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Dimensional Metrology for Functional Control

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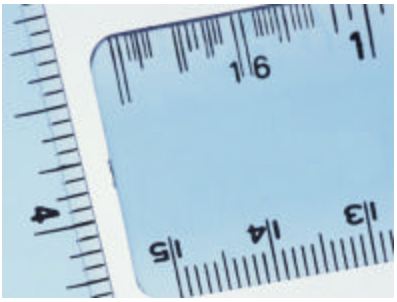
Most normal people...

... don't want to make measurements.



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Measure Twice, Cut Once...

BOB VILA'S HOME AGAIN

THE NEW YANKEE WORKSHOP

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Even though you measure twice...

What matters is the "cut"

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It's not the measurement...

It's what you do with it.

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A history of metrology for functional control...

NOTE: Any resemblance to actual metrologists is purely coincidental.

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Where have we been?

- Metrology in the production setting has undergone some generational changes.

We are currently entering the 4th generation.

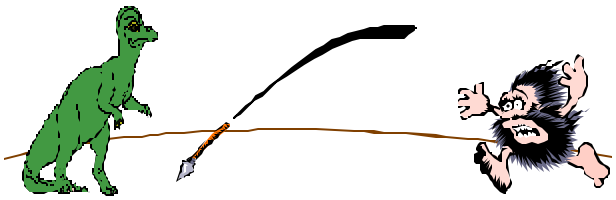
1st Generation

- The dawn of "trying and tweaking"

The generation of the craftsman.

1st Generation

1. Make it.
2. Try using it.
   - If it works, keep it.
   - If it doesn't work, go back to step #1.



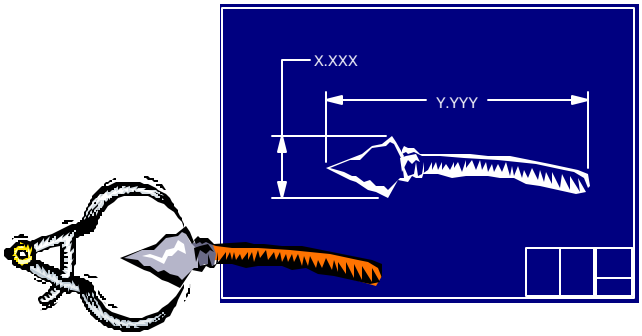
2nd Generation

- The implementation of "simple gaging"

The generation of the gage block.

2nd Generation

- Produce the part based on simple dimensions and measurements



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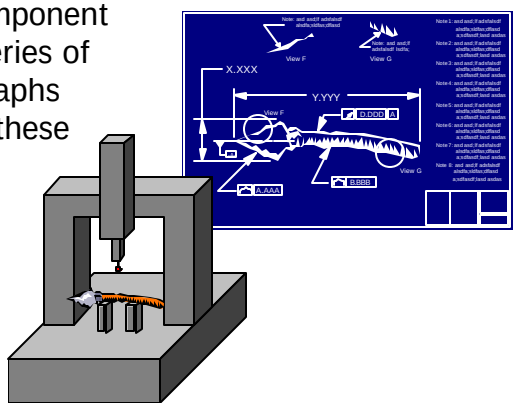
3rd Generation

- The advent of "analysis"

The generation of GD&T.

3rd Generation

- Produce the part based on complex dimensional requirements
  - Measure the component and provide a series of numbers and graphs associated with these requirements.



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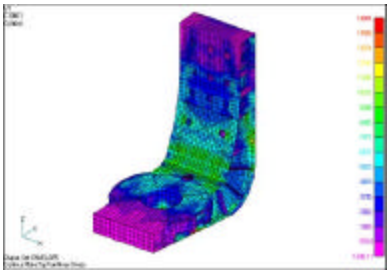
4th Generation

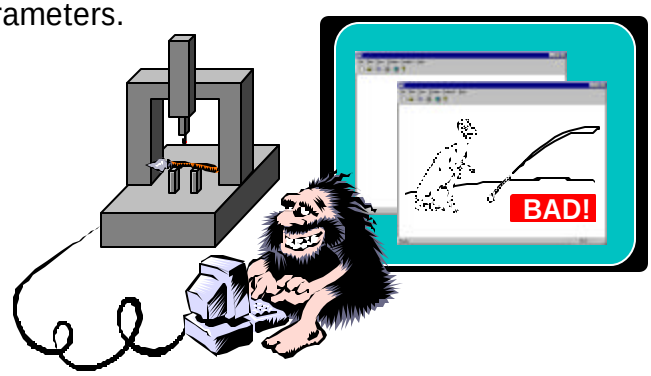
- The pursuit of "function"

The generation of simulation.



4th Generation

- Product specifications based directly on performance parameters.
  - Instead of indirectly related dimensional parameters.



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Today...

Dimensional metrology is suffering from an identity crisis.

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If we are to be in the business of functional control, we need to learn the

Language of Functional Control

Mechanical Functions

- Fit
- Sealing
- Sliding
- Load Carrying
- Noise Control
- Adhesion
- Motion Transfer
- etc.

4th Generation

- The Specification of:
  - Leakage
    - instead of flatness & waviness
  - Contact pressure/area
    - instead of geometry & form & size
  - Loading
    - instead of orientation & shape
  - Stress concentration
    - instead of radius
  - Optical Properties or Lubrication Performance
    - Instead of roughness

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OK, before you beat me up...

- Not all components and features requires "later generation" production control.
- The degree of criticality can dictate the generational type of production control.

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How do we simulate function?

- Analysis tools must be developed to address specific functionalities.
  - Many of these analytical tools are available or are being developed.
    - Fitting
    - Filtering/Extraction
    - Modeling

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Simulation-based Analysis

- A model of the functionality is applied to the measured data points.

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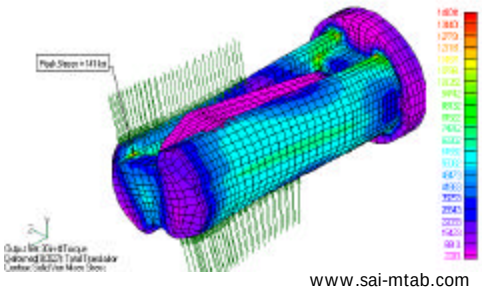
Simulation-based Analysis

- Functionality can be simulated directly via approaches such as:
  - Finite Element Analysis
  - Stress Analysis
  - Computational Fluid Dynamics



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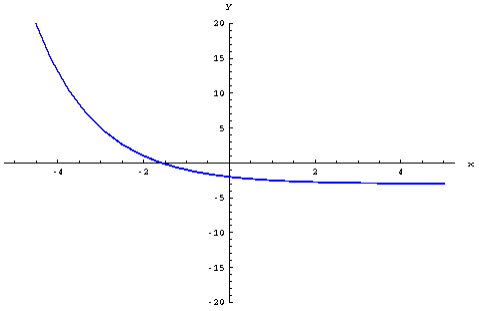
Simulation-based Analysis

- These kinds of analyses often require either algorithmic or "optimization" based analyses in order to arrive at a result.



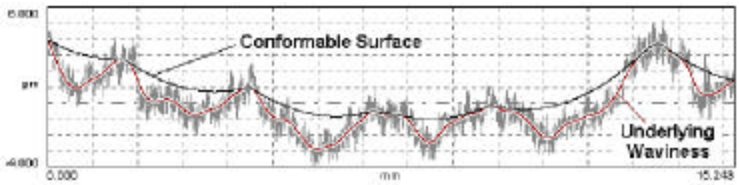
Putting it all together…

- Functional simulation based on measured data requires:
  1. Developing of a **model** of functionality.
     - *Determining a "parameter of functionality"*
  2. Collecting **data** on the relevant surfaces.
  3. Performing **preprocessing** on the data.
     - *Fitting, filtering, etc.*
  4. Performing the necessary **analysis**.
     - *Deriving the numerical value of the parameter.*

Case Studies

Gasket Leakage

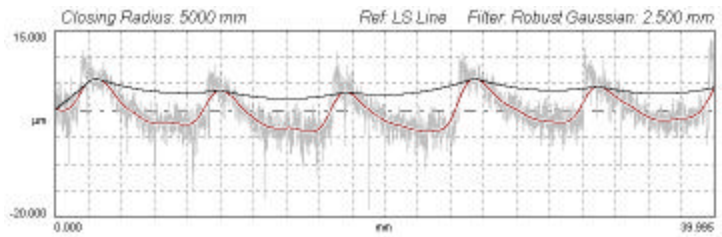
- Conformable component (gasket) tries to mold to a rigid surface. Leakage must be controlled.

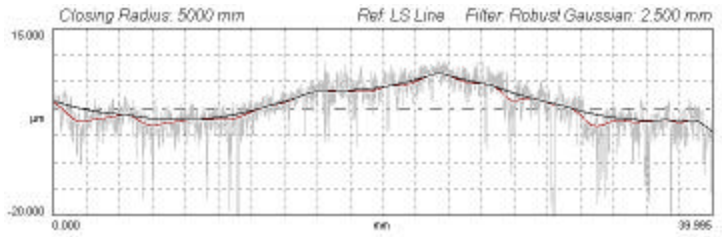


Gasket Leakage

- Model:
  - A virtual gasket.
- Data
  - Profile data points.
- Pre-processing
  - Leveling (LS Line)
- Analysis
  - A robust filter generates the waviness profile
  - A morphological (ball) closing filter is applied
  - The void areas are integrated.

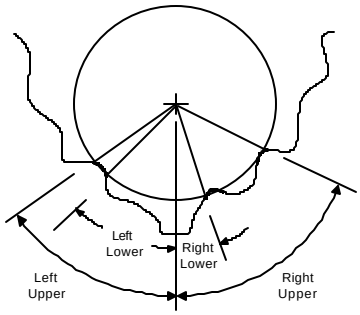
Gasket Leakage





Socket Geometry

- A spherical ball is located in a gothic arch socket. The contact locations must be controlled.



Socket Geometry

- Model:
  - A virtual gage ball.
- Data
  - Profile data points.
- Pre-processing
  - Corner detection (2nd deriv.); Leveling (LS Line)
- Analysis
  - A Gaussian filter generates the waviness profile.
  - A circle is applied to the waviness profile.
  - The contact areas are determined.

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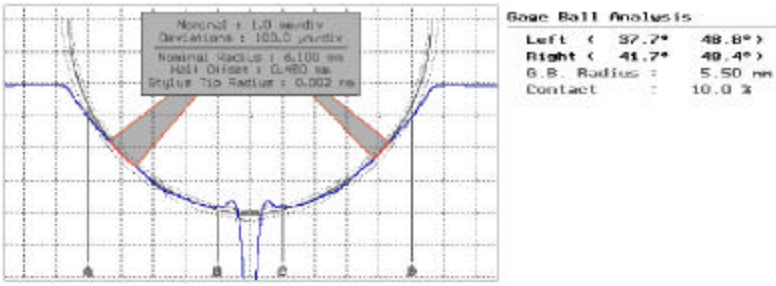
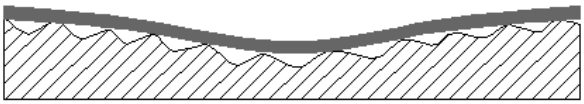
Socket Geometry



Crank Bearing Loading

- A semi-rigid bearing is in contact with a crank pin.
  - Localized waviness generates highly stressed areas.



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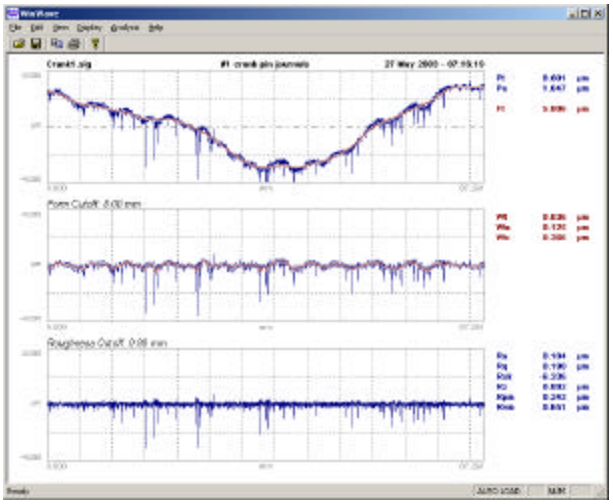
Crank Bearing Loading

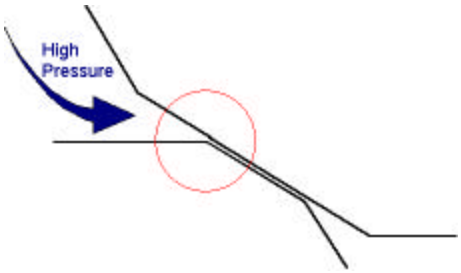
- Model:
  - Bandpass waviness.
- Data
  - Profile data points.
- Pre-processing
  - Leveling (LS Line)
- Analysis
  - A Gaussian filter generates the form profile.
  - A Gaussian filter generates the waviness profile.
  - Peak to valley form and waviness are controlled.

Crank Bearing Loading



Corner Blending/Sealing

- A certain corner is critical to sealing. Too much blending can lead to leakage.



Corner Blending/Sealing

- Model:
  - Maximum corner blend zone.
- Data
  - Profile data points.
- Pre-processing
  - Corner detection via 2nd derivates
  - Leveling of upper region
- Analysis
  - The linear *seat region* is detected via 2nd derivs.
  - The departure from ideal is reported as a percentage of the available zone.

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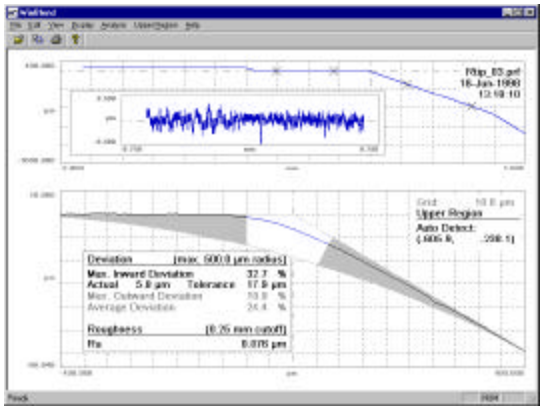
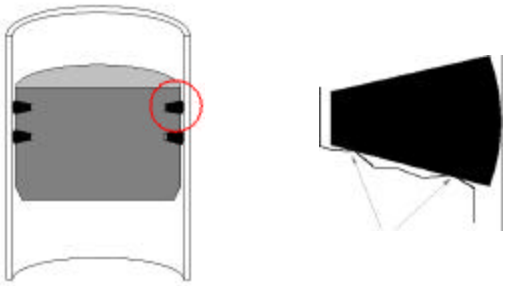
Corner Blending/Sealing



Effective Ring Groove Angle

- The functional ring groove is based on the seating of the piston ring on the peaks of the groove.



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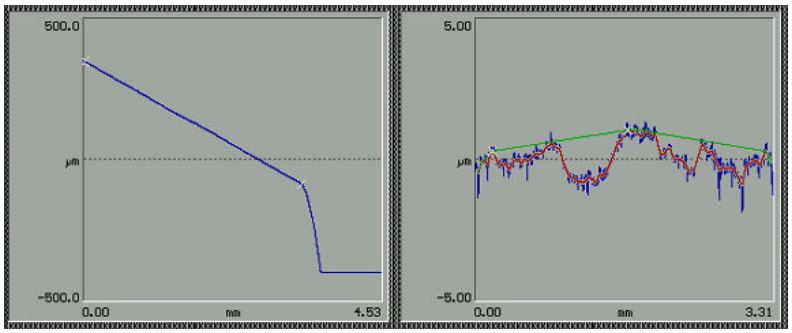
Effective Ring Groove Angle

- Model:
  - Largest area between contacting peaks.
- Data
  - Profile data points.
- Pre-processing
  - Corner detection via 2nd derivates
  - Filtering with Gaussian filter.
- Analysis
  - A convex hull is applied to the waviness profile.
  - The largest facet of the hull is used to calculate the functional angle.

Effective Ring Groove Angle



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Contact Length

- A certain surface has chamfered edges. A minimal contact length must be ensured for loading considerations.

Contact Length

- Model:
  - Determine the central (linear) region of a surface.
- Data
  - Profile data points.
- Pre-processing
  - Corner detection via 2nd derivates
  - Leveling of central region
- Analysis
  - The central, linear region is detected via a combination of 2nd derivatives and a convex hull.

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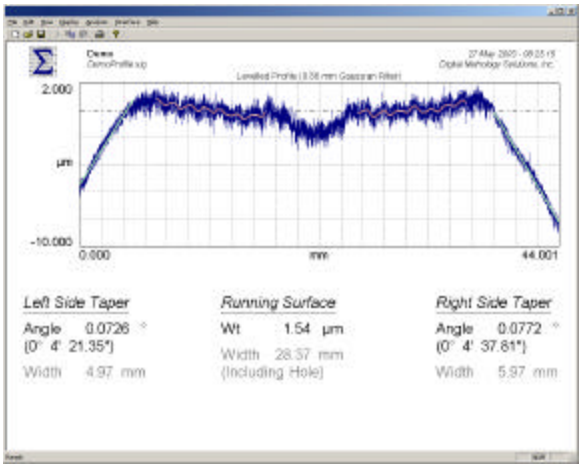
Contact Length



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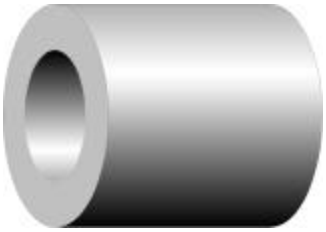
Roller Stress

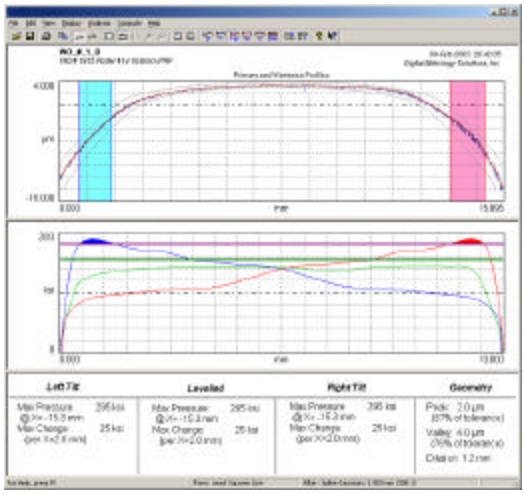
- Crowned rollers are common used in highly stressed interfaces. The crown geometry must be controlled in order to reduce stress concentrations.



Roller Stress

- Model:
  - Two crowned geometries (cam & roller) in contact at various alignments and loads.
- Data
  - Profile data points.
- Pre-processing
  - Leveling via LS fit of central region (optimization)
- Analysis
  - A Gaussian filter generates the waviness profile.
  - A stress analysis model is applied.

Roller Stress



A Paradigm Shift

- In many cases, the direct control of a functional parameter represents a paradigm shift.
- Key elements:
  - "Marketing"
  - "Packaging"

Marketing

- The direct control of functional attributes can be cost effective.
  - "What matters" can be directly specified.
  - Reduced stress associated with the judgment of non-conforming material.
  - Increased freedom in manufacturing process development.

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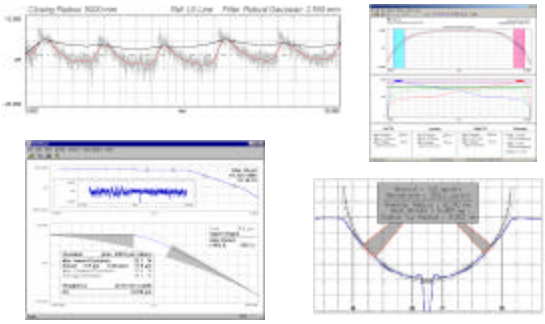
Packaging

- The direct control of functional attributes requires some degree of graphical presentation in order to provide process control.



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