Apples and Oranges:

Why Dimensional Measurements Don't Agree

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Digital Metrology Solutions, Inc.

www.digitalmetrology.com

Have you ever measured anything that somebody else has already measured or will be measuring?

The world in which we live...

- Specifications
- Instruments
- Locations

Specifications

- The good old days...

Surface Texture // **Shape** // **Size/Orientation**

increasing scale →

Specifications

- Things are getting messy...

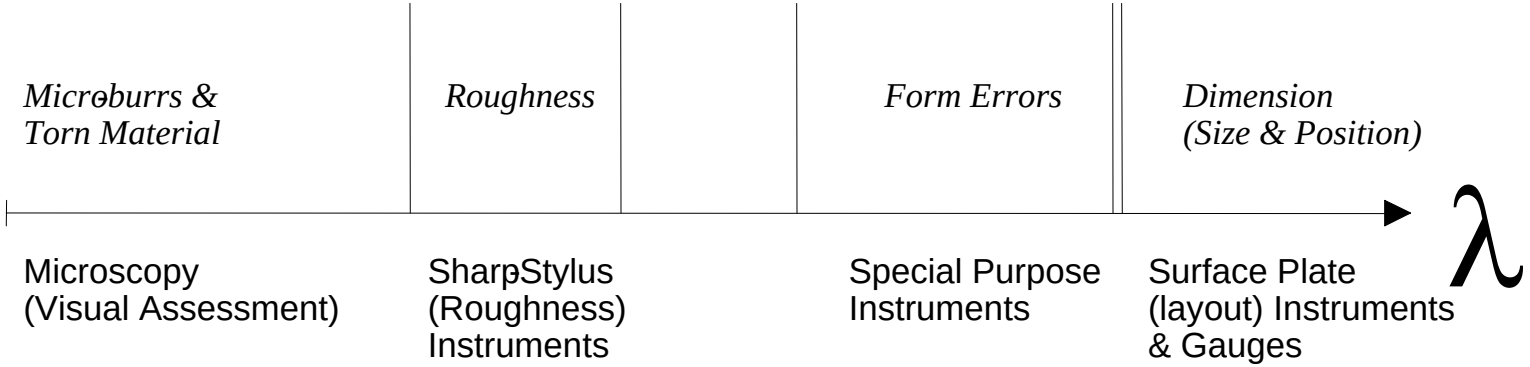
shrinking tolerances

Surface Texture **Shape** **Size/Orientation**

increasing scale

Instruments

- The good old days...



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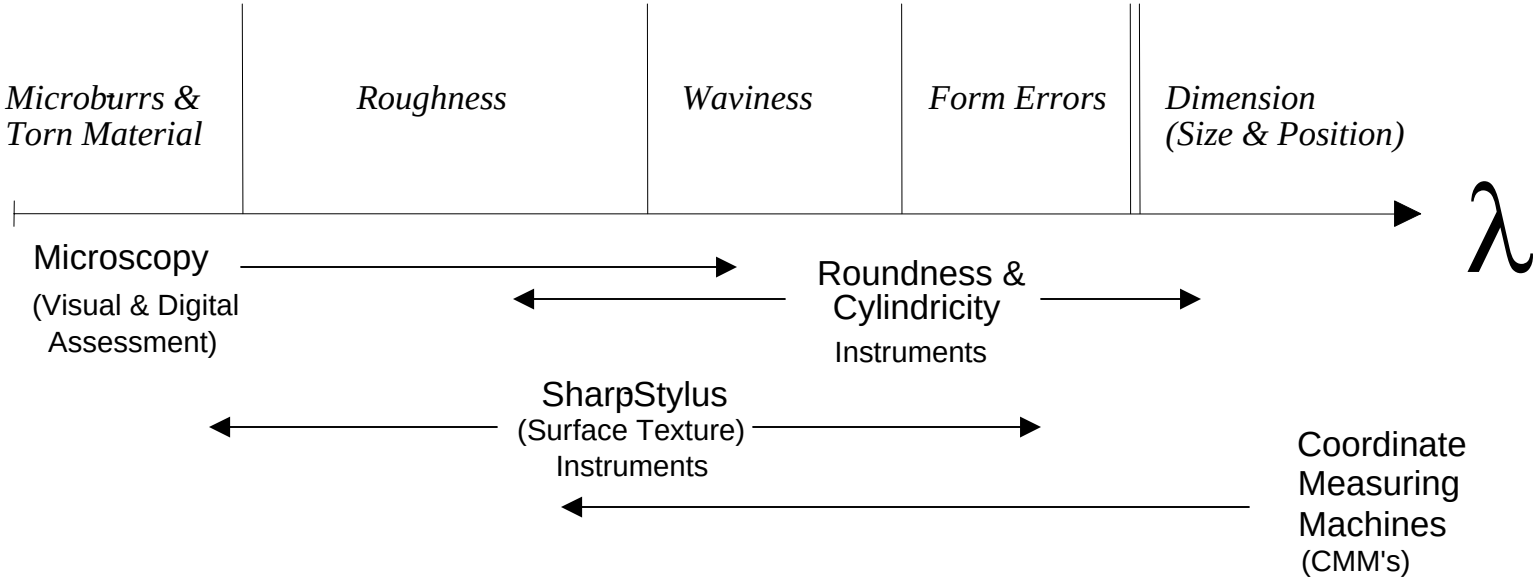
Instruments

- Things are getting messy...



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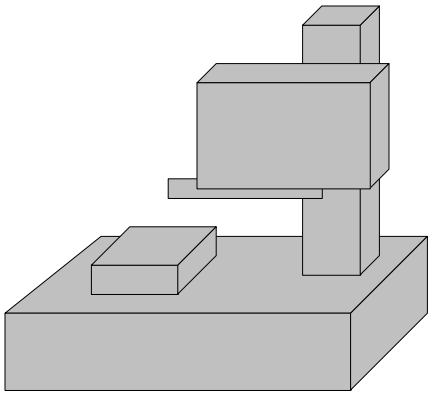
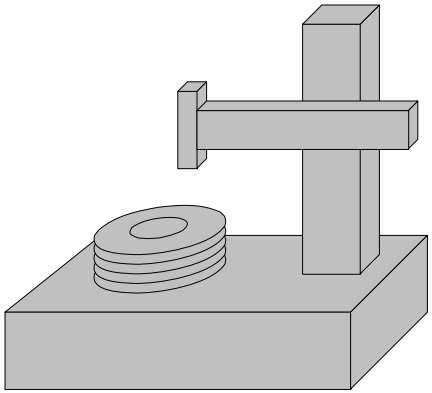
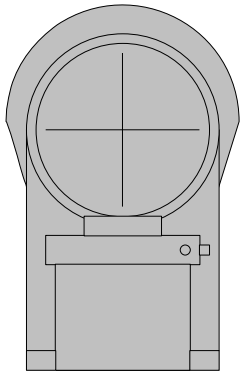
Instruments

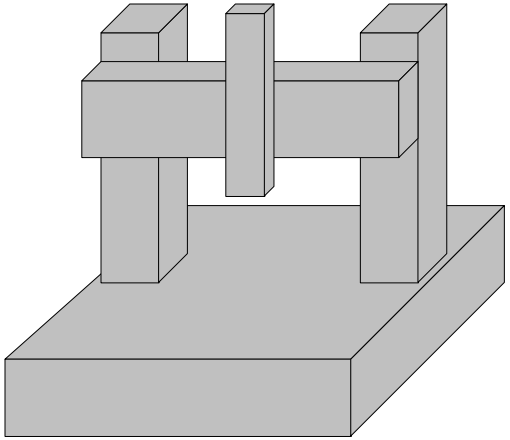
- Things are getting messy...

—	0.010









etc. …

Locations

- Globalization
  - Car (5,000 components, domestic% = ?)
  - Expanding Markets (global assembly)

Ideally...

Measurements should adequately agree:
between locations,
between operators,
and between devices.

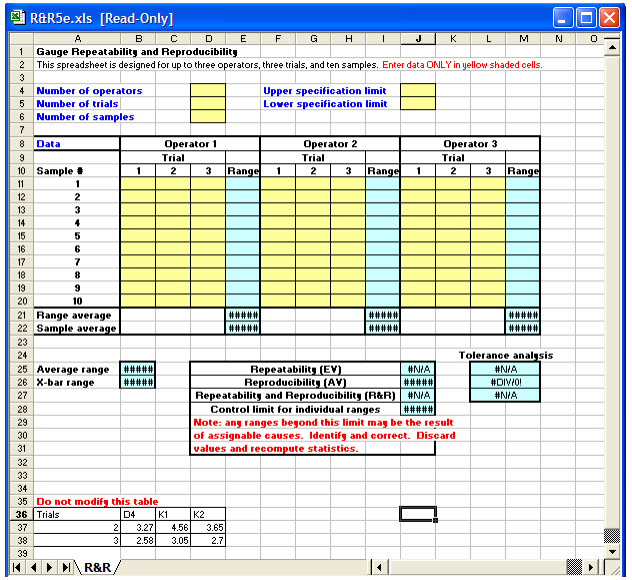
Unfortunately, they don't...

So where do we begin?

The Myth of Repeatability

The Myth of Repeatability

- Repeatability and Reproducibility
  - % R&R < 10%
    - Gage System is OK


R&R5e.xls [Read-Only]

Gauge Repeatability and Reproducibility

This spreadsheet is designed for up to three operators, three trials, and ten samples. Enter data ONLY in yellow shaded cells.

Number of operators
Number of trials
Number of samples

Upper specification limit
Lower specification limit

Data	Operator 1				Operator 2				Operator 3			
	Trial				Trial				Trial			
Sample #	1	2	3	Range	1	2	3	Range	1	2	3	Range
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
Range average				#####				#####				#####
Sample average				#####				#####				#####

Tolerance analysis

Average range	#####	Repeatability (EV)	#N/A
X-bar range	#####	Reproducibility (AV)	#####
		Repeatability and Reproducibility (R&R)	#N/A
		Control limit for individual ranges	#####

Tolerance analysis: #N/A, #DIV/0!, #N/A

Note: any ranges beyond this limit may be the result of assignable causes. Identify and correct. Discard values and recompute statistics.

Do not modify this table

Trials	D4	K1	K2
2	3.27	4.56	3.65
3	2.58	3.05	2.7

R&R

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The Myth of Repeatability

- A dead measurement system has <u>perfect</u> repeatability!
  - *And it can't be "adjusted" into correlation*.

Beginning to understand...

Specification is a "**language**".

Beginning to understand...

- Unfortunately things get lost in translation.

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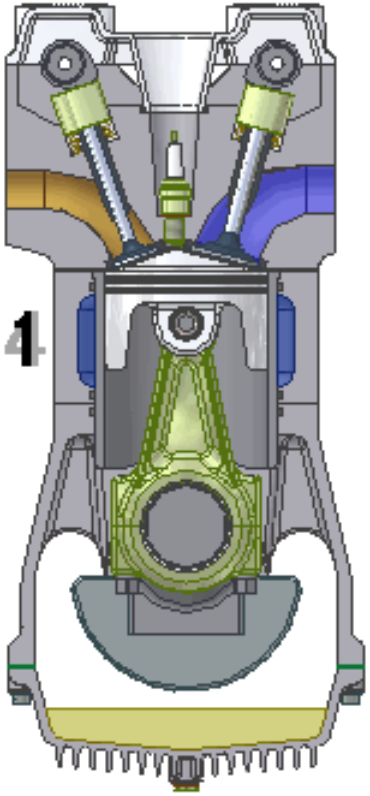
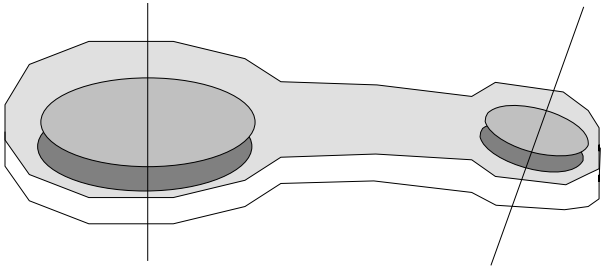
A couple of examples...

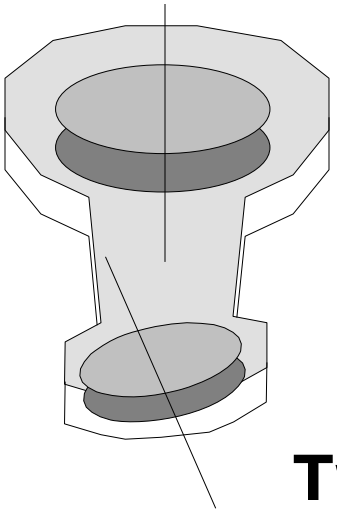
Example: Connecting Rod



The connecting rod “language”



Bend



Twist

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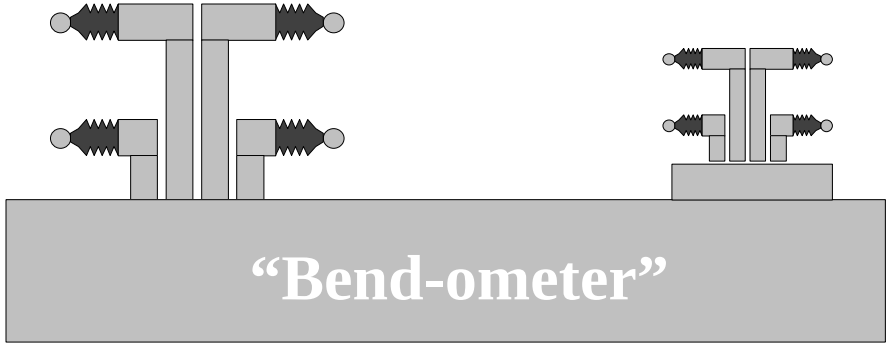
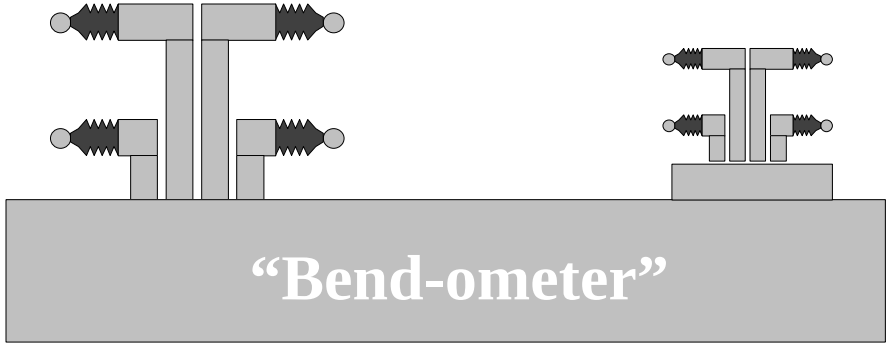
Bend & Twist

- The "gauge" interpretation



Bend & Twist

- The “gauge” interpretation

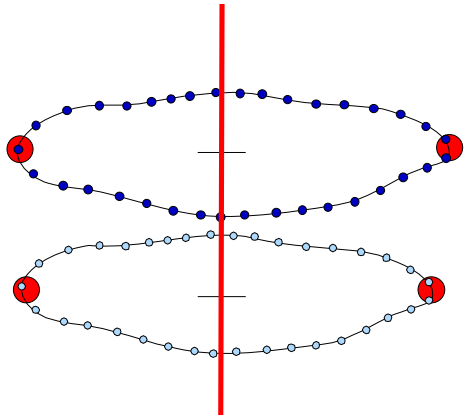


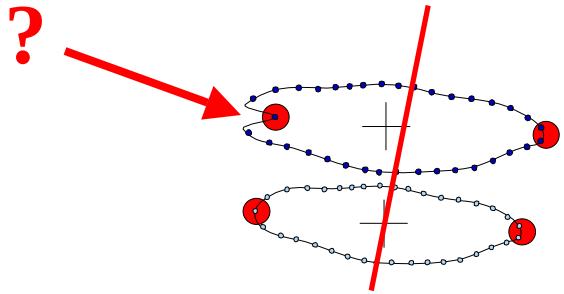
- The “scanning” interpretation

Bend & Twist

- When "things go wrong" different interpretations can give wildly different results.

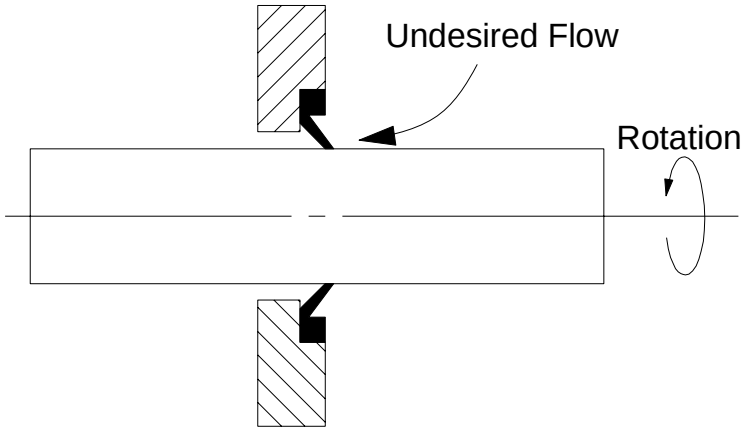
Apparent "Bend"
with fixed gauging

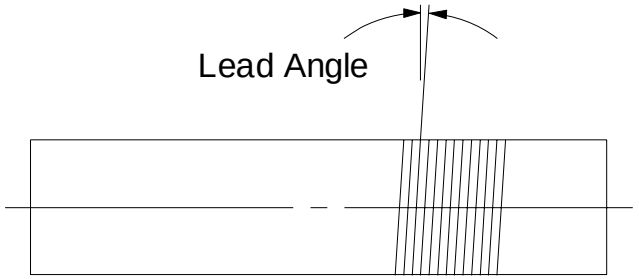




Example: Shaft leakage

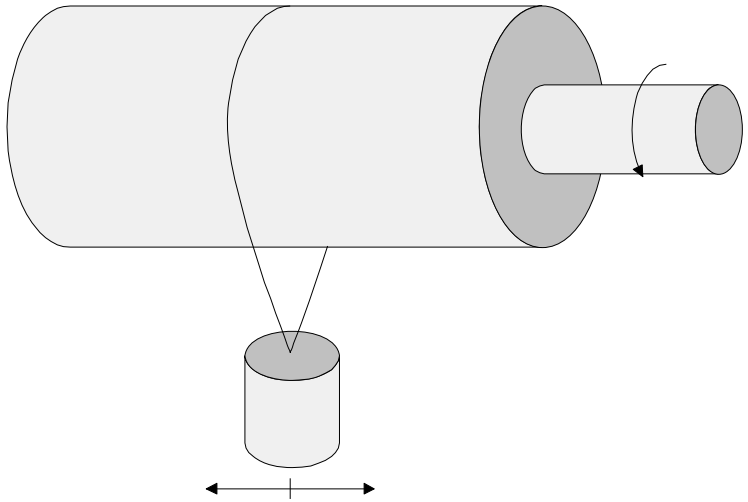
- A “spiral” surface texture pattern can act like a pump.
  - To control this, a maximum “lead angle” is specified.



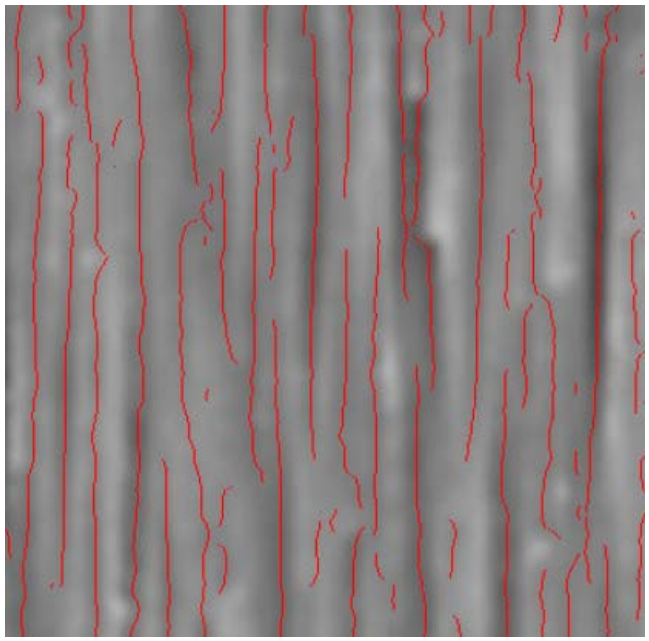


Lead Angle Assessment

- "String test"



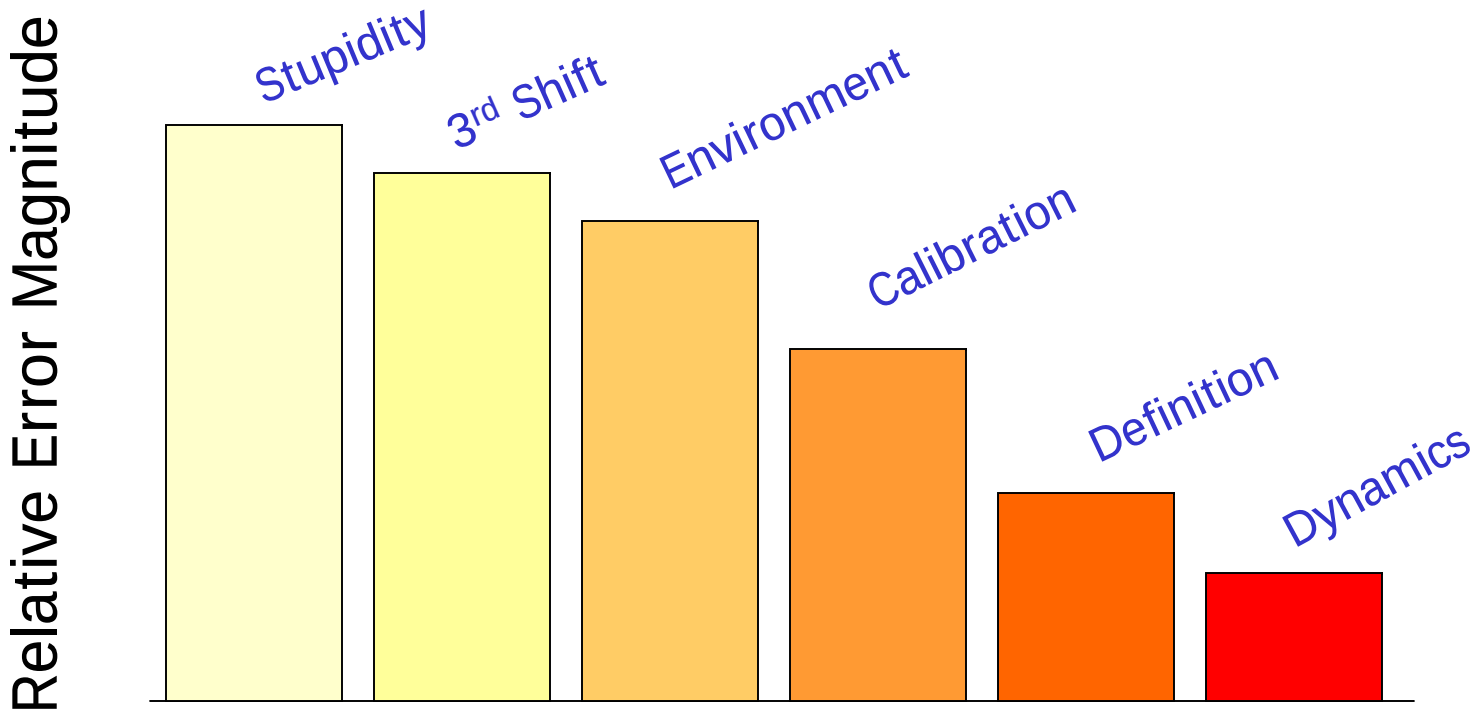
- "Surface texture"



Unfortunately...

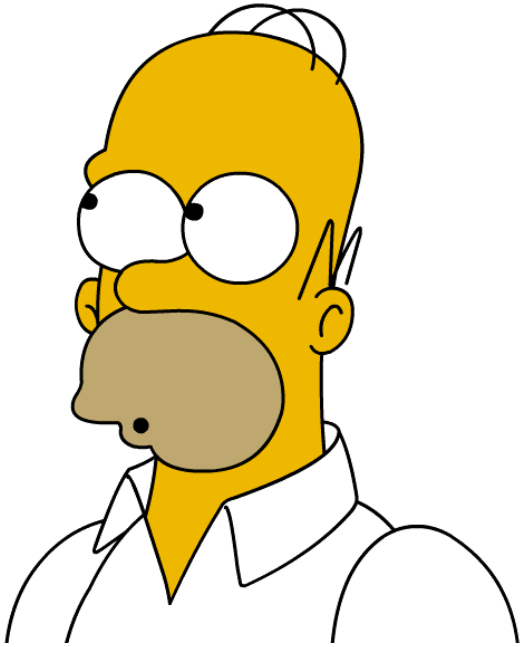
- Even in cases where the "language" is understood problems still arise.

The Problem Pareto



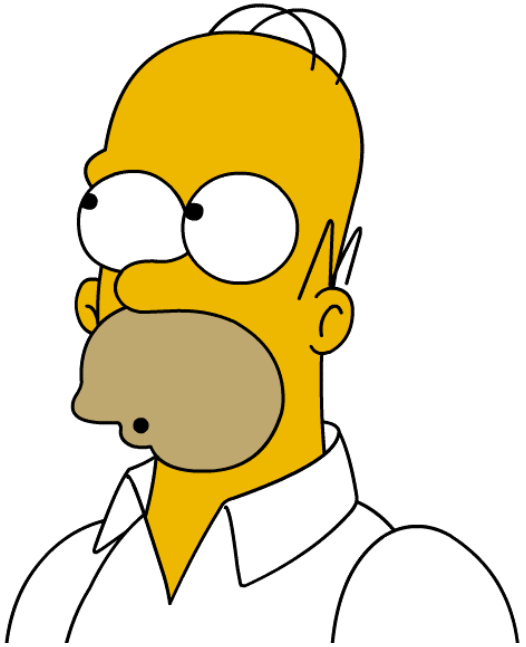
The Problem Pareto

- "Stupidity" Errors



The Problem Pareto

- "Stupidity" Errors
  - Wrong Part Program
  - Wrong Units
    - Mars Explorer
  - Typos
    - Applying calibration
    - Data transfer



The Problem Pareto

- "3rd Shift" Errors

The Problem Pareto

- "3rd Shift" Errors
  - Must have happened before I got here.
    - Broken/Bent Stylus
    - Crashed probe

The Problem Pareto

- Calibration Errors

CERTIFICATE of CALIBRATION

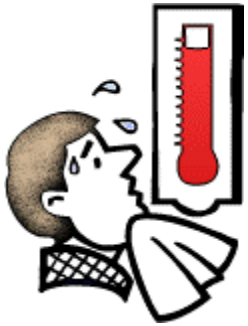
REPAIR AND CALIBRATION TRACEABLE TO NRC AND NIST

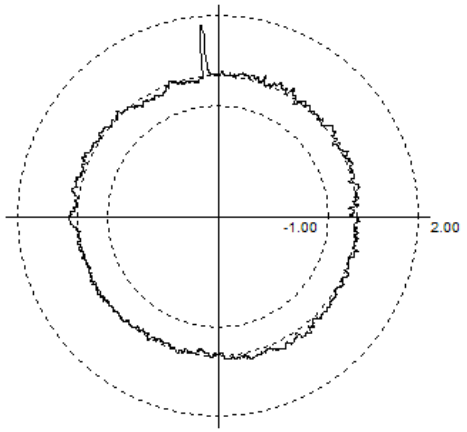
The Problem Pareto

- Calibration Errors
  - Adjustment?
  - Validation?

The Problem Pareto

- Environment





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Why Dimensional Measurements Don't Agree

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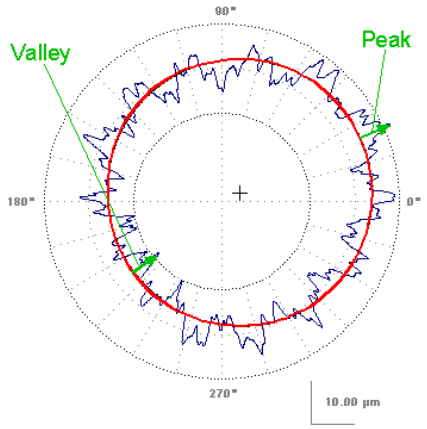
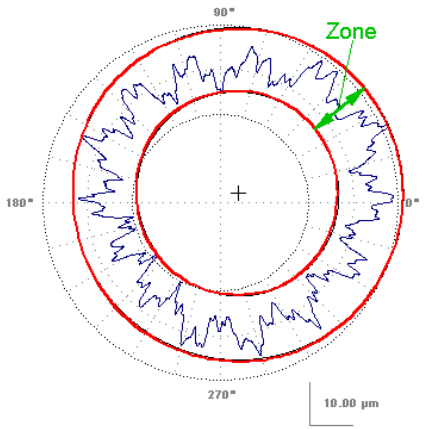
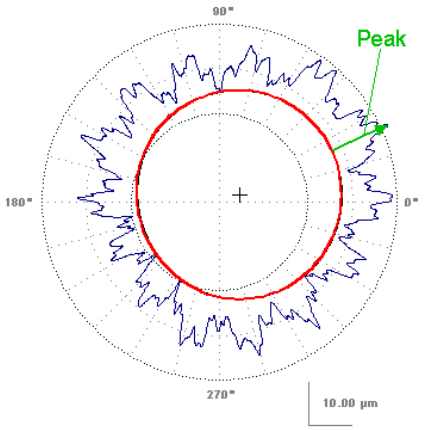
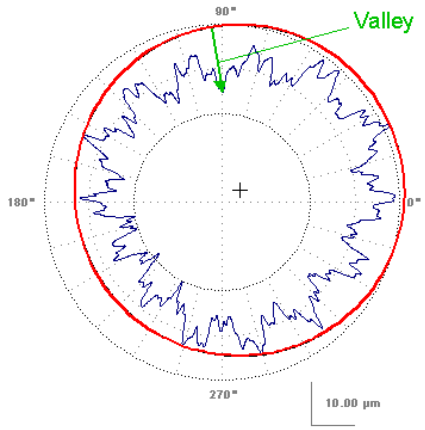
The Problem Pareto

- Definition Errors









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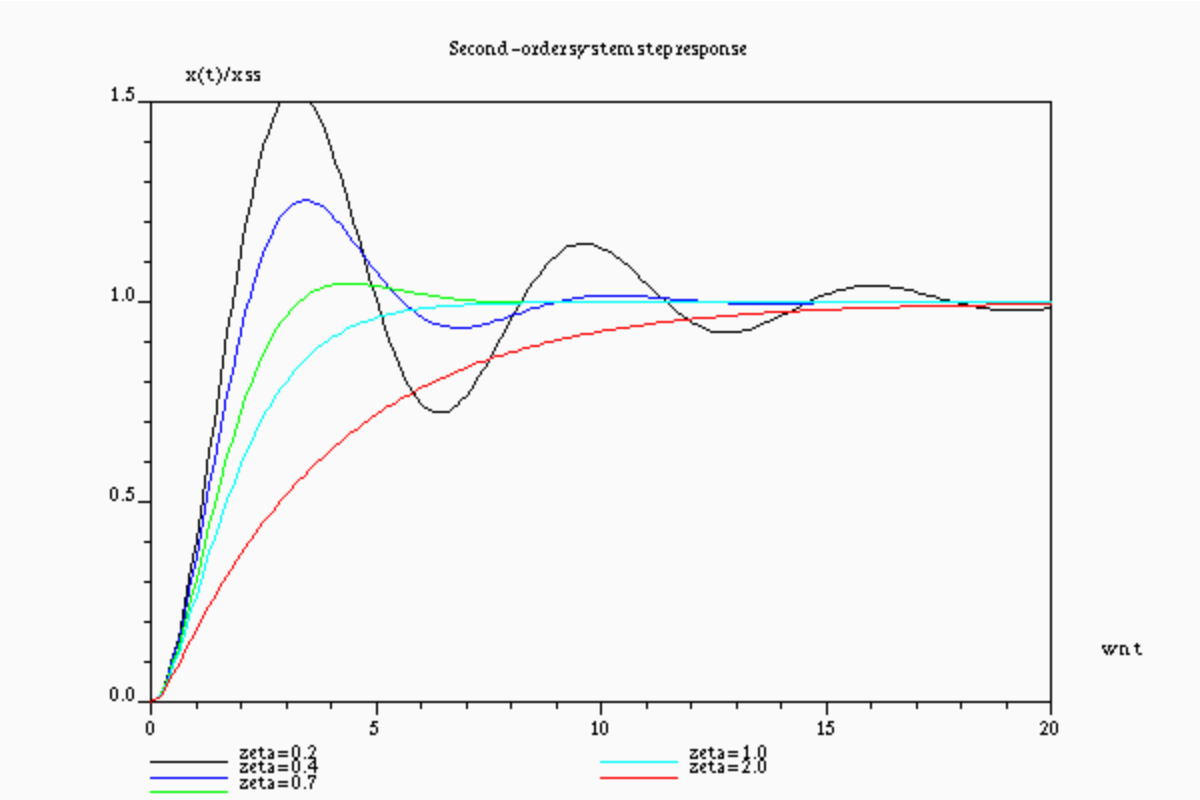
The Problem Pareto

- Dynamics



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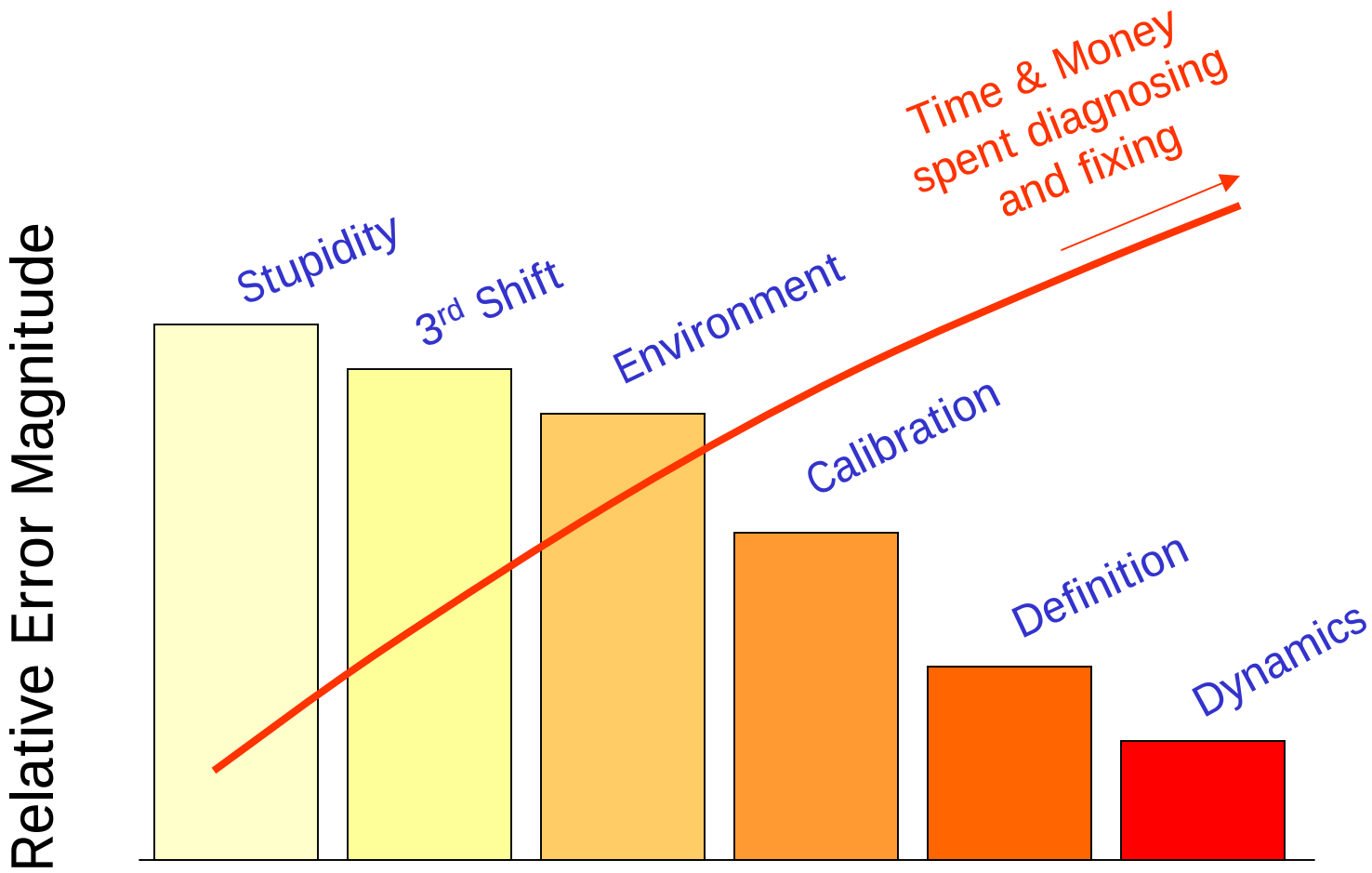
Errors cost money!

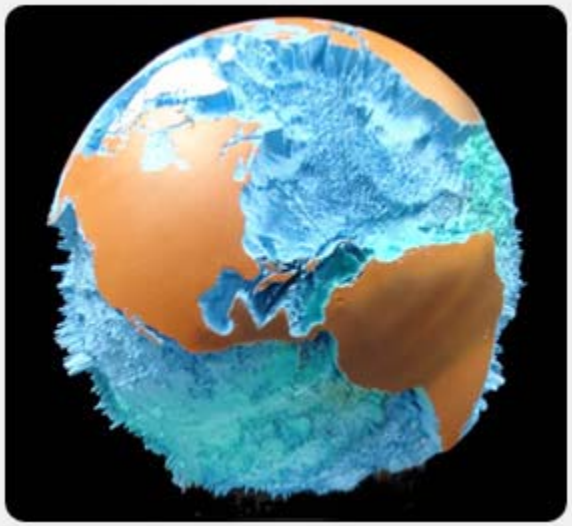


A Closer Look at "Dynamics"

Since nobody likes to talk about it.

Contrary to popular belief...

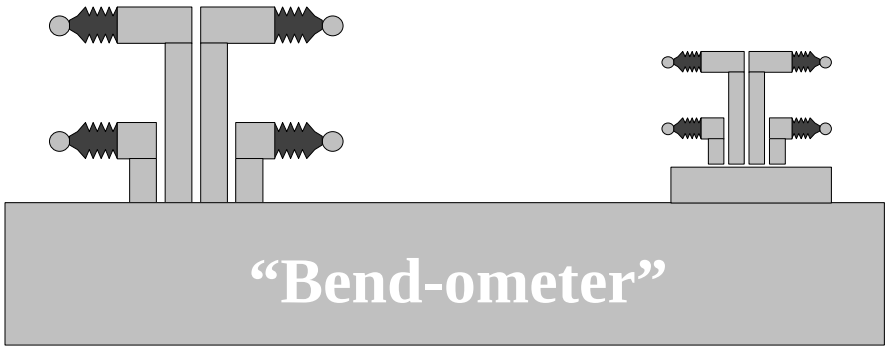
The world is not round.

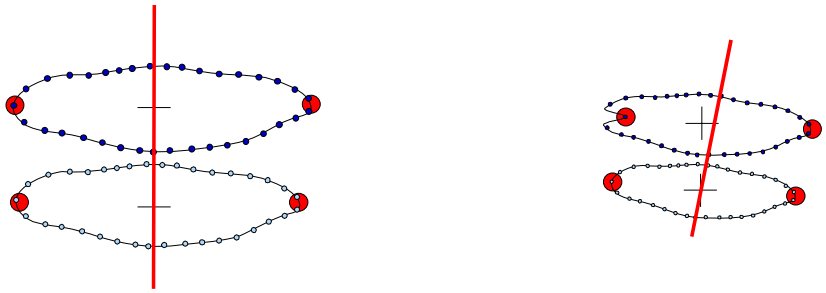


www.spectrum3d.com

An "out of round world"...

- Perfect geometry is a bad assumption when dealing with the "last 10%".



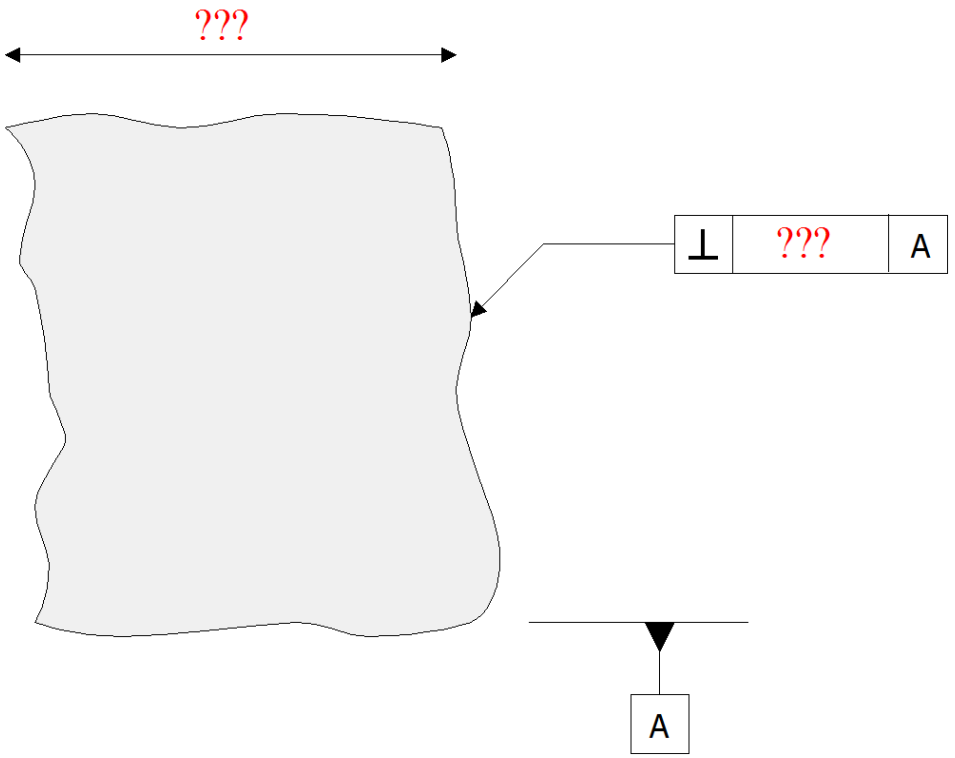


An "out of round world"...

- Dimensional measurements must accommodate imperfect geometry.
  - Specification implications
  - Instrumentation implications

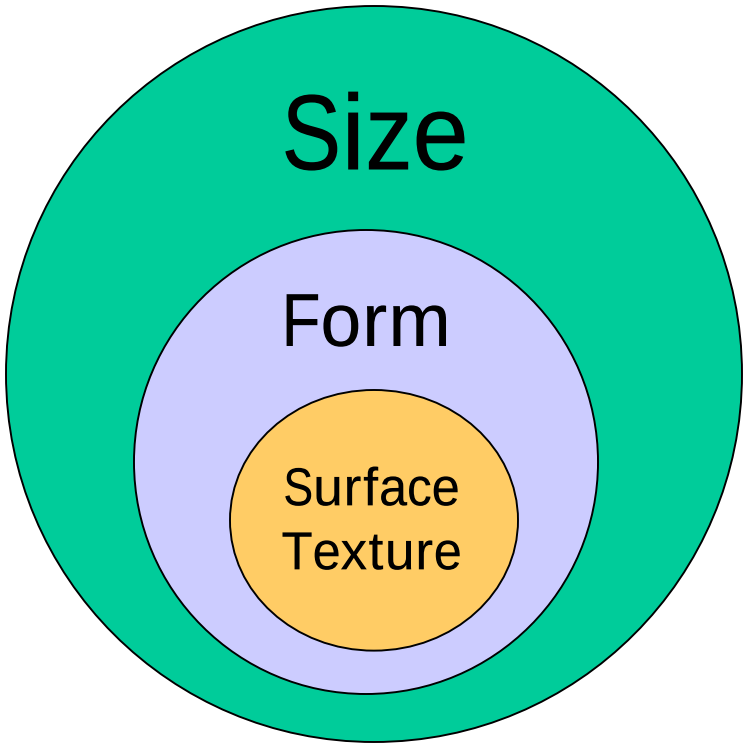
Specification

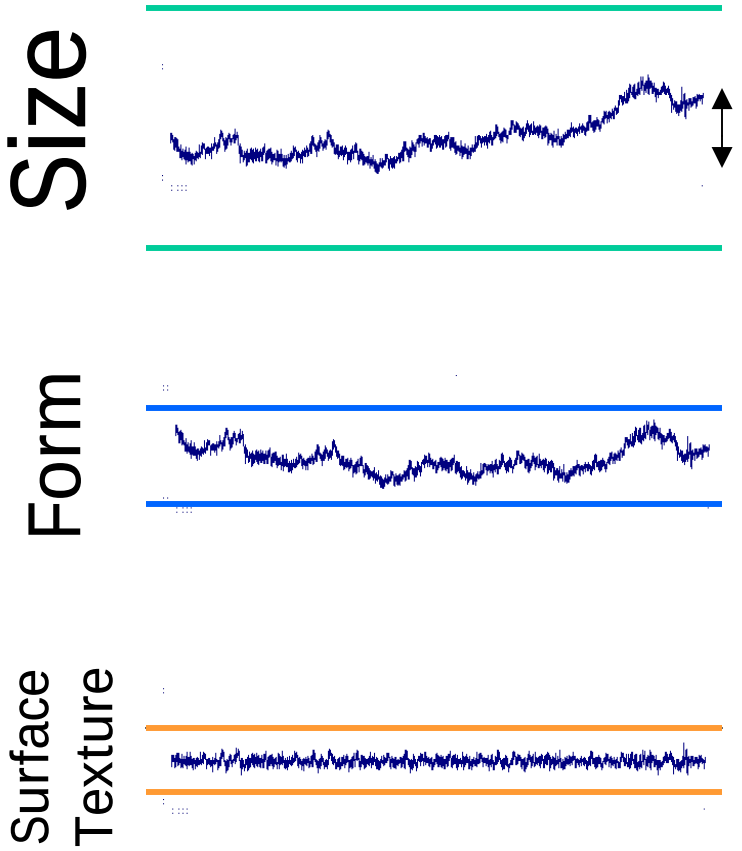
- How do you deal with bumpy surfaces?
  - Size?
  - Orientation?



Specification

- Conventional Wisdom





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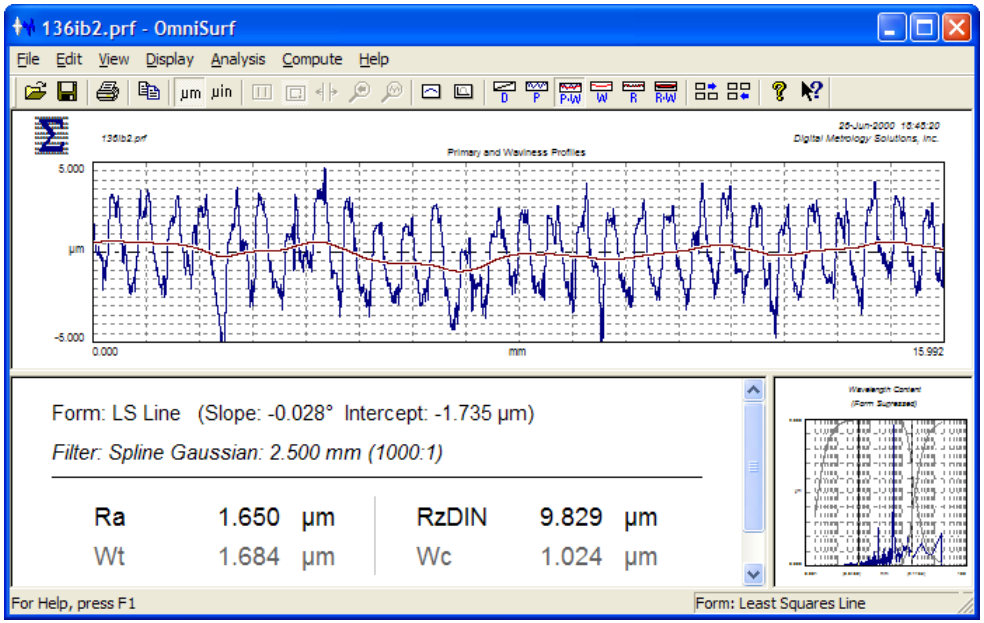
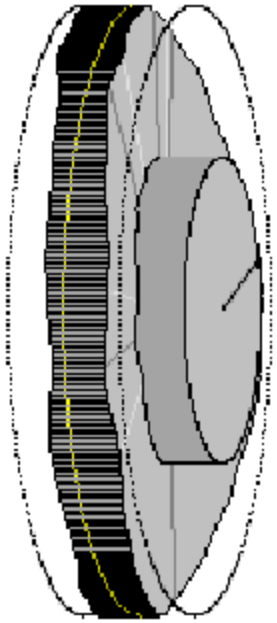
Brake Rotors

- Flatness ~2-5 µm
- Peak-to-Valley Roughness ~10-15 µm





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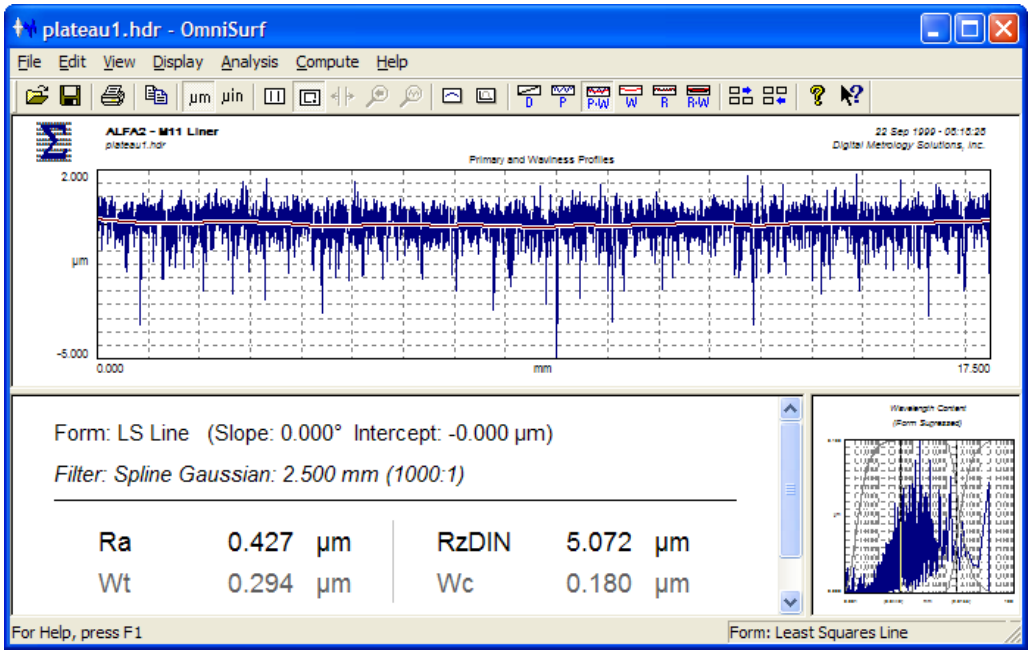
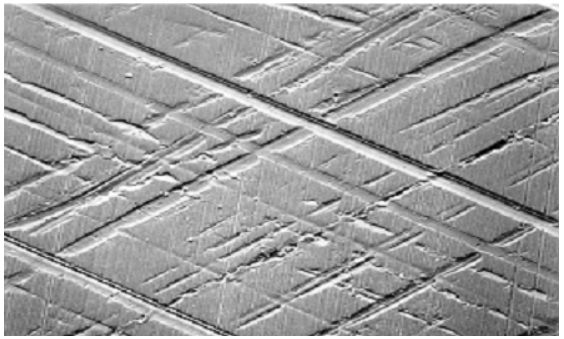
Cylinder Bores

- Line element straightness: 1-3 µm
- Peak to Valley Roughness: 4-8 µm





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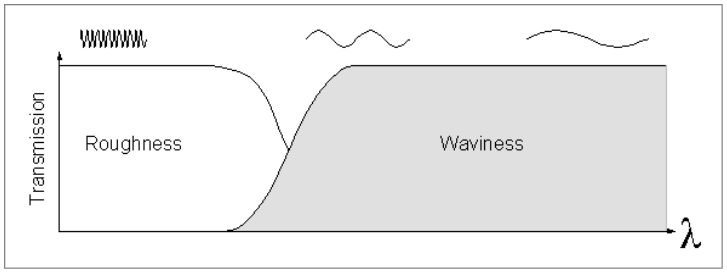
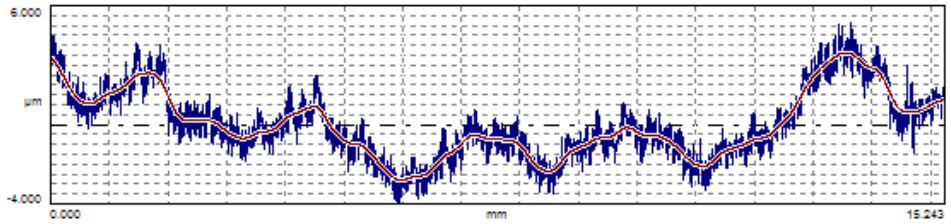
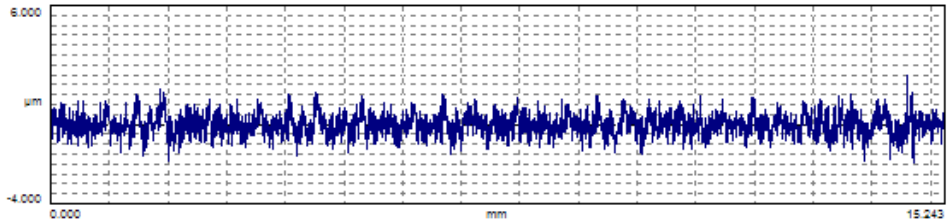
Wavelength Based Specification







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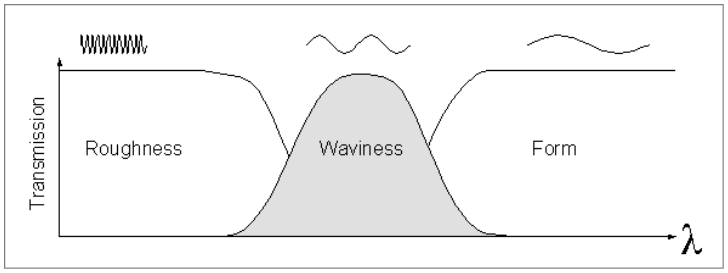
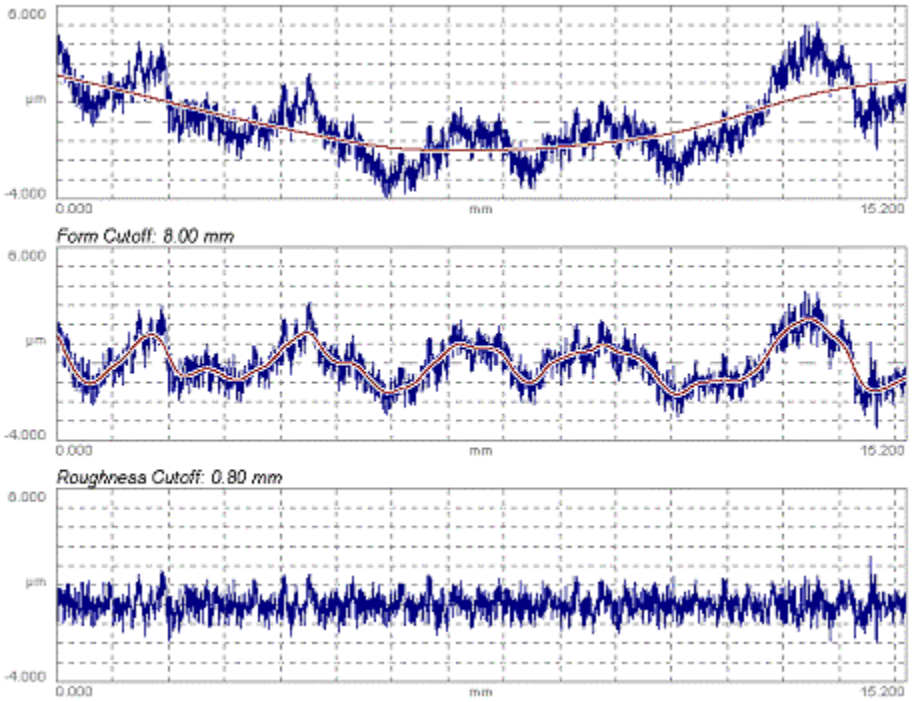
Wavelength Based Specification





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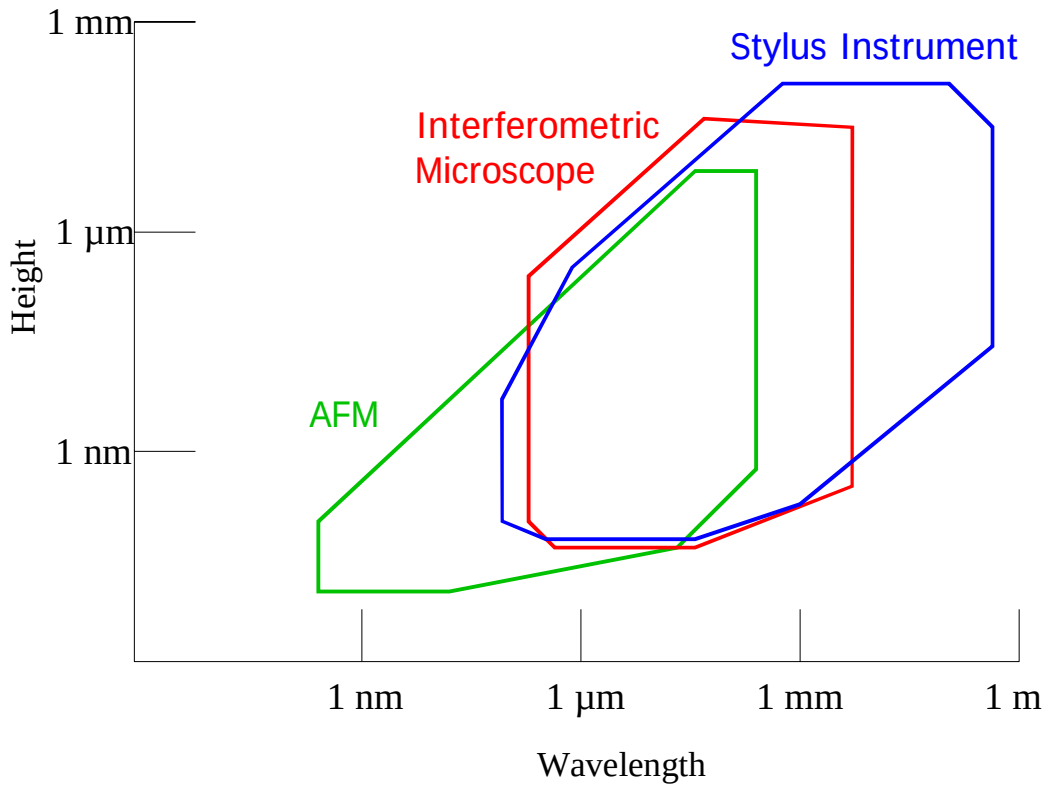
Can we see the same surface?

(between instruments)

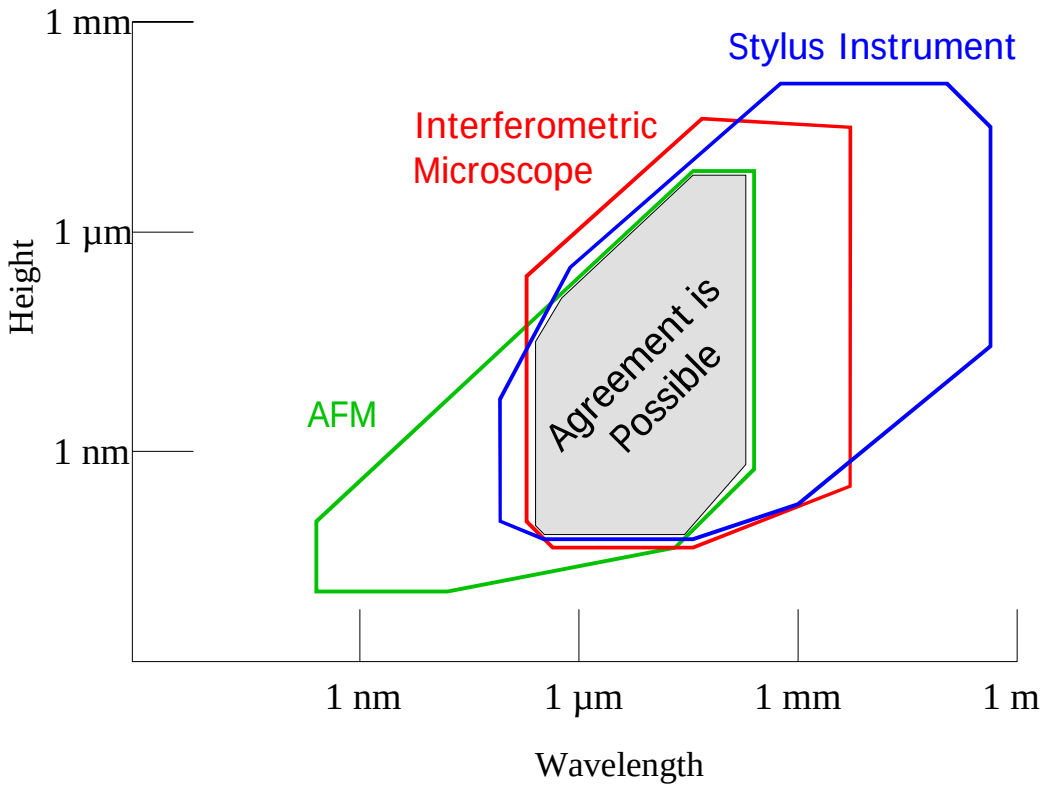
Understanding your instrument

- Surface Texture Instrument Overlaps



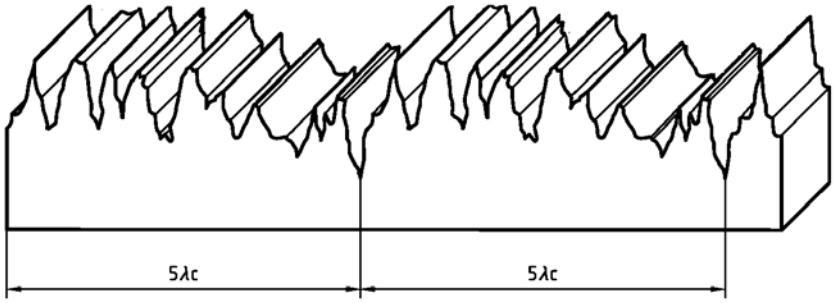
Understanding your instrument

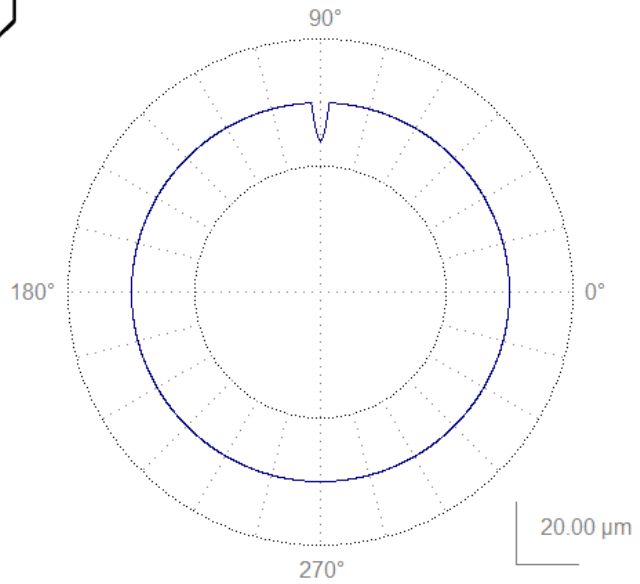
- Surface Texture Instrument Overlaps



Understanding your instrument

- "Dynamic" calibrations





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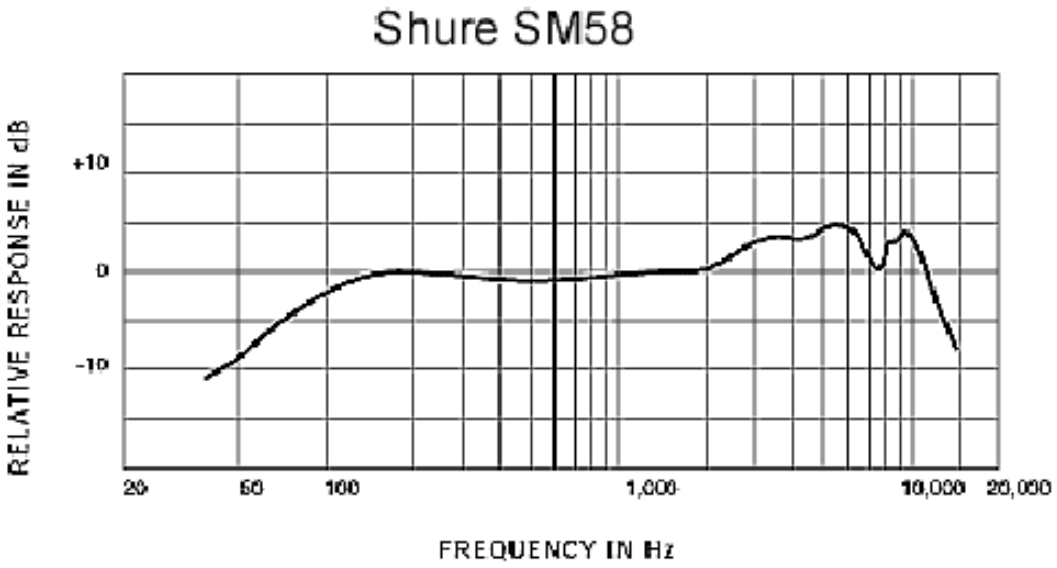
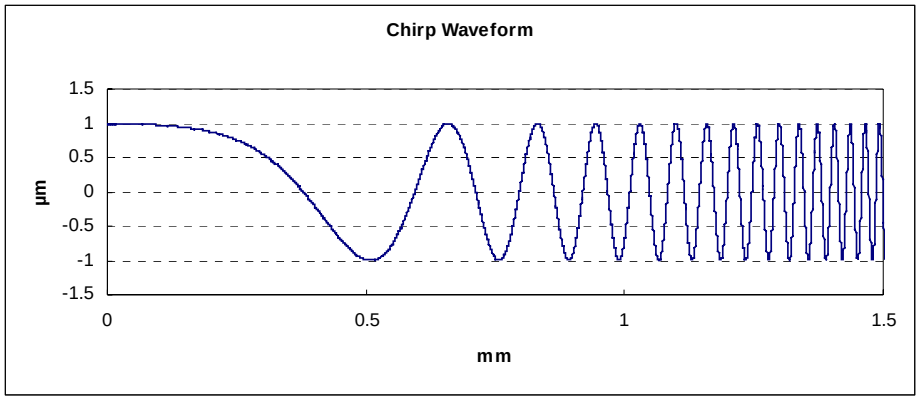
A better dynamic assessment...

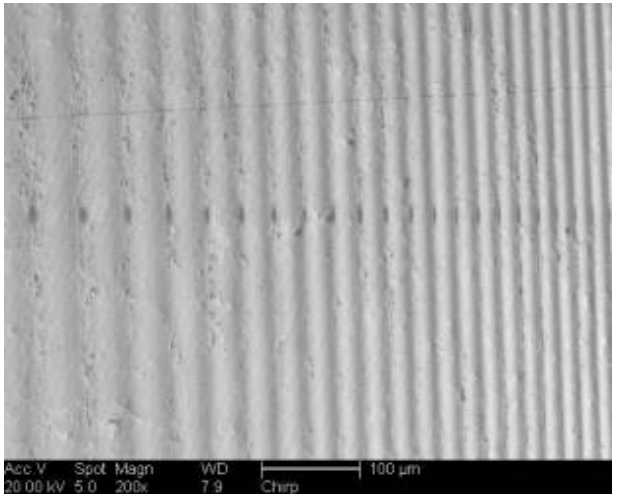
- Microphones...

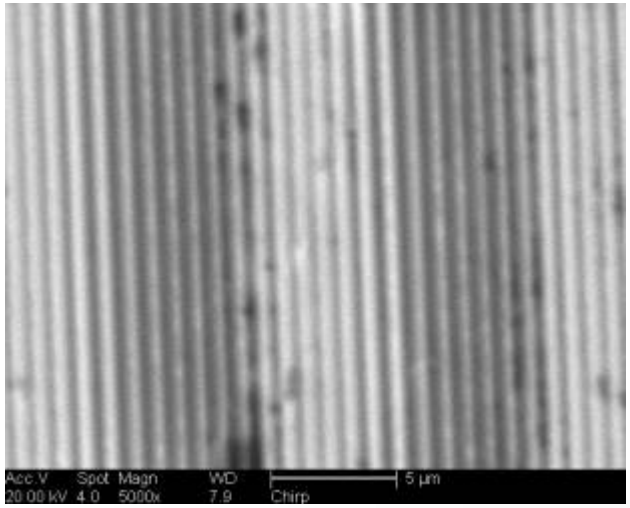


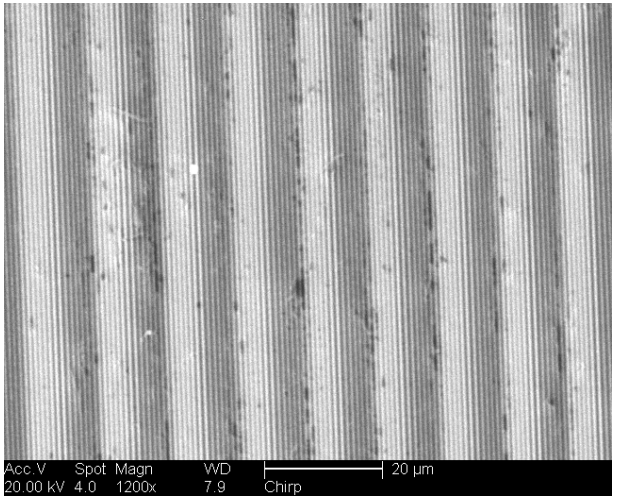
A better dynamic assessment...

- A “chirp” waveform.









Apples and Oranges:
Why Dimensional Measurements Don't Agree

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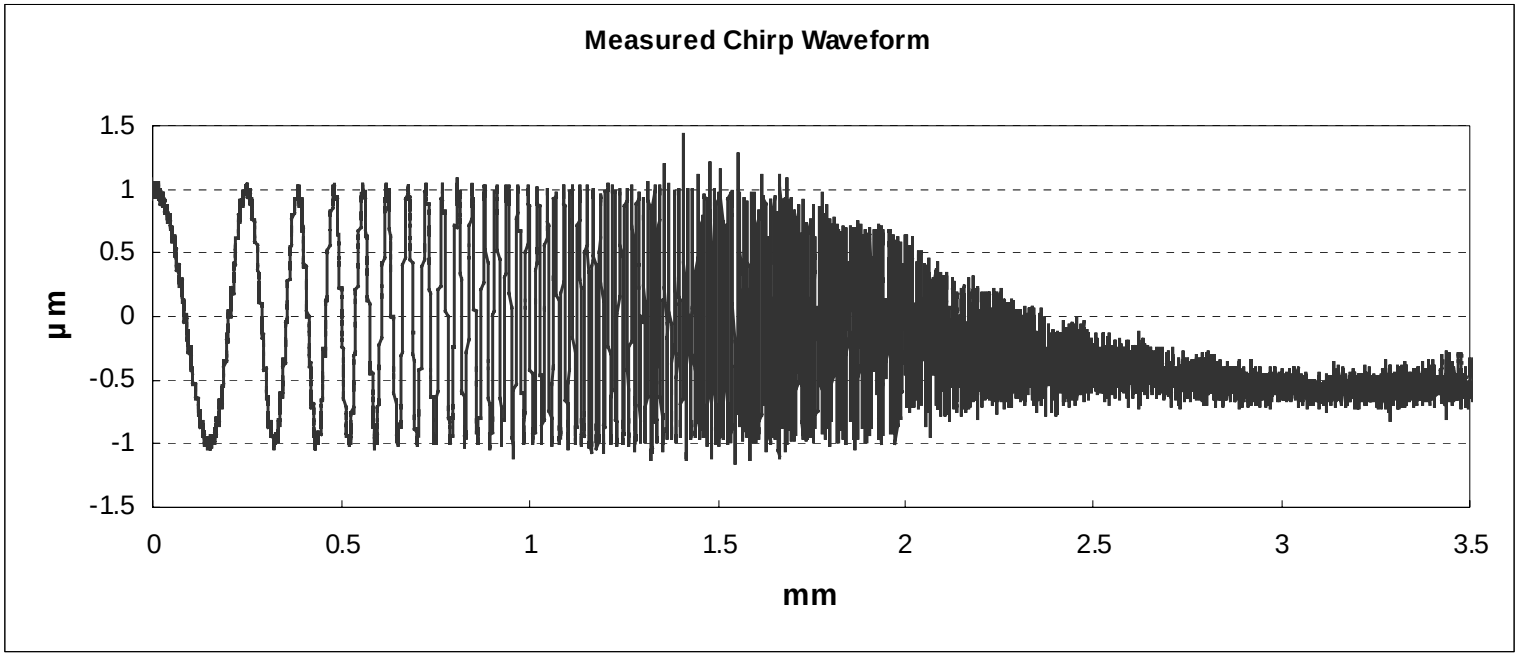
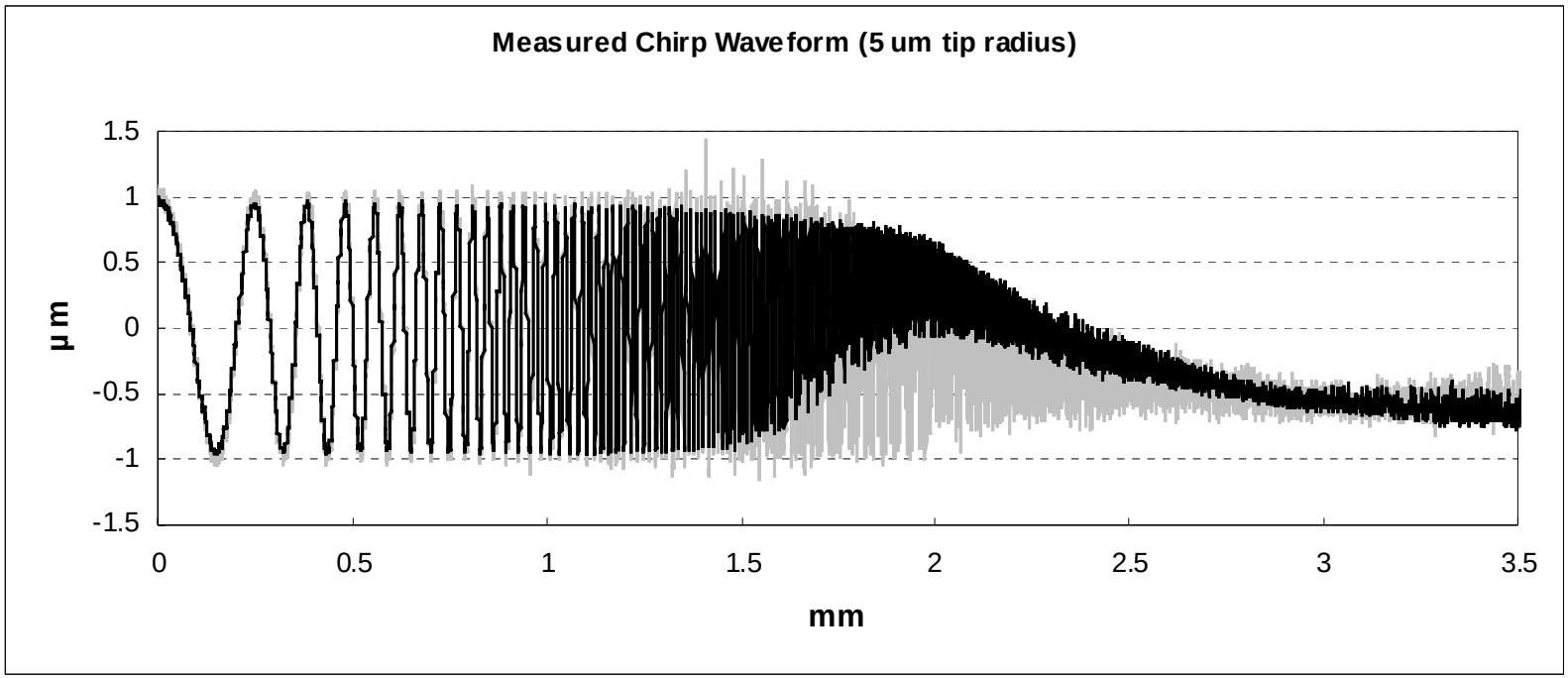
“Chirp-based” comparisons...

- The “chirp” waveform
  - Current tool geometry causes deterioration of amplitude.



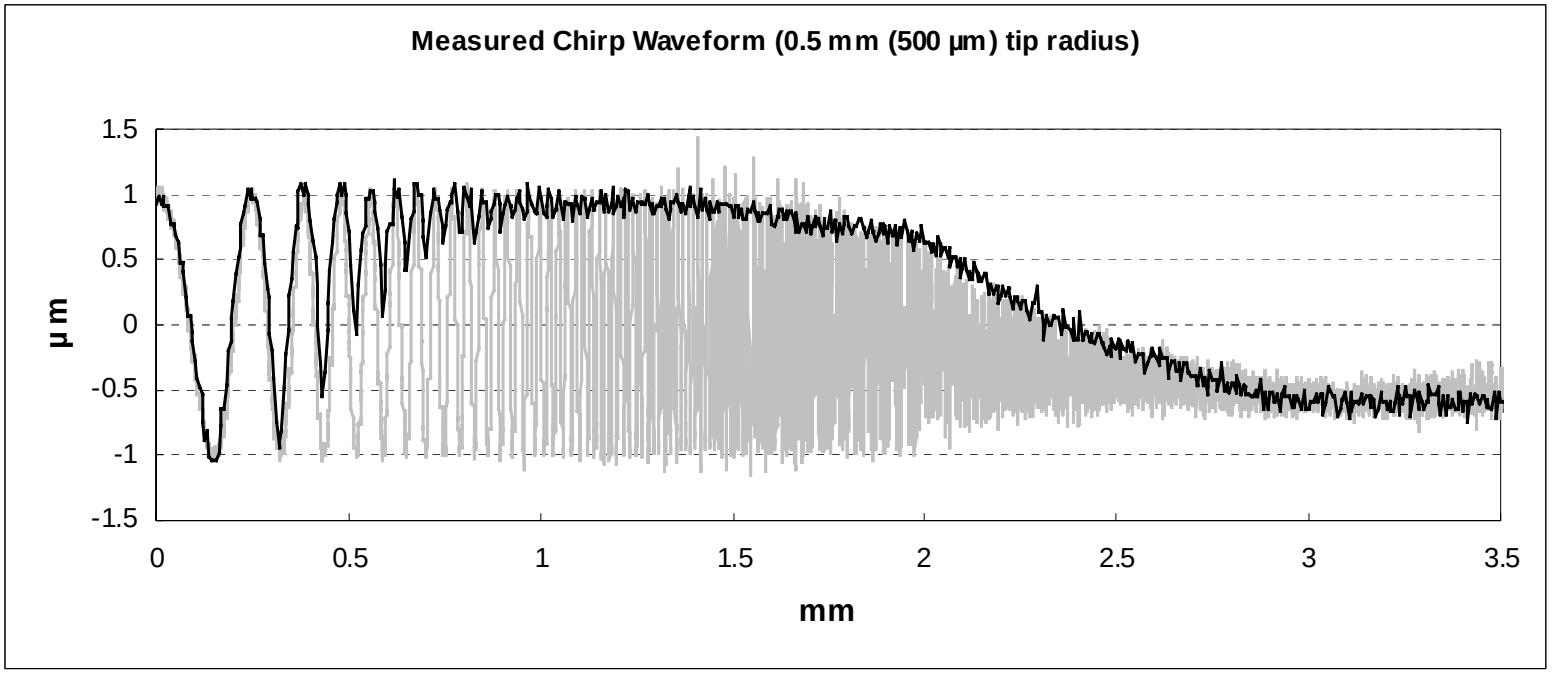
"Chirp-based" comparisons...

- Tip radius implications
  - 5 µm tip radius



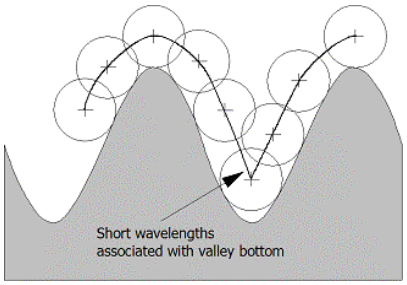
“Chirp-based” comparisons...

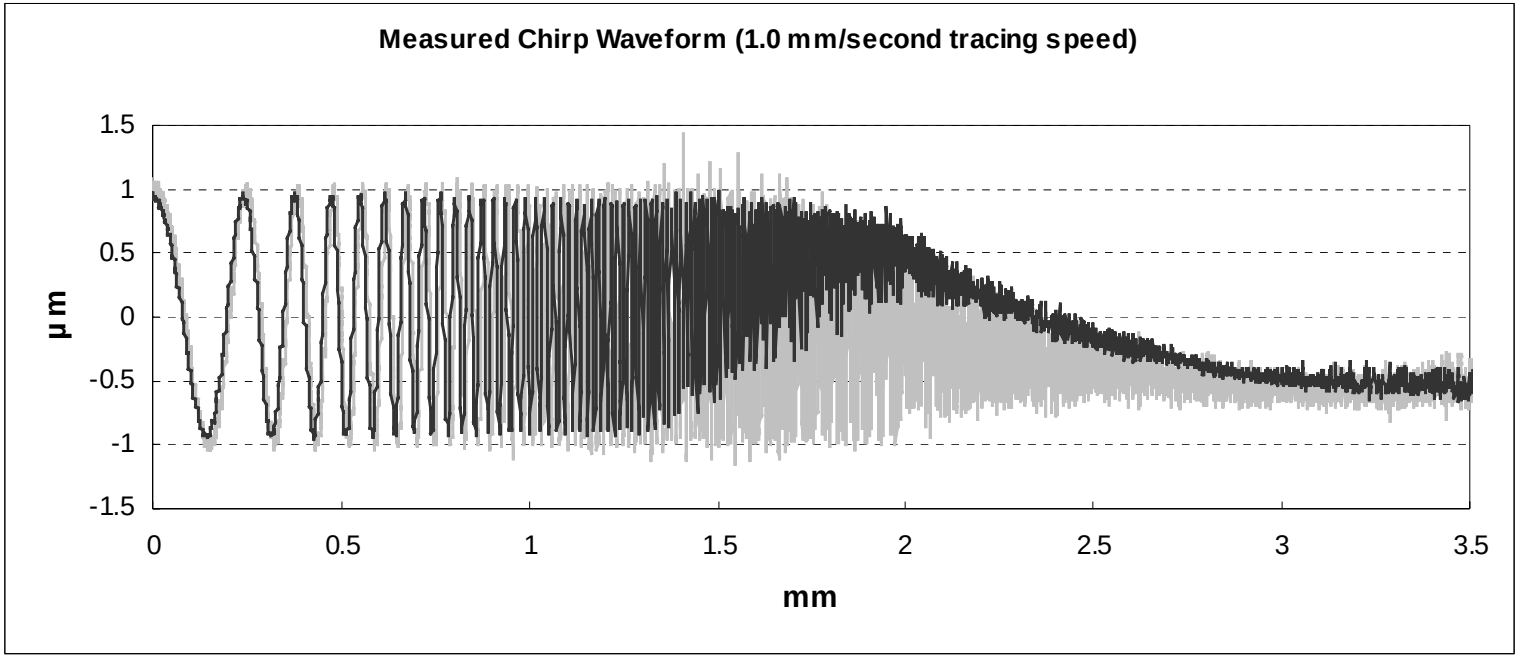
- Tip radius implications
  - 0.5 mm tip radius



“Chirp-based” comparisons...

- Tracing speed implications
  - Doubling the speed





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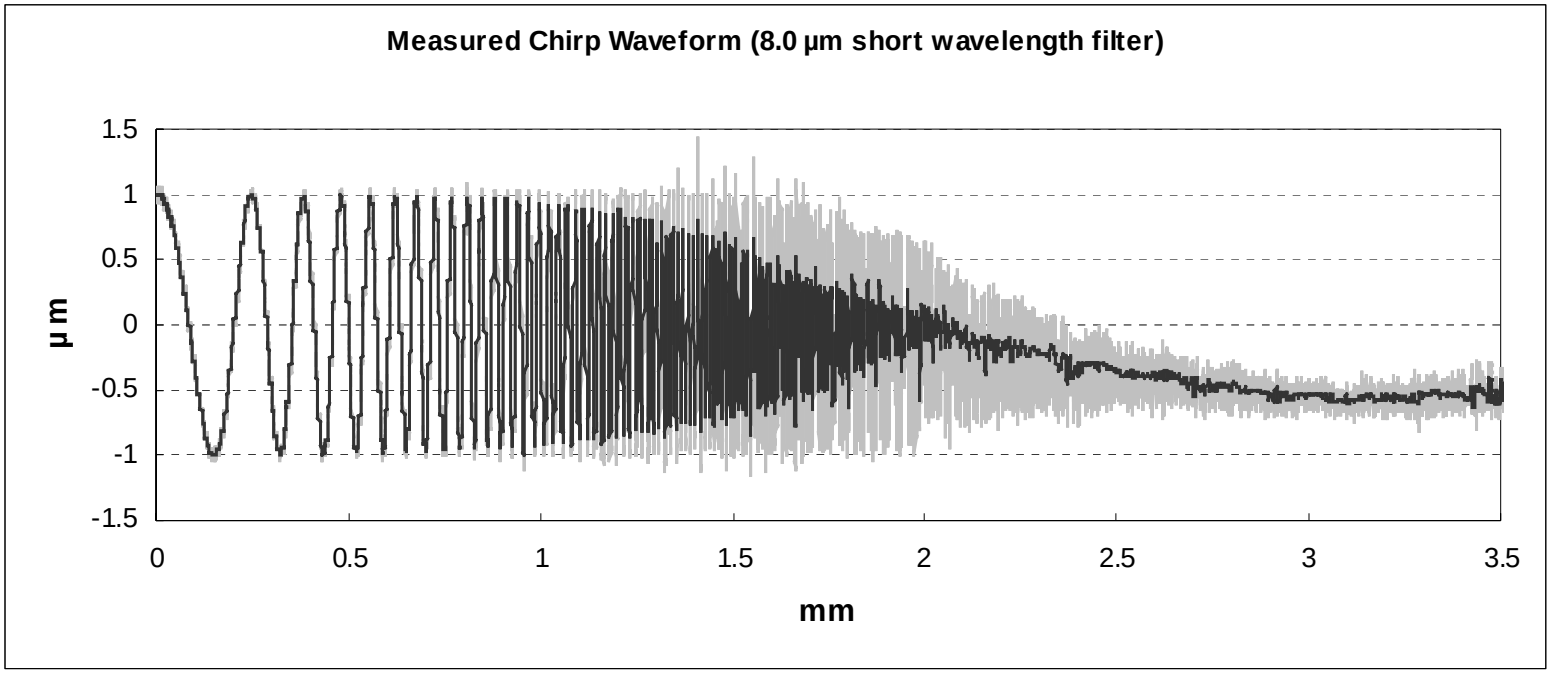
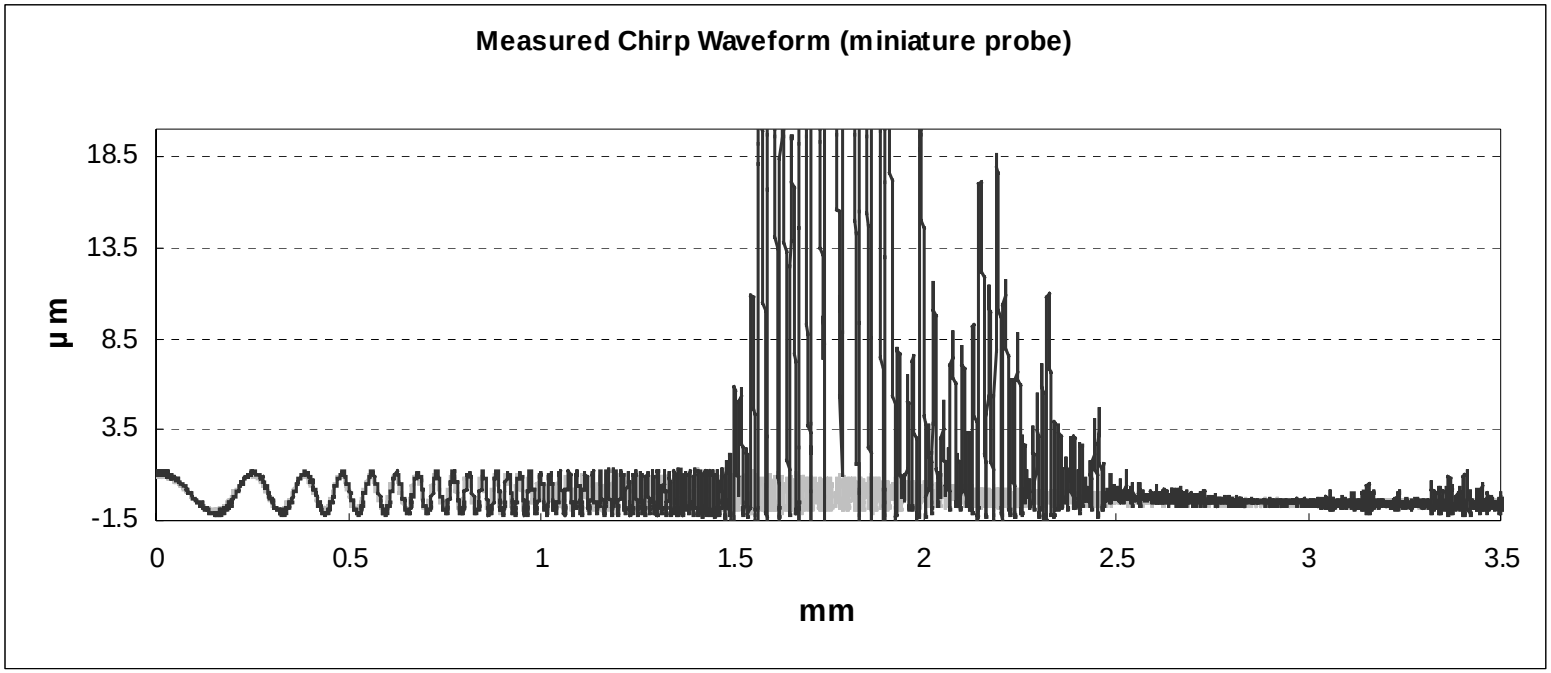
“Chirp-based” comparisons...

- Filtering implications
  - 8.0 µm long-pass filter



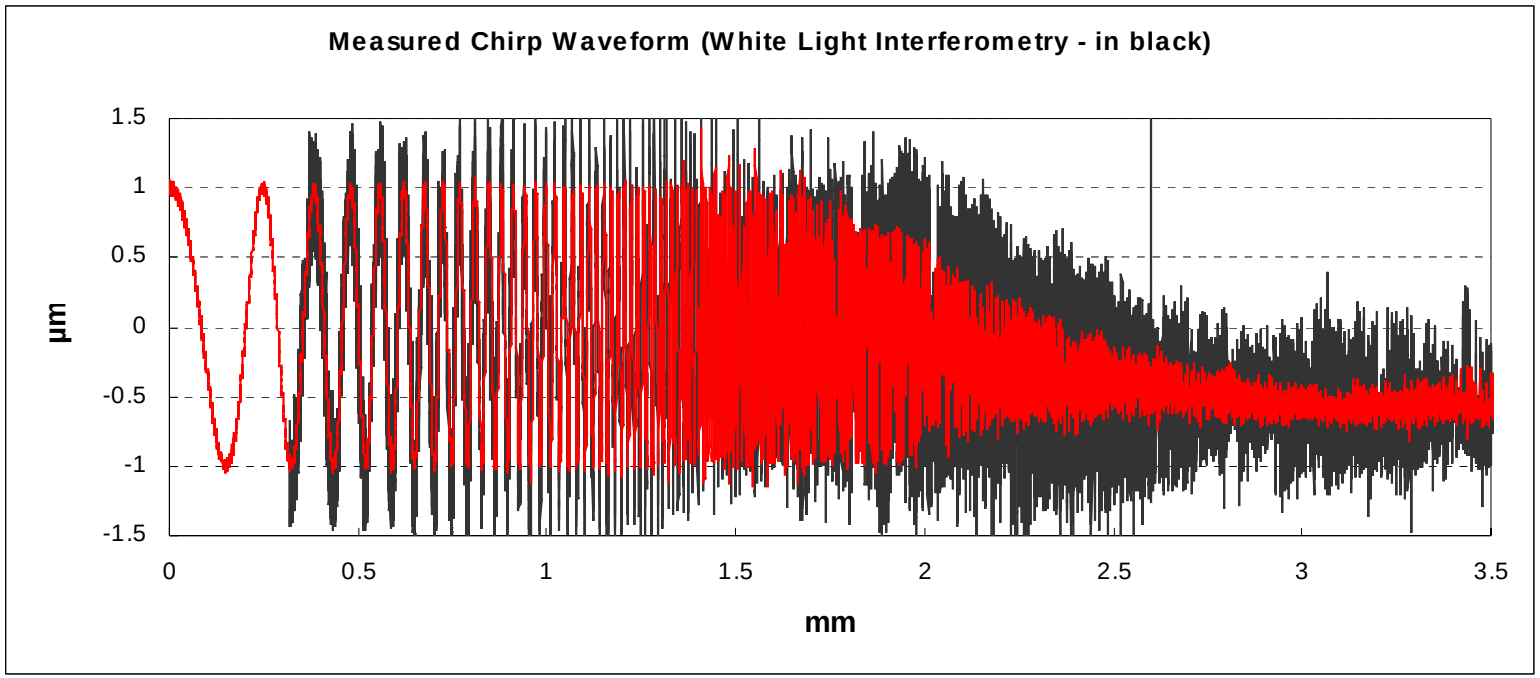
"Chirp-based" comparisons...

- Stylus arm dynamics
  - "Super small bore" stylus



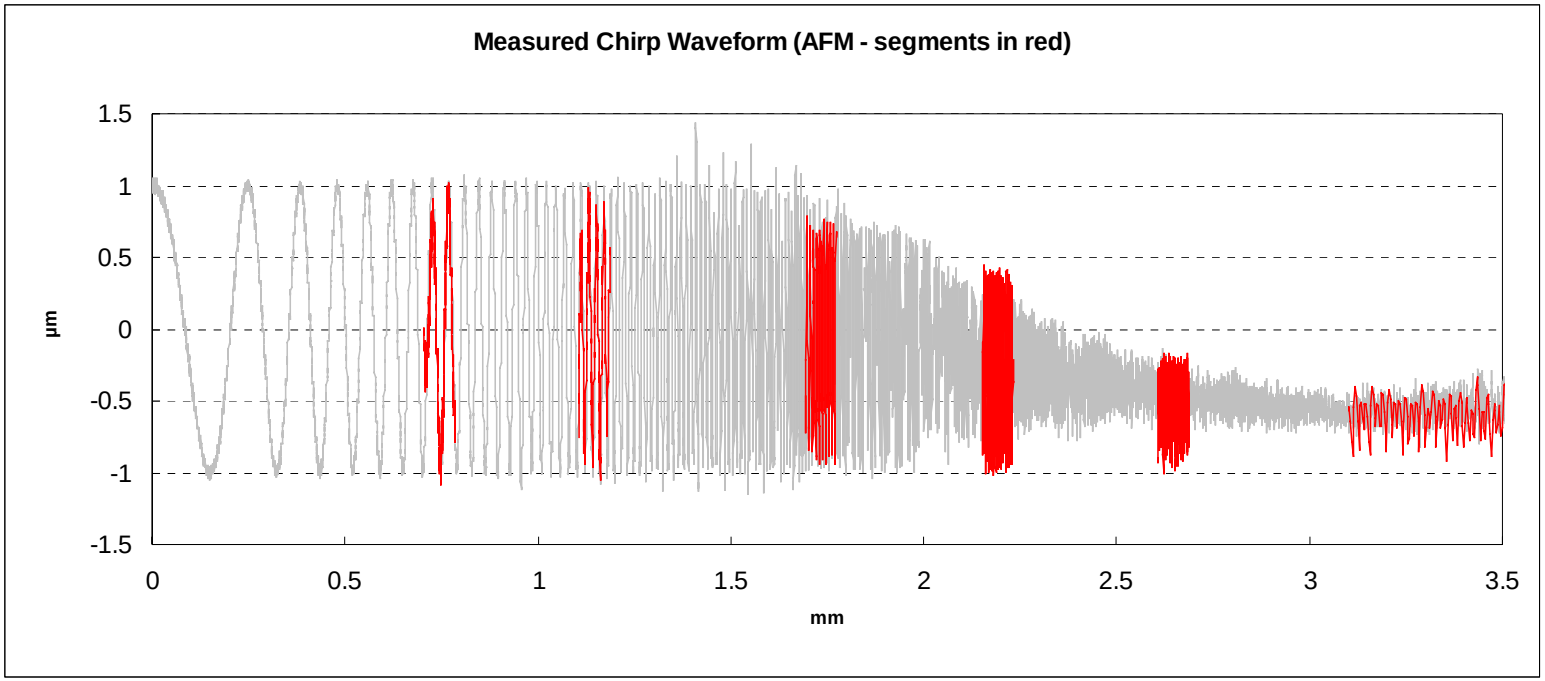
“Chirp-based” comparisons...

- Optical Methods
  - “White Light Interferometry” (shown in black)



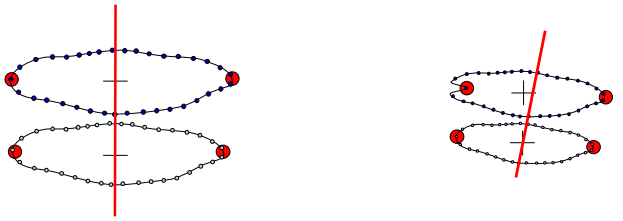
"Chirp-based" comparisons...

- AFM

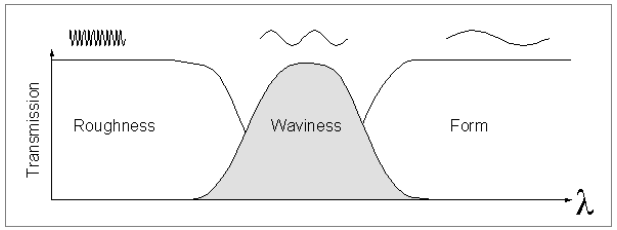


So what are we to do?

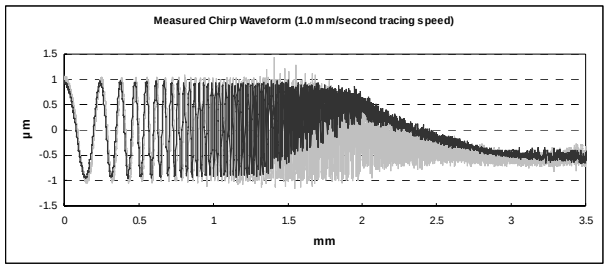
1. Realize that the world isn't round.



2. Accommodate "shape" in specifications and measurement.



3. Understand your instrument!



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Apples and Oranges: Why Dimensional Measurements Don't Agree

Apples and Oranges:

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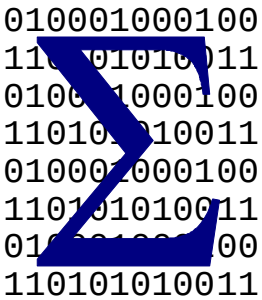

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