of measuring equipment, which may influence the results of measurement
  - ISO 14978:2006

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Standard Trend: Not Providing Standardized Tolerance Values and Classes

- Encouraging competition amongst manufacturers
- Encouraging improvements over time

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Measurement Equipment Acceptance Testing

- The general uncertainty principle applies to proving conformance with a specification for measurement equipment
- However some of the uncertainty components are not the tester's fault:
  - E.g. the probing error of a CMM is an inherent characteristic of the CMM and should not be counted as part of the uncertainty when testing its ability to measure size

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Tester Responsibility Principle:

- Test Uncertainty: The components of the uncertainty that are under the tester's control
  - Includes:
    - Uncertainty of standards used
    - Uncertainty due to fixtures etc. provided
    - Etc.
  - Excludes:
    - Influences from the equipment being tested
    - Influences from an environment that is not under the testers control
    - Etc.

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Tester Responsibility Principle:

- Test uncertainty is different from measurement uncertainty
- Only the test uncertainty is taken into account when proving conformance or non conformance according to ISO 14253-1

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Conclusions

- GPS is a toolbox that allows designers, manufacturing engineers, metrologists etc. to communicate the geometrical requirements to and properties of mechanical products
- GPS is evolving to make this communication more precise
  - This allows more cost effective manufacturing

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Conclusions

- GPS standards for measuring equipment are evolving to make them GUM compatible with tests that are more relevant to the traceability and uncertainty estimation of the measurements made on the equipment
  - Easier for users to select the right equipment for their needs
  - Tests add value for uncertainty estimation

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Final Thought

Make things as simple as possible…

But no simpler

- Albert Einstein

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