Dimensional & Surface Metrology

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Digital Metrology Solutions

Dimensional and Surface Metrology

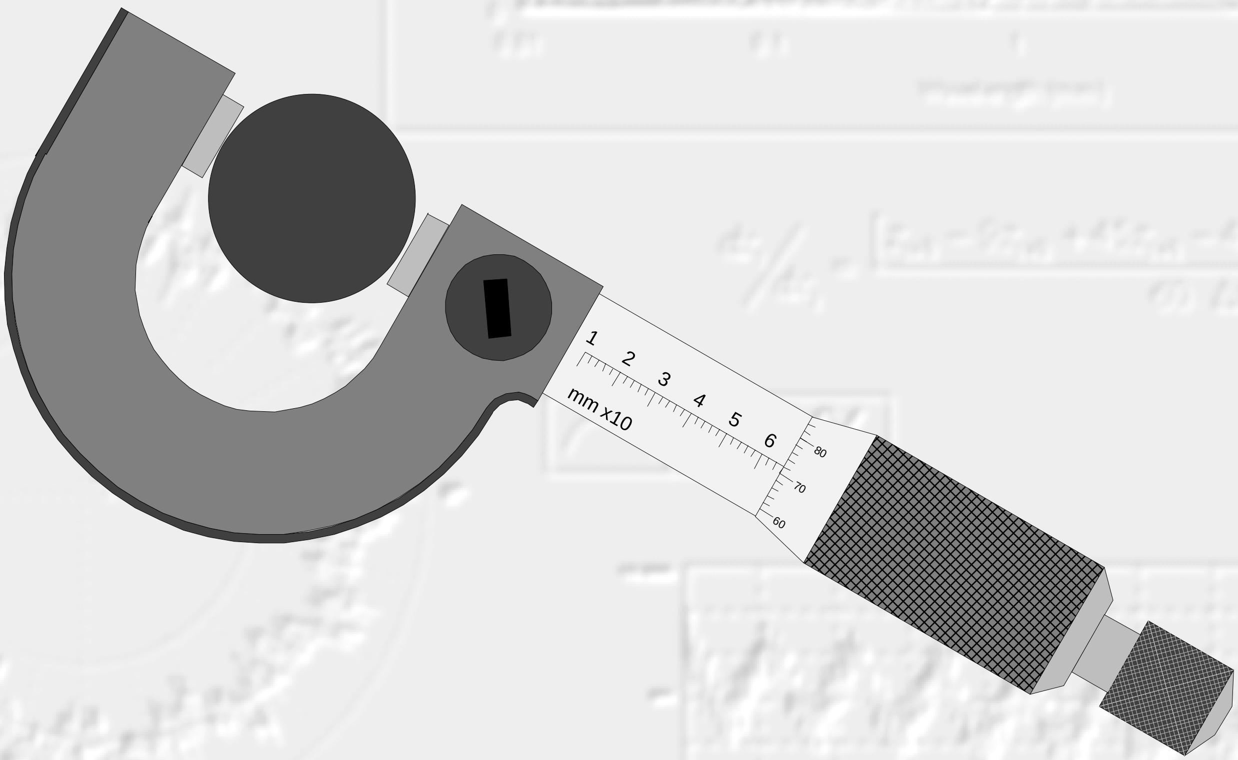
- Where We Are
  - Historical Overview
  - Information Overload
  - Instrument Overlaps
- Customer Concerns
- Where We Should be Going
  - Understanding of Functionality
  - Underlying Standards Providing Tools
  - Uncertainty as a Connection to Reality
- Case Studies
- Recommendations

Where We Are

A Brief Historical Overview

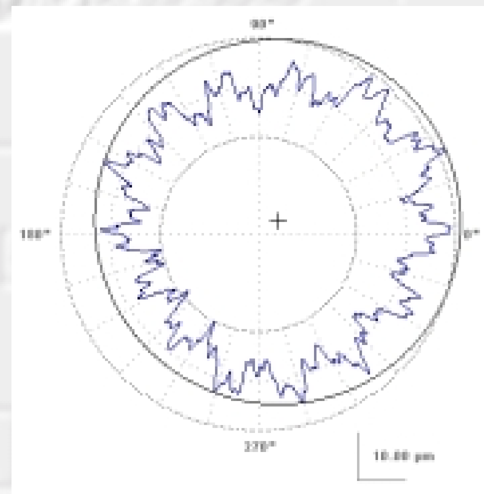
Historical Metrology Thinking

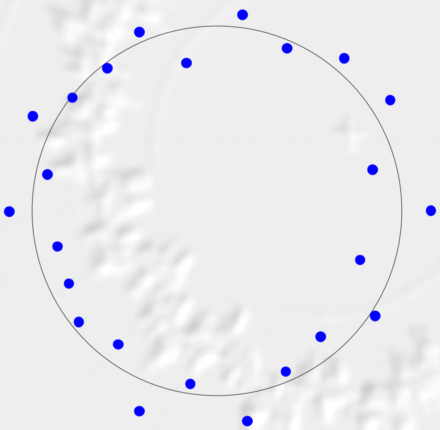
- The historical approach to "size"



Modern Metrology Thinking

- Some modern approaches to “size”





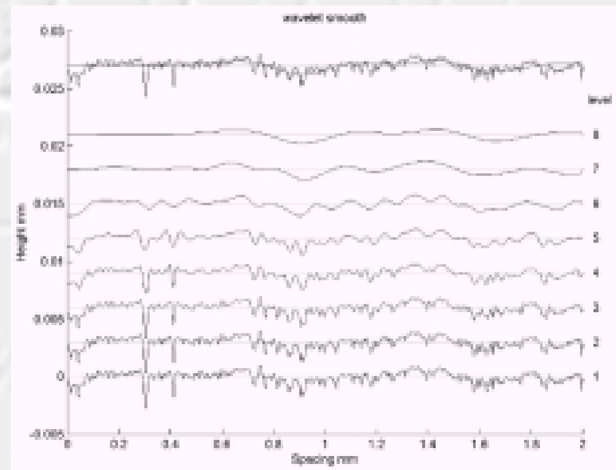
	Tolerance Ref	Nominal	++Up/Lo Tol	Actual	Dev/Error	mm
** 50mm hole. **						
4	N0010 Diameter	50.000	0.550	50.519	0.519	-----***---
			0.450			
4	N0011 Position	50.630	0.157	50.648	0.066	xy ***---
		48.830	0.020	48.802		MMC: 4, 4

Historical Metrology Thinking

- Historical Surface Roughness Assessment

Modern Metrology Thinking

- Modern Surface Texture Analysis



Filter - M1 (Gaussian 50%): 0.0025 - 0.800 mm

Slp.	0.0000 °	Ra	0.406 µm	RTwi	47.1 %
Pt	11.114 µm	Rq	0.643 µm	Vc (-3.0)	14 #
Pp	1.914 µm	Rsk	-3.105	Rpq	0.371 µm
Pv	9.200 µm	Rku	22.105	Rvq	1.745 µm
Pa	0.424 µm	Rt	10.801 µm	Rmq	89.3 %
Wt	1.065 µm	Rp	1.916 µm	Rk	0.963 µm
Wp	0.363 µm	Rv	8.885 µm	Rpk	0.367 µm
Wv	0.702 µm	Rz	4.379 µm	Rvk	1.369 µm
Wa	0.152 µm	Rpm	1.212 µm	Mr1	8.7 %
		Rvm	3.167 µm	Mr2	84.3 %

Historical Developments and the State of Metrology

- Historically metrology instrumentation provided a "number"
  - This "number" was often influenced by the operator's skill.
    - Alignment, scale-reading, force, etc.
- Today's metrology instrumentation is capable of proving many "numbers"
  - These "numbers" are often influenced by several configurable parameters and controls.
    - Data density, filtering, algorithms, etc.

Where We Are

Information Overload

Information Overload

- Today's metrology instrumentation is providing more and more analytical capabilities.
  - See also:
    Whitehouse D.J., 1982,
    The Parameter Rash - Is There a Cure?",
    Wear, 83, 75

Increased Data Processing in a Simple Context

Taylor Hobson Form Talysurf Series

DOS Software rev 6.0

– 71 Parameters
– 3 Filter Types
– 9 Roughness Cutoffs
– Up to 3 Bandwidths at each cutoff

And this is for a “simple” stylus instrument!

Information Overload

- These additional capabilities are not necessarily a “bad” thing.
  – However, this introduces a new culture requiring additional training and interpretation.

Information Overload

"The phenomenon of information overload is in its infancy. If according to some estimates, the amount of information doubles every eighteen months, then by 2015 there will be 1,000 bits of data for every fact in existence.

Information Overload

"But we will not necessarily be better informed. Meaningful facts – those that have reliable and relevant information – will become our most valuable resource."

- Richard Worzel

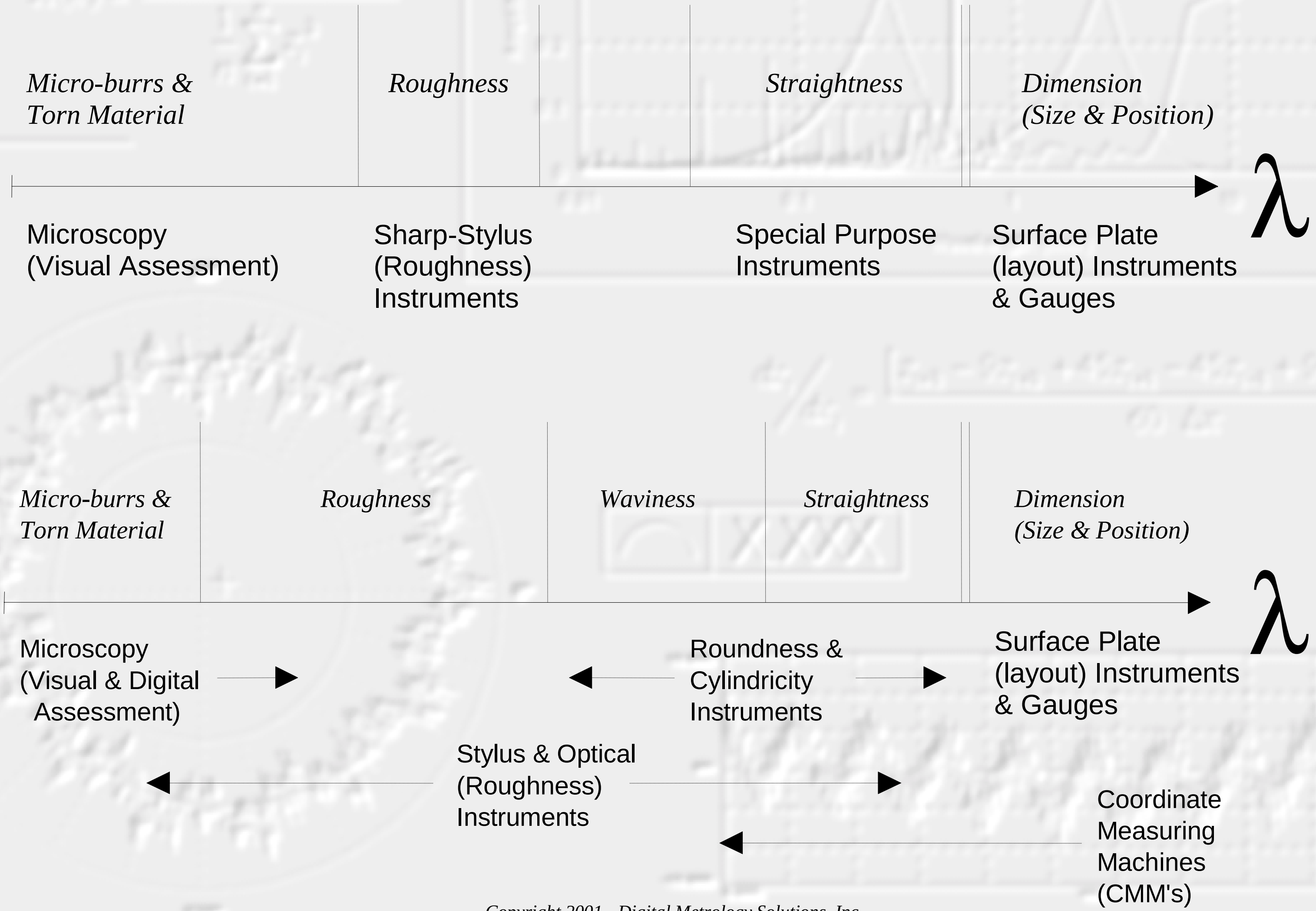
Flying with Fast Company

American Way – February 1, 2000

Where We Are

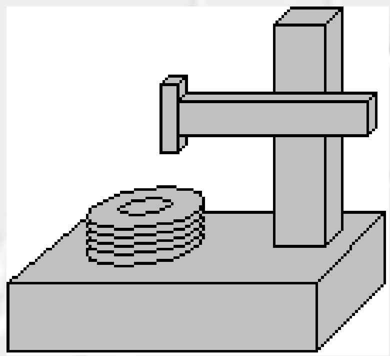
The Overlap of Instrumentation

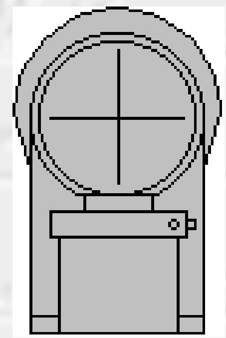
The Evolution of Measurement (*in one really busy slide*)

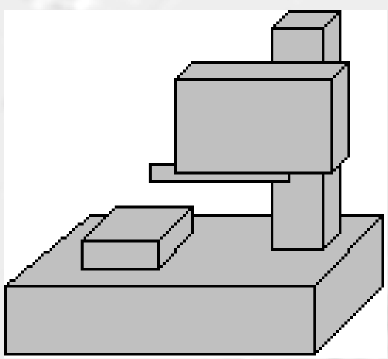


Instrument Overlaps

- Straightness







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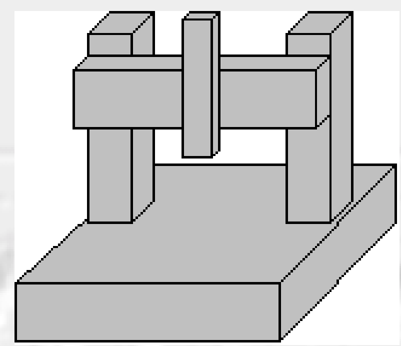
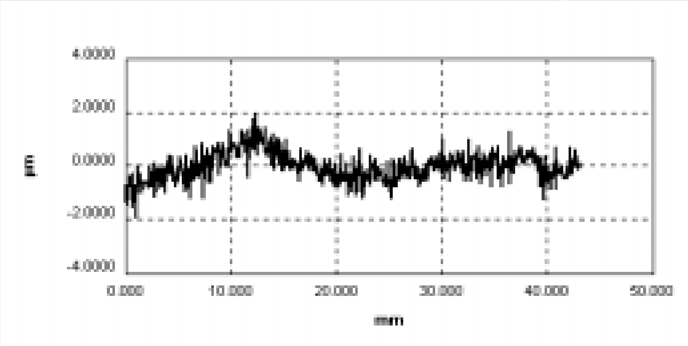
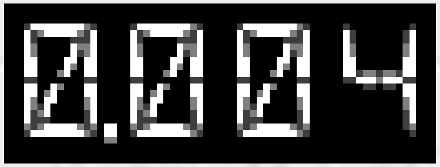


Instrument Overlaps

- Who is right?





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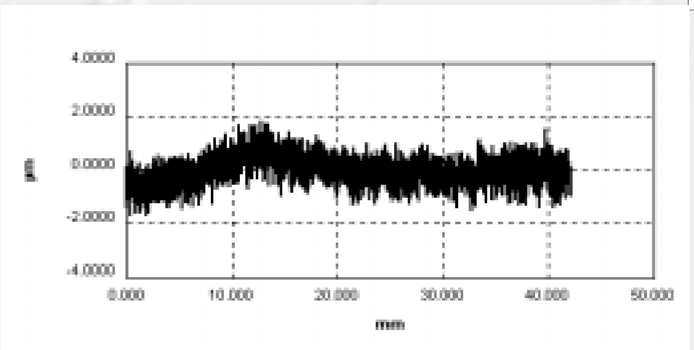
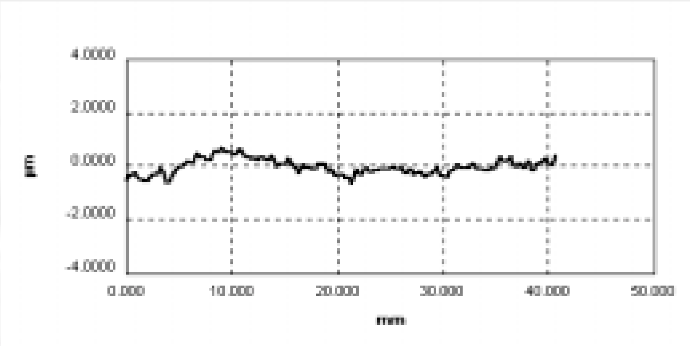
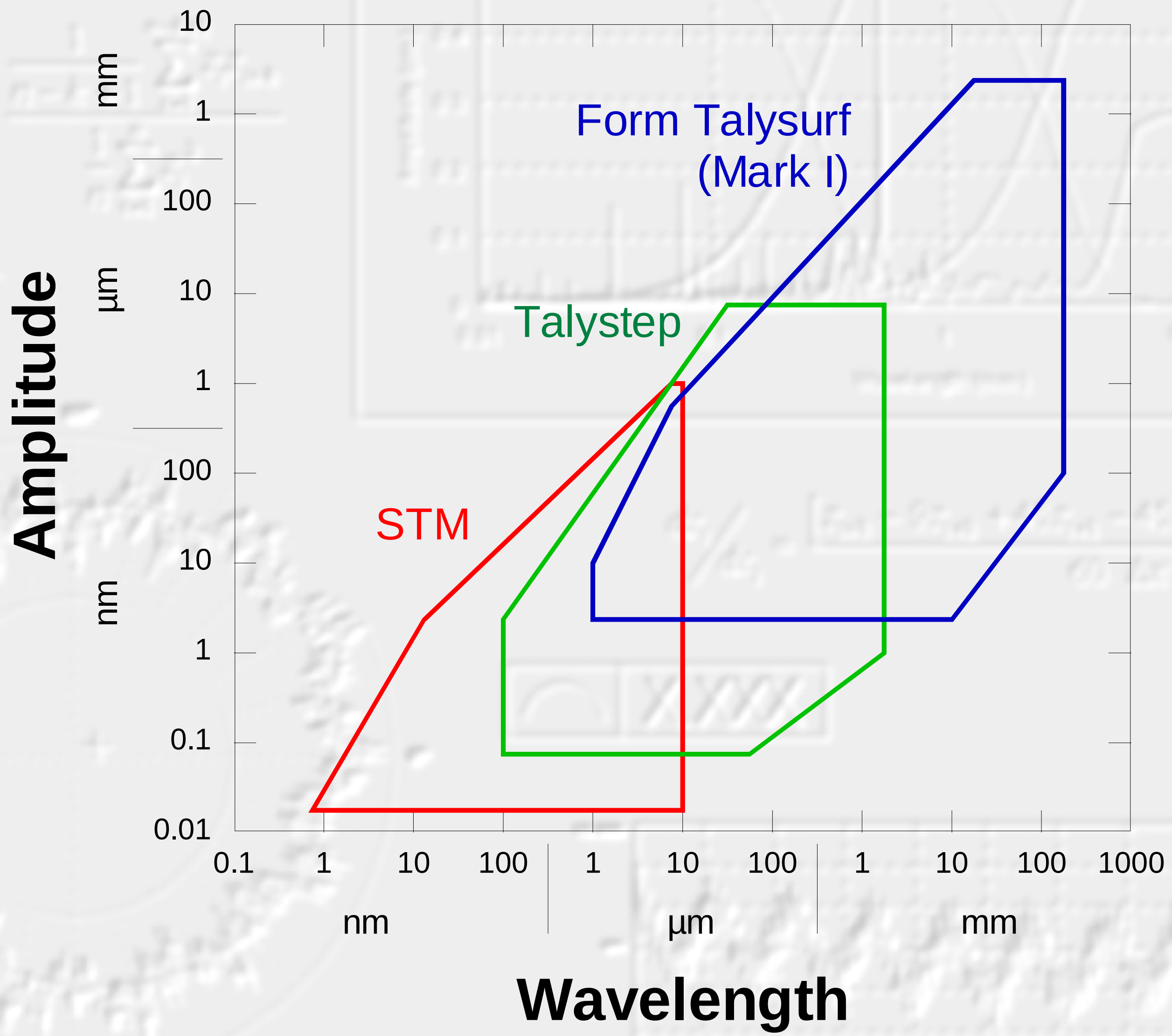




Instrument Overlaps



Quality Today, April 1990

Instrument Overlaps

- The overlap in surface metrology instrumentation produces problems as well as opportunities.

Instrument Overlaps

Costs

- Increased time spent dealing with correlation.
- Customer / Supplier Disputes

Benefits

- Allows for a broader selection of instruments.
- Provides for competition between technologies.
- Provides a means for comparison.

Customer Concerns

Why does this stuff matter, anyway?

What has value?

- Numerical results that relate to the <u>performance</u> of a component.
  - Product functionality
- Numerical results that relate to <u>process</u> controls.
  - Process control
- Numerical results that are <u>reproducible</u>.
  - Commerce enabling

The Value of Measurement

Customers don't generally want better metrology for the sake of metrology...

...customers want better information in order to make their products better.

Metrology is a means to an end.

Where We Should be Going

An understanding of functionality

Functionality

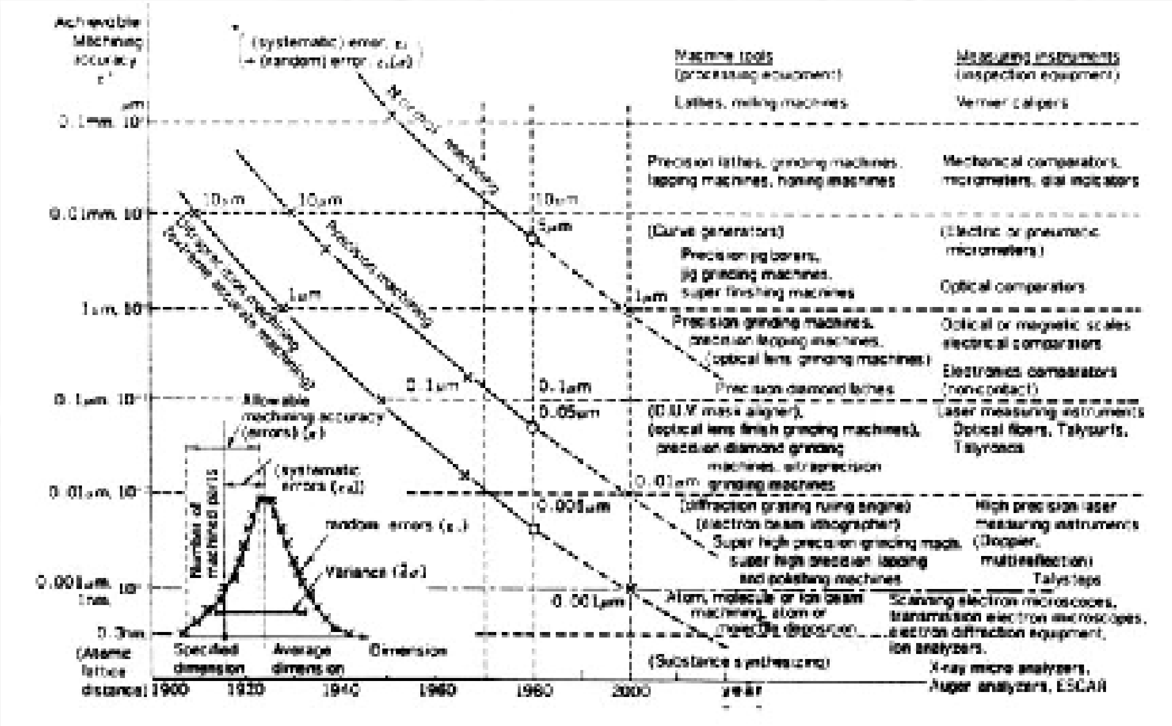
"A picture may be worth a thousand words, but I'm an engineer, not a poet – give me a number."

- Chris Brown

ASME B46 Subcommittee

on Fractal Analysis of Surface Texture

Does this help functionality?



Current status in, and future trends of, ultraprecision machining and ultrafine materials processing
by Norio Taniguchi, Tokyo Science University. Annals of the CIRP Vol. 32/2/1983 page 573

Tolerance Reductions

- In many cases, reducing of tolerances is necessary in order to enhance or ensure performance levels.
- However, there are many cases where tolerance reductions may not be the ideal approach.

First Principle in Tolerance Reduction:

Be sure that you are measuring the right thing!

Tolerance Reduction

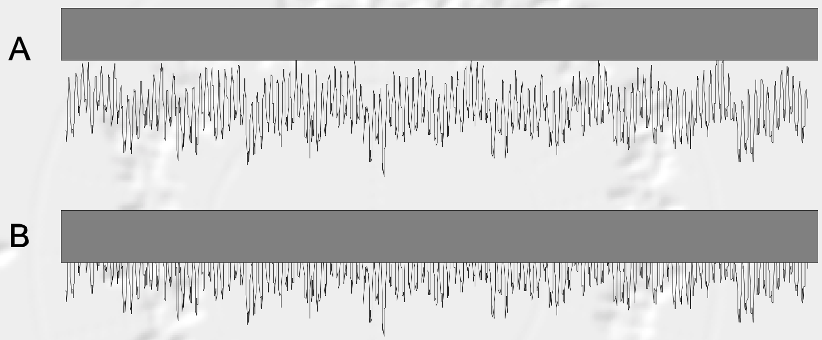
- A major automotive manufacturer was dealing with camshaft failures.
  - *All dimensional attributes met the specifications.*
  - *Roughness values met the specifications.*
- As the first step to improvement, the roughness tolerance was lowered.
  - *The failure rate increased.*

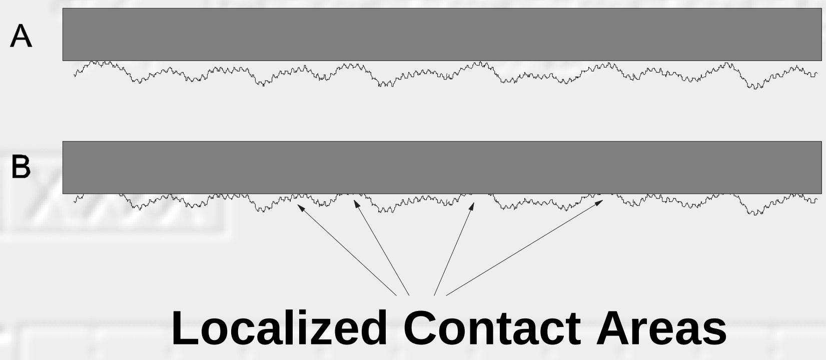
Tolerance Reduction

- Given these results, it was decided to further reduce the roughness in an effort to get “past the sensitive area”.
  - *Failure rates increased further.*
- Additional analysis determined that the cause of failure was an underlying waviness.
  - *Reduction in roughness exposed more of the damaging effects of waviness.*

Tolerance Reduction

- Be careful what you wish for. Making things smoother may not make them better!



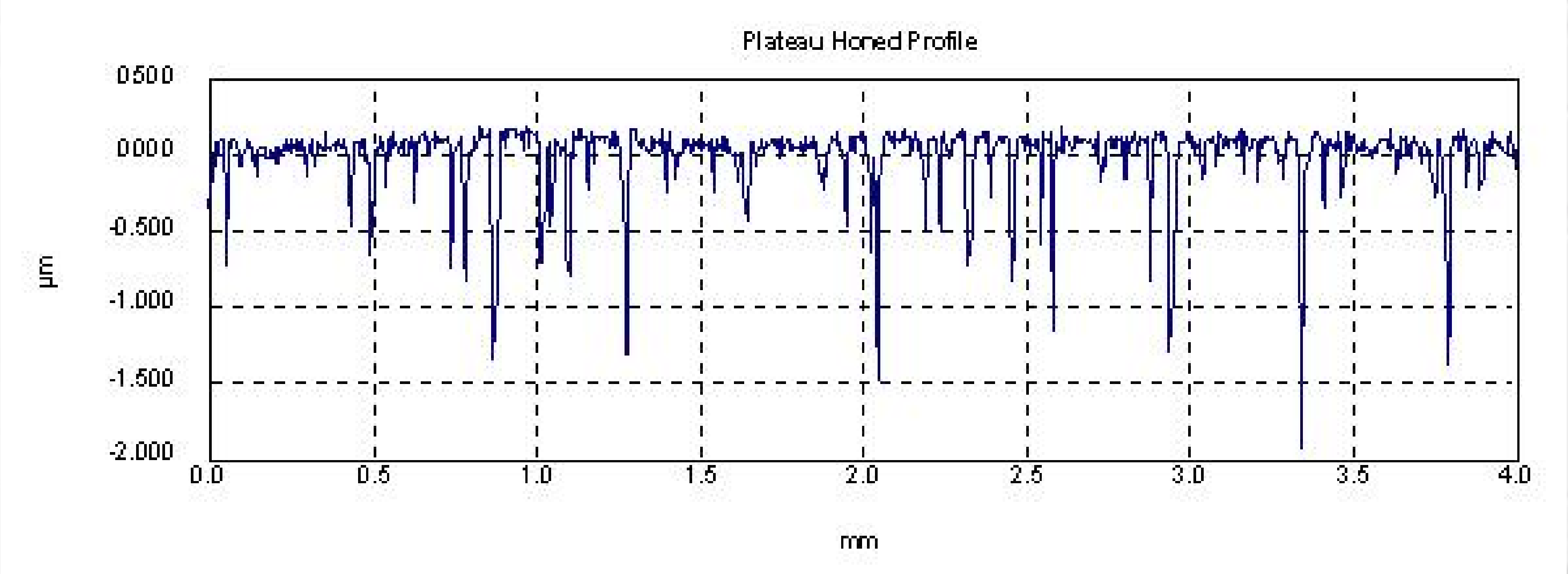


Two Approaches to Establishing Functional Correlation

- *"Mathematical"* Correlation
  - Correlating a parameter or set of parameters to a functionality via statistical methods.
- *"Physical"* Correlation
  - Developing a model of functionality and a description of this functionality in terms of measured parameters.

Two Approaches to Establishing Functional Correlation

- Example: Plateau Honing



Mathematical Correlation

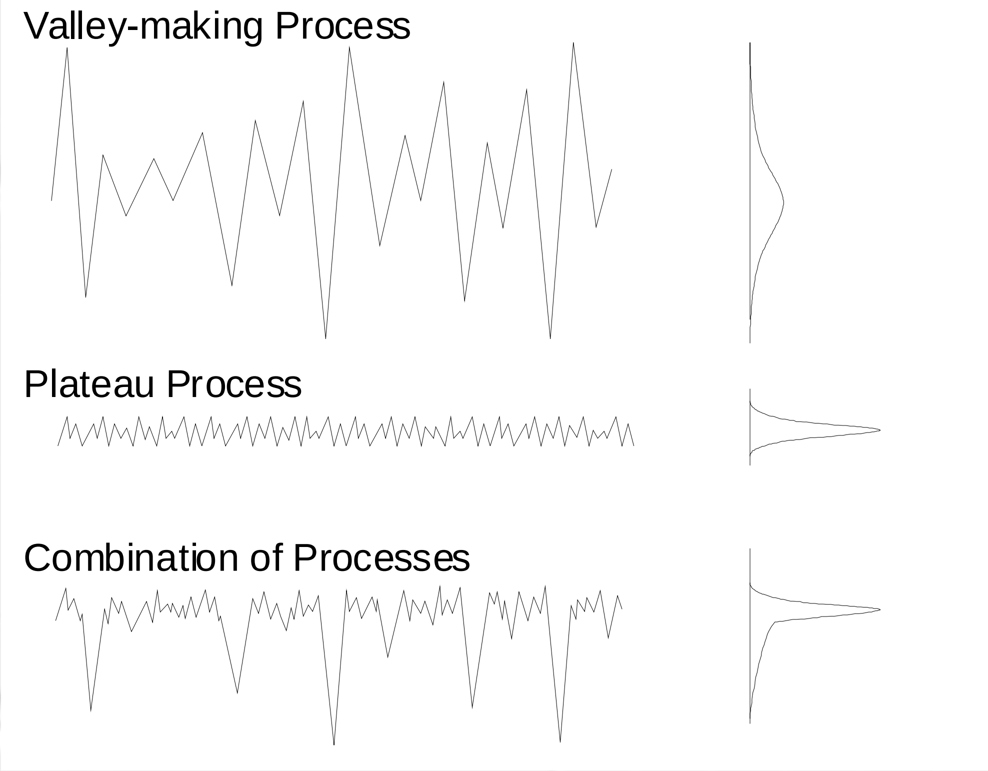
- Plateau Honing
  - A set of parameters where evaluated in the comparison of “good” components to “bad” components.
  - A mathematical relationship was developed based on tolerance limits for 5 different parameters and 2 ratios of the these parameters.

Physical Correlation

- Plateau Honing
  - The underlying functionalities were explored:
    - Smooth running surface.
    - Deep grooves for oil retention / debris collection.
    - Controlled contact area.
  - The underlying process controls were explored:
    - Rough honing
    - Fine honing
    - Placement of the fine honing within the base texture.

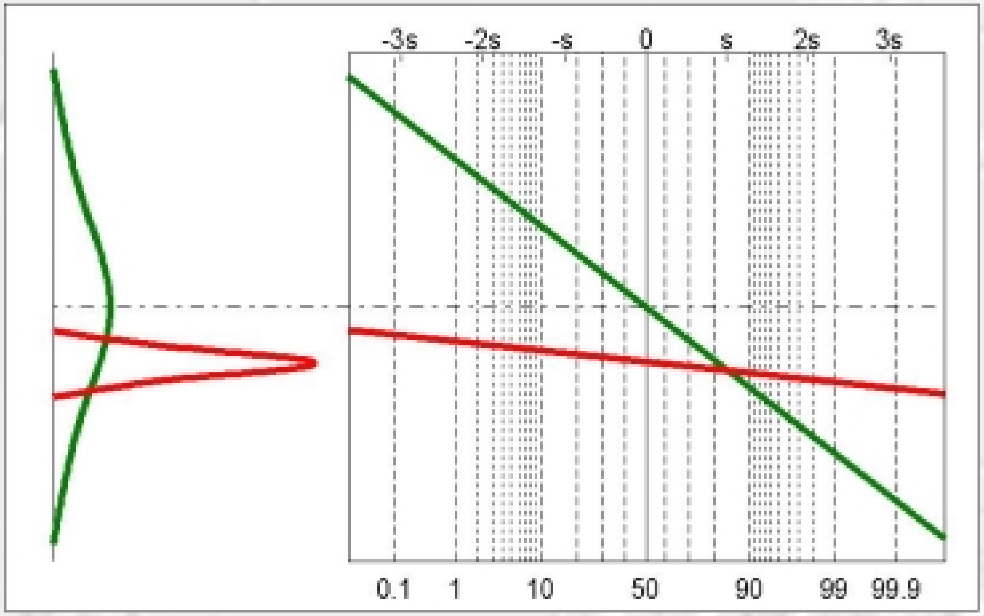
Physical Correlation

- Model of Plateau Honing
  - The combination of two random processes.



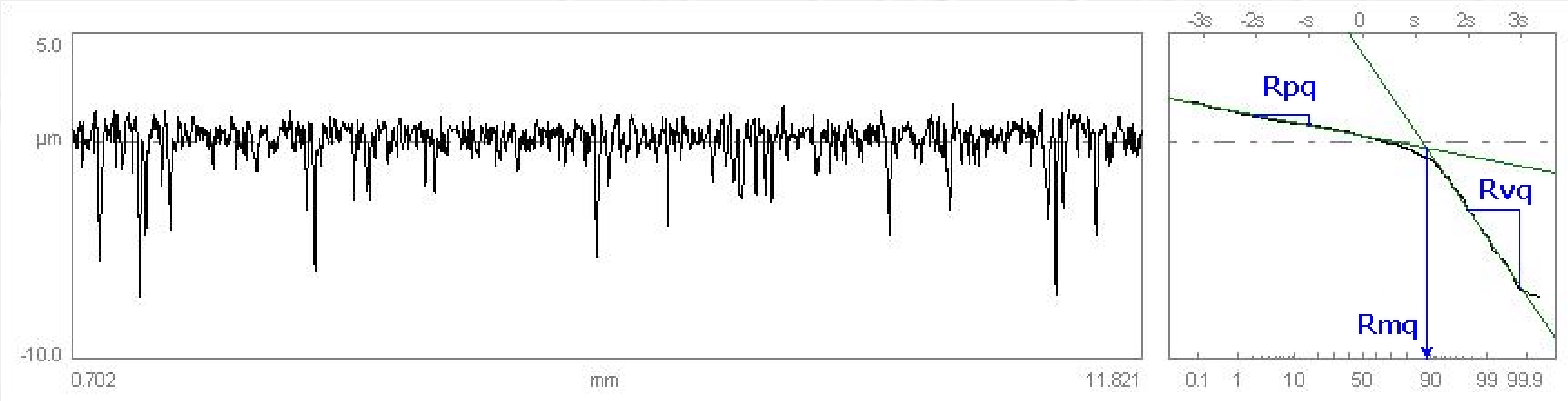
Physical Correlation

- Application of mathematics to the model.
  - Normal probability analysis.



Physical Correlation

- Development of parameters for the model.



Rpq: Plateau RMS Roughness

Rvq: Valley RMS Roughness

Rmq: Material Ratio at Plateau to Valley Transition

Functional Correlation

- Sometimes *“mathematical”* correlation is the only available option in developing a specification.
  - No underlying mechanism can be established.
  - This can cause significant problems in the development of manufacturing processes.
- “*Physical*” correlation is preferred.
  - However, the underlying model is often very difficult to generate.

Where We Should be Going

National and International Standards providing "Toolboxes"

National & International Surface Texture Standards

- There is a difference in philosophy between international (ISO) and national (ASME) standards regarding surface texture:
  - American Standards tend to attempt to describe common practice.
  - International Standards tend to attempt to define an arbitrator method.

Standards Reflecting Practice

Advantages

- Provides a description of many new and historical methods.
- Tend to be more tutorial in nature.
- Recognizes other methods.

Disadvantages

- Very difficult to ascertain the “correct” measurement method.
- Difficult to apply in arbitration.

Standards Defining an Arbitrator

Advantages

- Provides a clear description of the "correct" method.
- Useful in disputes or arbitration.
- A "safety net"
  - Unless otherwise specified.

Disadvantages

- Not generally as tutorial in nature.
- Older instrumentation tends to be ignored.

How Full is the Toolbox?

ISO / TC 213 Geometrical Product Specification (GPS)

– Chains of Standards

Chain Link number		1	2	3	4	5	6
Geometrical Characteristic of feature		Product documentation indication - Codification	Definition of tolerances – Theoretical definition and values	Definitions for actual feature – characteristic or parameter	Assessment of the deviations of the workpiece – Comparison with tolerance limits	Measurement equipment requirements	Calibration requirements – Measurement standards
1	Size						
2	Distance						
3	Radius						
4	Angle (tolerance in degrees)						
5	Form of a line independent of datum						
6	Form of a line dependent on a datum.						
7	Form of a surface independent of a datum						
8	Form of a surface dependent on a datum						
9	Orientation						
10	Location						
11	Circular run out						
12	Total run out						
13	Datums						
14	Roughness Profile						
15	Waviness Profile						
16	Primary Profile						
17	Surface Defects						
18	Edges						

Chains of Standards

- These "chain links" define the arbitrator for specification and measurement.
  - Typically they define a single approach with the clause:

"Unless otherwise specified..."

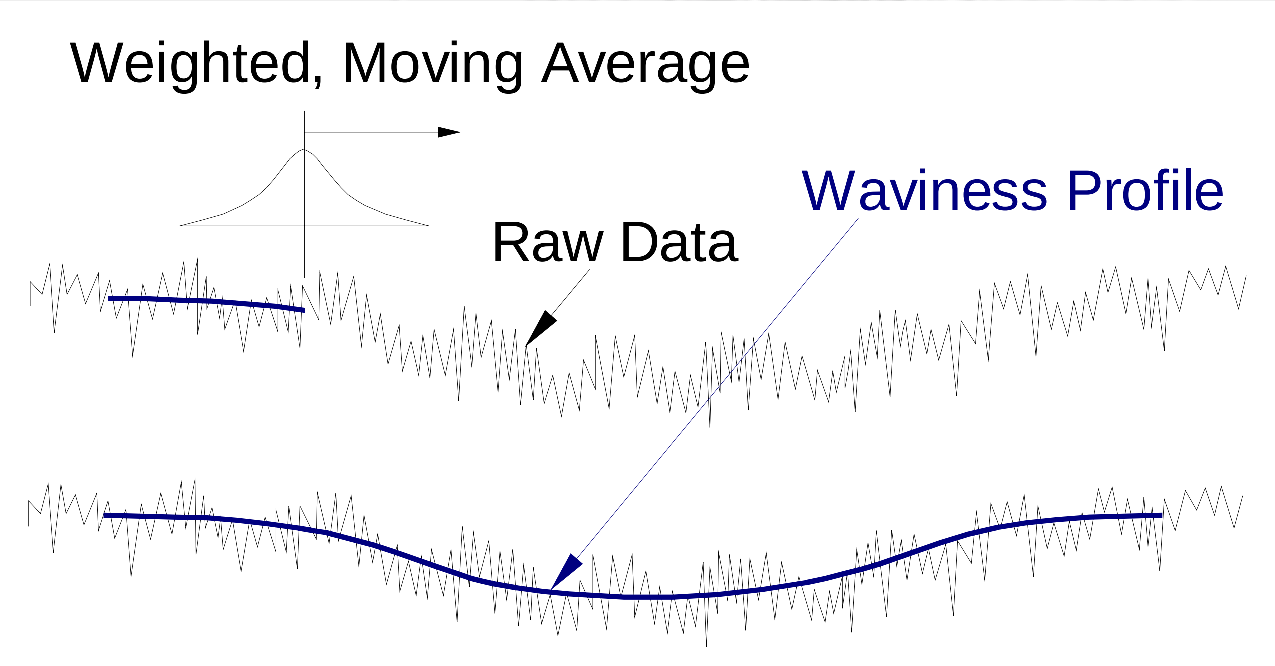
NOTE: This default approach may not be the best approach for all applications!

Good News!

- Surface metrology standardization efforts are beginning to provide alternative methods for measurement and analysis.
  - Filtering and Extraction Methods
  - Parameters and Analysis Approaches

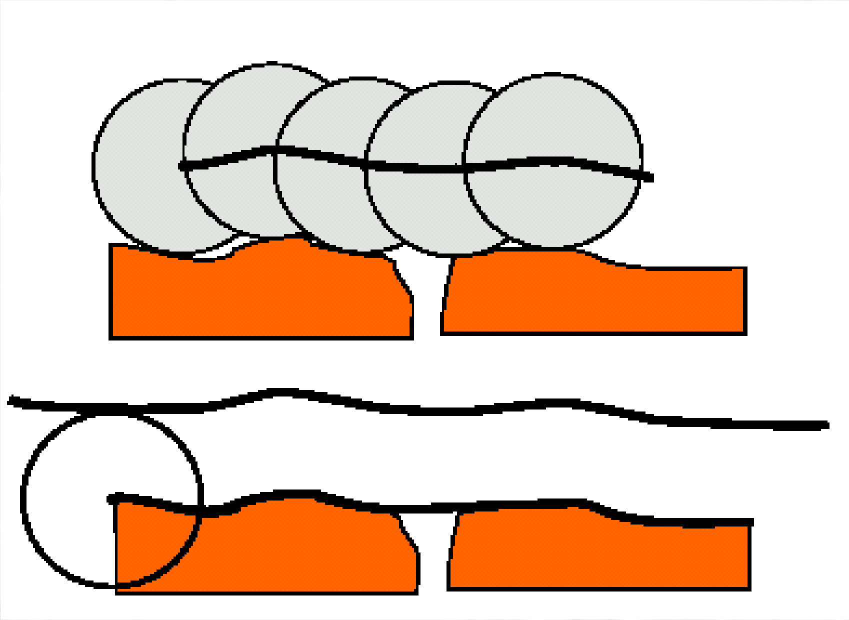
Filtering and Extraction Methods

- Convolution Filters



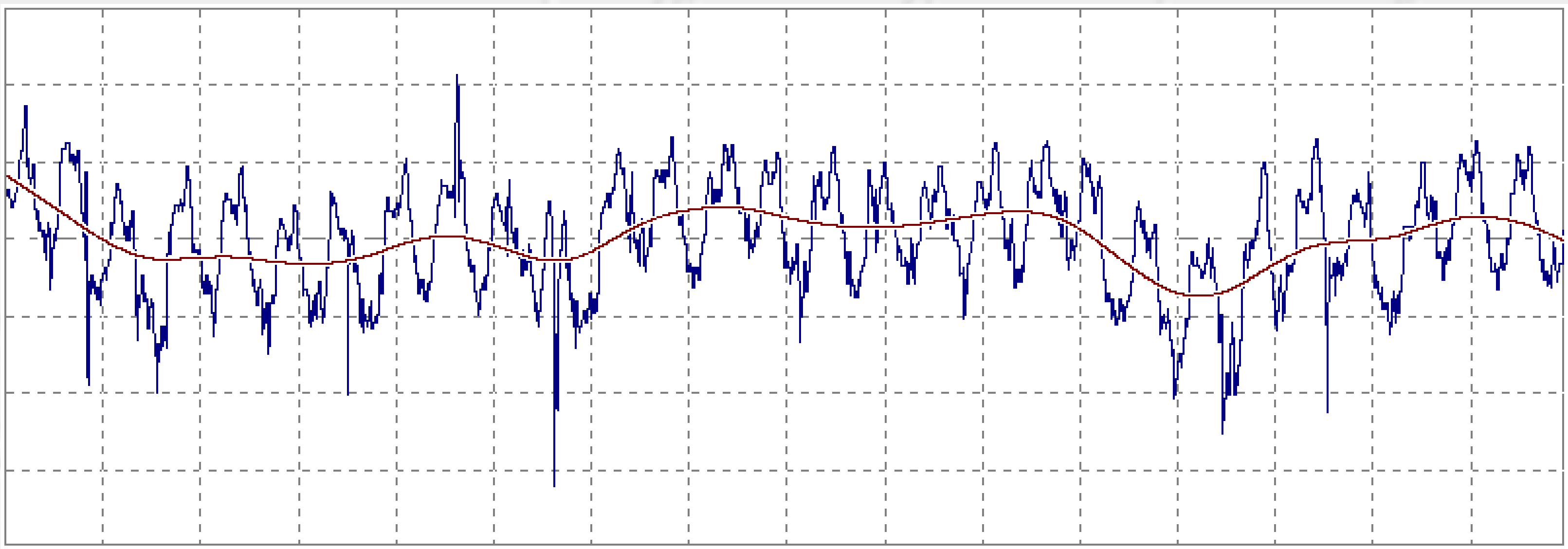
Filtering and Extraction Methods

- Morphological Filters
  - Based on various “structuring elements”.



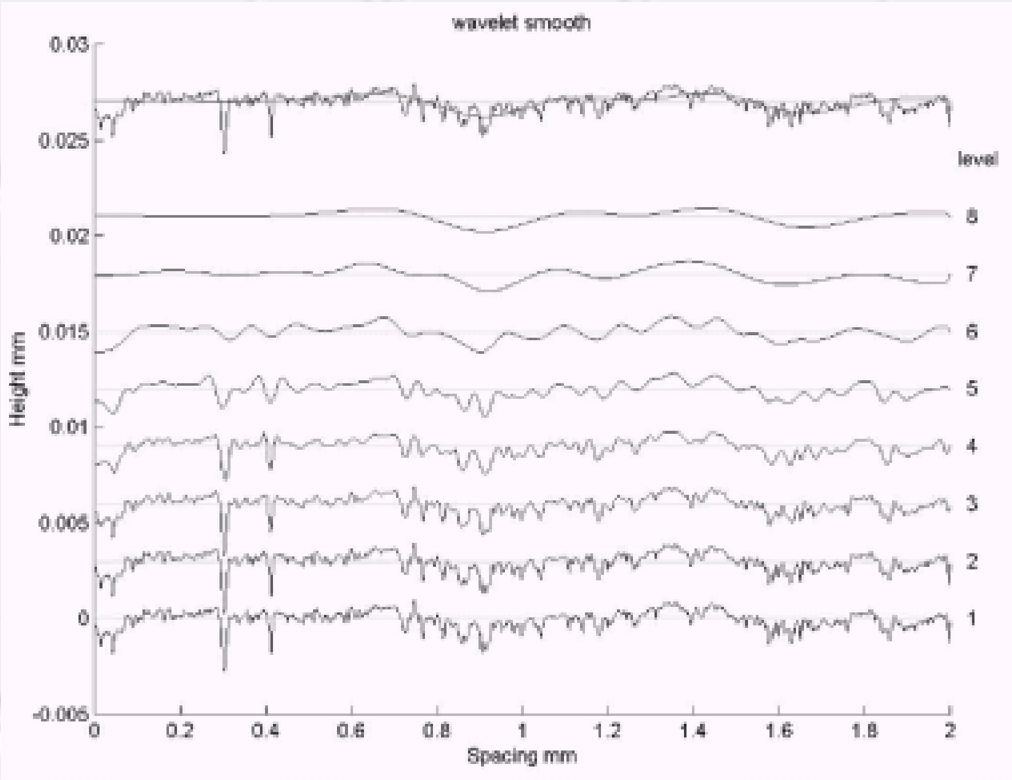
Filtering and Extraction Methods

- Spline-based filters



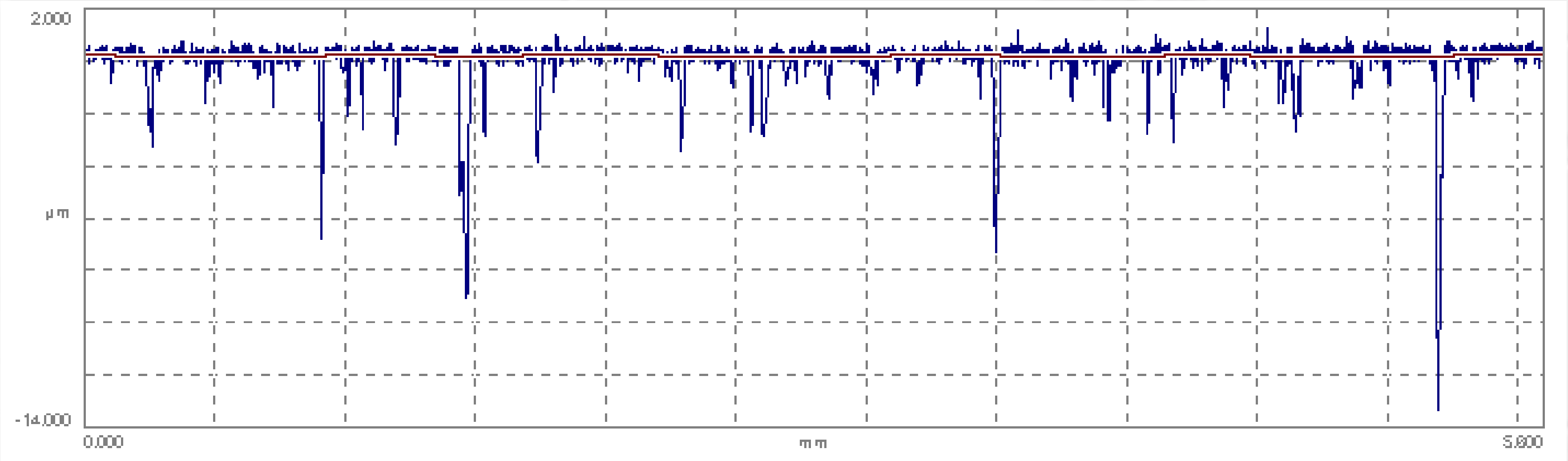
Filtering and Extraction Methods

- Wavelets and Alternating Sequence Filters
  - Multi-resolution analysis



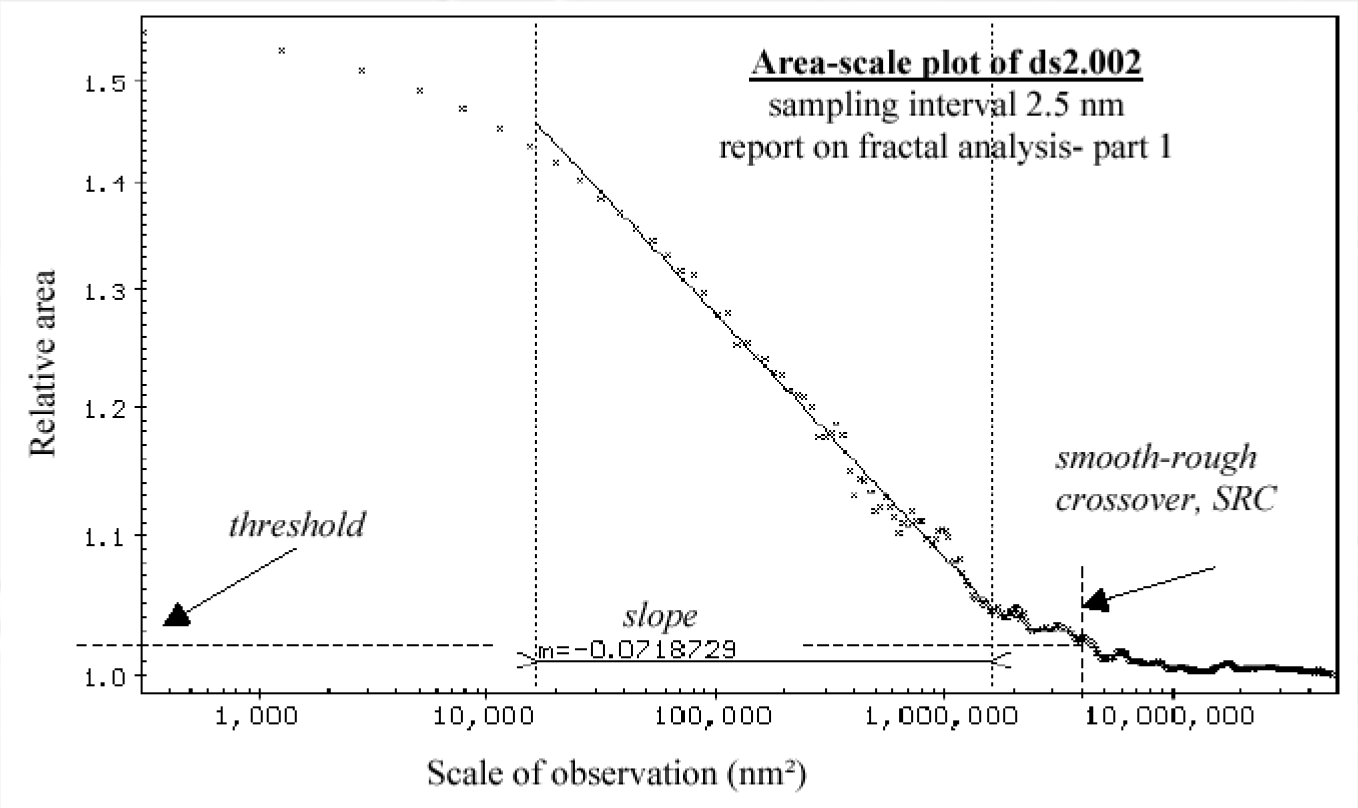
Filtering and Extraction Methods

- Robust Filters
  - Spline and Regression based



Parameters and Analysis Approaches

- Evaluation of Surface Texture Using Fractal Geometry



One Size Fits All..
(not necessarily)

- These and future "tools" are providing users with many of techniques which can be applied to address a specific measurement of functionality issue.
  - Various combinations of filtering and parameterization can be developed to address specific needs.

Where We Should be Going

Uncertainty as a Connection to Reality

Measurement Uncertainty

- Dealing with Measurement Uncertainty is a tremendous hurdle for many metrology users.

- Measurement Uncertainty doesn't necessarily mean that you are wrong.
  - It means that you are smart enough to know your limits!!!

Measurement Uncertainty

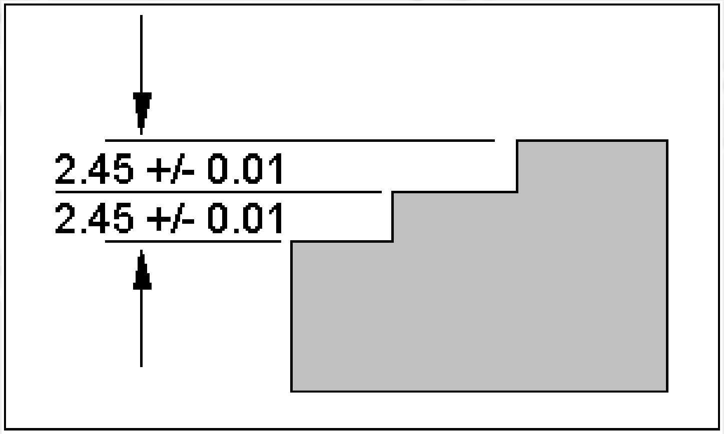
- Uncertainty analysis can be a very beneficial exercise.
  - Helps to further refine the definition of the "measurand".
  - Developing an understanding of significant instrument variables.
  - Establishing correlation limits between instrumentation methods.
  - Determining the "effective tolerance zone" and potential instrument influences.

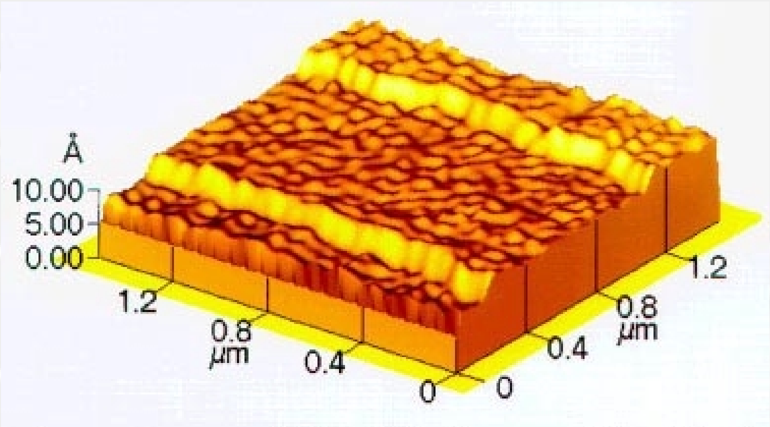
Case Studies

Working in the overlap between dimensional and surface metrology

Working in the overlap...

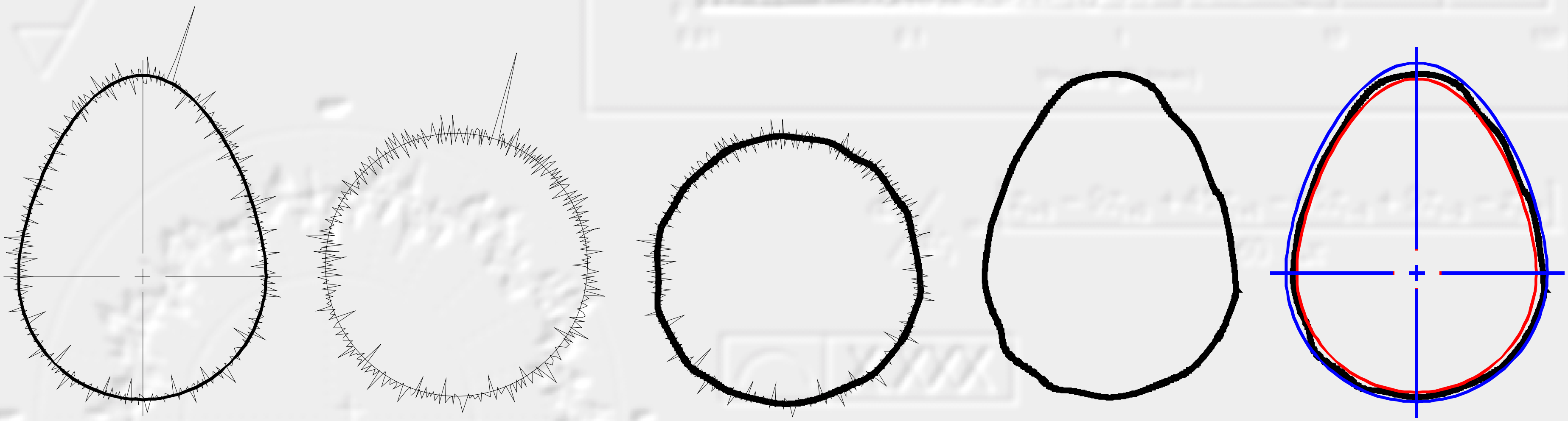
- Scale is irrelevant
  - For example: step heights occur in inches as well as angstroms.





Working in the overlap...

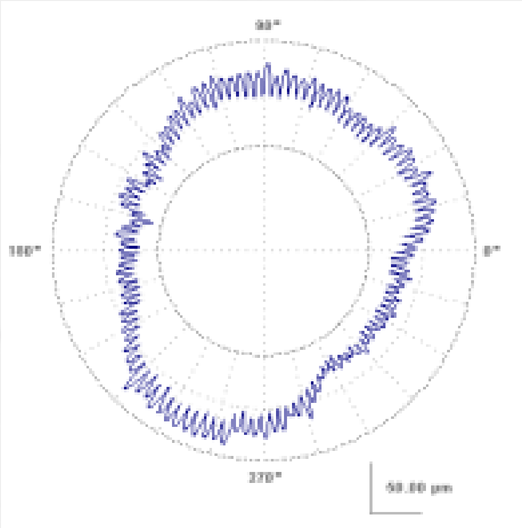
- Extraction is essential

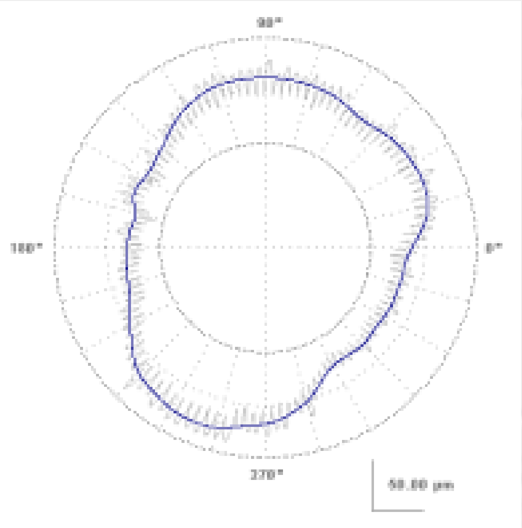


Initial Least Squares Fit | Suppression of Geometry | Outlier Removal and Filtering | Re-application of Geometry | Analysis of the Feature

Working in the overlap...

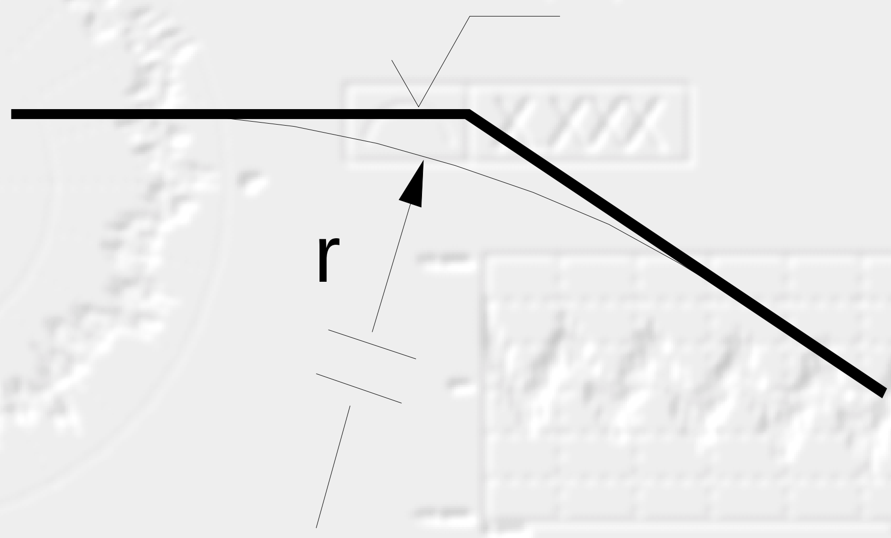
- Size and shape and wavelength content can be interrelated





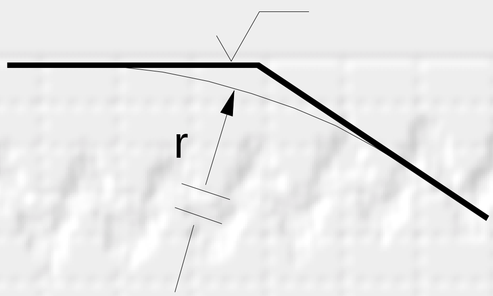
Case Study #1
A “Simple” Corner

- A certain corner should be “sharp” and “smooth” in a sealing application.
  - Limits were established for maximum blend radius and maximum roughness.
  - Tolerances were such that a stylus based profiling instrument was required.



The Corner

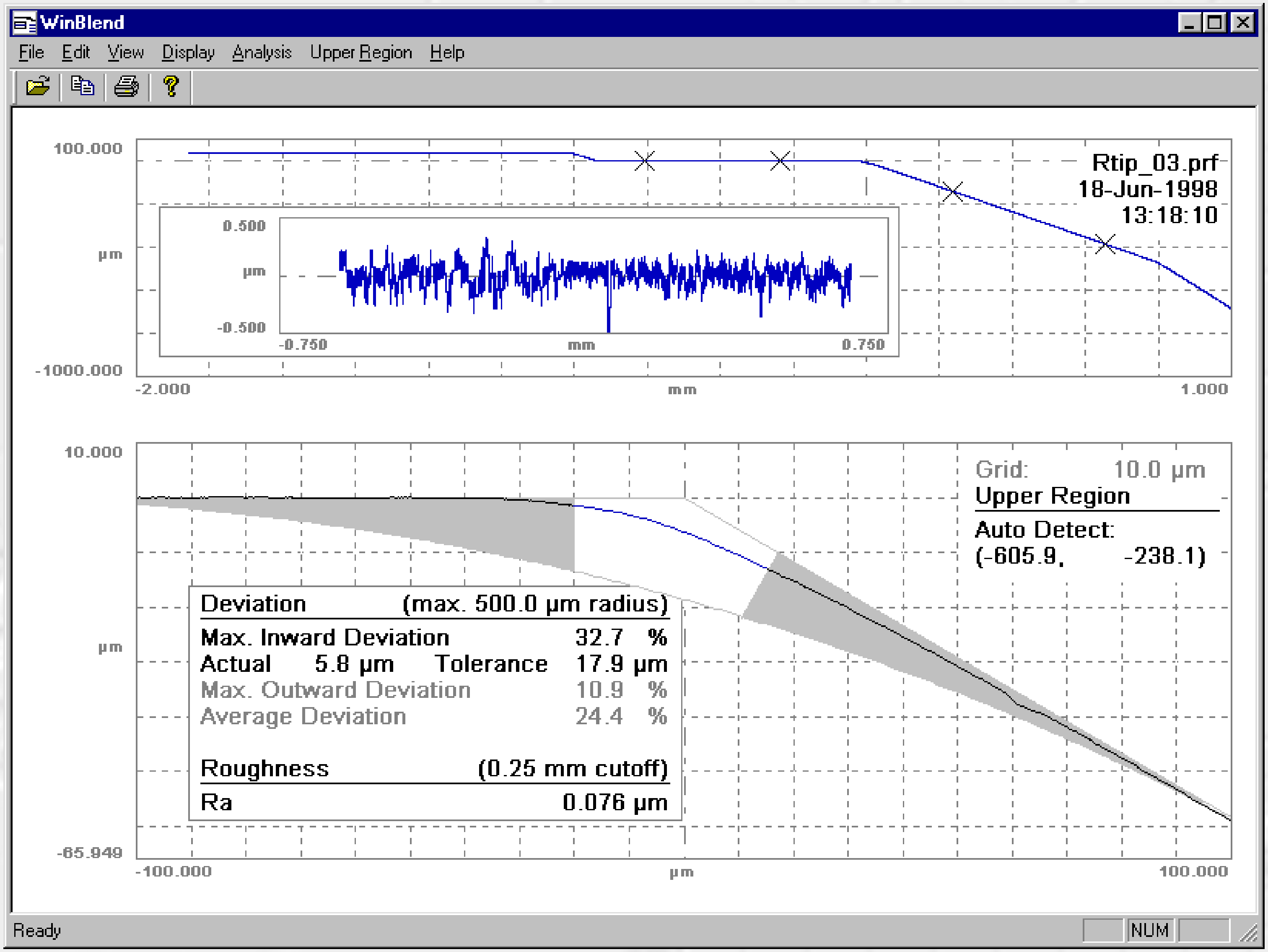
- Issues:
  - The measurement of a calculated radius is not reliable
    - Very small arc segment
    - Local flats cause infinite radius
  - A zone-based approach is difficult.
    - Tolerance zone is not constant
    - Tolerance goes to zero at tangencies
  - Roughness around a corner is not well defined



Dealing With the Corner

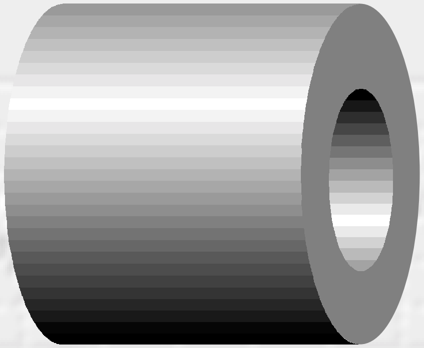
- The angle was determined based on least squares fitting of two lines.
- Based on the intersection, a mathematical zone was established based on the maximum allowed blend radius.
  - This zone was bounded to avoid tangencies.
  - A "percentage consumed" value was reported.
- The corner was "unrolled" based on a convex hull to arrive at a roughness profile.

Dealing with the Corner



Case Study #2
A "Complex" Crown

- A roller geometry is designed such that the pressure distribution is relatively uniform with no significant edge loading.
  - The geometry is such that the edges are "rolled-off" based on a lookup table.
  - The tolerance zone increases near the edges.
  - The overall length of the roller has a relatively loose tolerance.
  - Local concavities cannot be present.



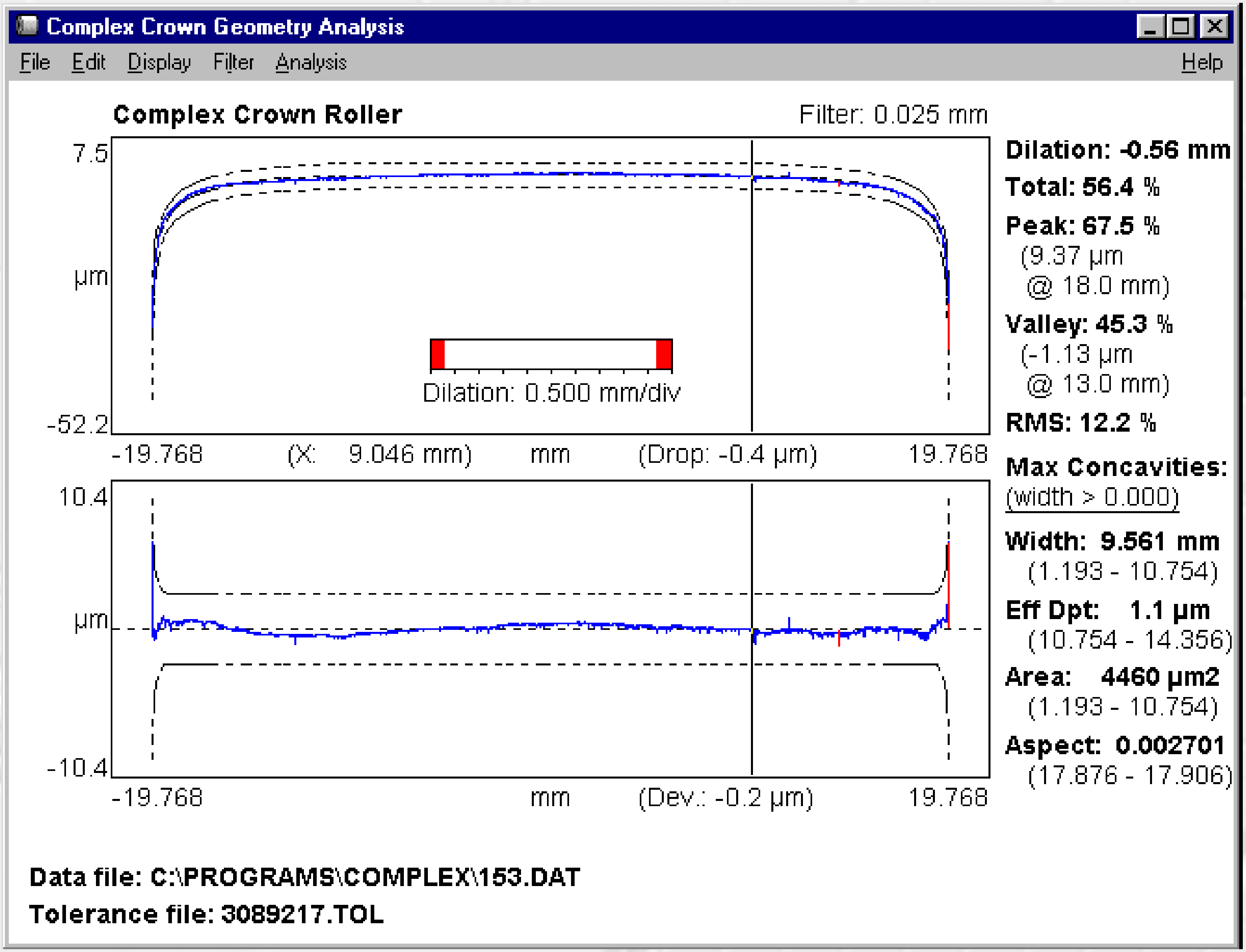
Dealing with the Crown

- Issues:
  - The nominal profile is based on a look-up table.
    - This table is based on finite element analysis of the contact pattern.
  - The look-up table position moves axially based on the roller width.
    - The roller width can "dilate" and "contract".
  - Local concavities are not readily exploited by standard parameters.
  - A non-uniform tolerance zone
    - Small deviations near the edges can be tolerated, while similar deviations near the center cannot.

Dealing with the Crown

- A long-pass Gaussian filter was applied to the data to reduce roughness effects in the profile analysis.
- A 4-dimensional least squares fit was applied to compare the measured profile to the nominal (dilated or contracted) geometry.
- A convex hull was applied to exploit local concavities.
- A "percentage consumed" approach was developed to accommodate the variable tolerance widths along the profile.

Dealing with the Crown



Where do we go from here?

A few ideas...

Recommendations

- Continue to develop "customizable" metrology technology as the analytical tools are going to continue to evolve.
  - Recognize the distinction between "data acquisition" and "data analysis"
- Continue to "grow" the toolbox
  - Through the sharing and standardizing of methods

Recommendations

- Train, Educate, Teach, Instruct, Mentor, Tutor, Coach, School, Inform, Guide
  - Today's engineering community is becoming more aware of metrology, but very few understand metrology.
  - Metrology doesn't sell and apply itself. It requires educated customers.

Recommendations

- Strive to provide "information" rather than just "data".
  - Consider the questions behind the measurement:
    - Is this part in tolerance?
    - How well with this part perform?
    - What do I need to change in the process?

Recommendations

- Continue to emphasize the importance of measurement uncertainty
  - This may be difficult at first, but significant benefits can be achieved.
- Continue to interact (openly) in forums such as this!
  - Recognizing a balance between competition and collaboration.