Apples and Oranges:

Why Dimensional Measurements Don’t Agree

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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
• Things are getting messy…

shrinking tolerances

Surface Texture   Shape   Size/Orientation

increasing scale
Instruments

• The good old days…
• Things are getting messy…

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• Things are getting messy…

— 0.010 —
• 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
The Myth of Repeatability

- A dead measurement system has perfect 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.
A couple of examples...
Example: Connecting Rod
The connecting rod “language”

Bend

Twist
Bend & Twist

- The “gauge” interpretation

“Bend-ometer”
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

- Stupidity
- 3rd Shift
- Environment
- Calibration
- Definition
- Dynamics
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
The Problem Pareto

- Calibration Errors
  - Adjustment?
  - Validation?
The Problem Pareto

• Environment
The Problem Pareto

- Definition Errors
The Problem Pareto

- Dynamics
Errors cost money!

Relative Error Magnitude

- Stupidity
- 3rd Shift
- Environment
- Calibration
- Definition
- Dynamics

Time & Money spent diagnosing and fixing
A Closer Look at “Dynamics”

Since nobody likes to talk about it.
Contrary to popular belief…

The world is not round.
An “out of round world”…

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

“Bend-ometer”
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?
Specifying

• Conventional Wisdom
Brake Rotors

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

- Line element straightness: 1-3 µm
- Peak to Valley Roughness: 4-8 µm
Wavelength Based Specification
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
A better dynamic assessment…

- Microphones…

![Graph of Shure SM58 microphone frequency response](image)
A better dynamic assessment...

- A “chirp” waveform.
“Chirp-based” comparisons...

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

- Tip radius implications
  - 5 µm tip radius

![Measured Chirp Waveform (5 µm tip radius)](image-url)
“Chirp-based” comparisons...

- Tip radius implications
  - 0.5 mm tip radius
“Chirp-based” comparisons...

- Tracing speed implications
  - Doubling the speed

Measured Chirp Waveform (1.0 mm/second tracing speed)
“Chirp-based” comparisons...

- Filtering implications
  - 8.0 µm long-pass filter
“Chirp-based” comparisons...

- **Stylus arm dynamics**
  - “Super small bore” stylus

![Measured Chirp Waveform (miniature probe)](image)
“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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