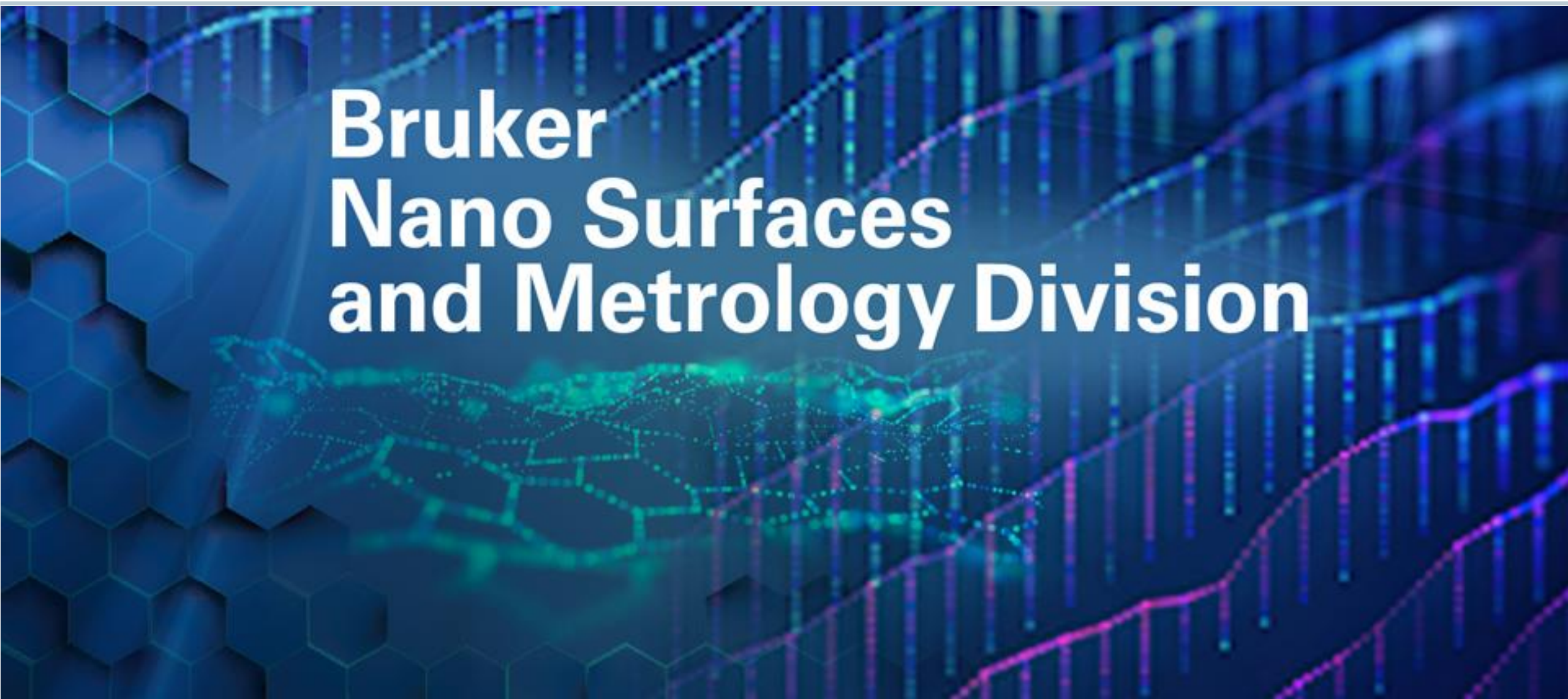
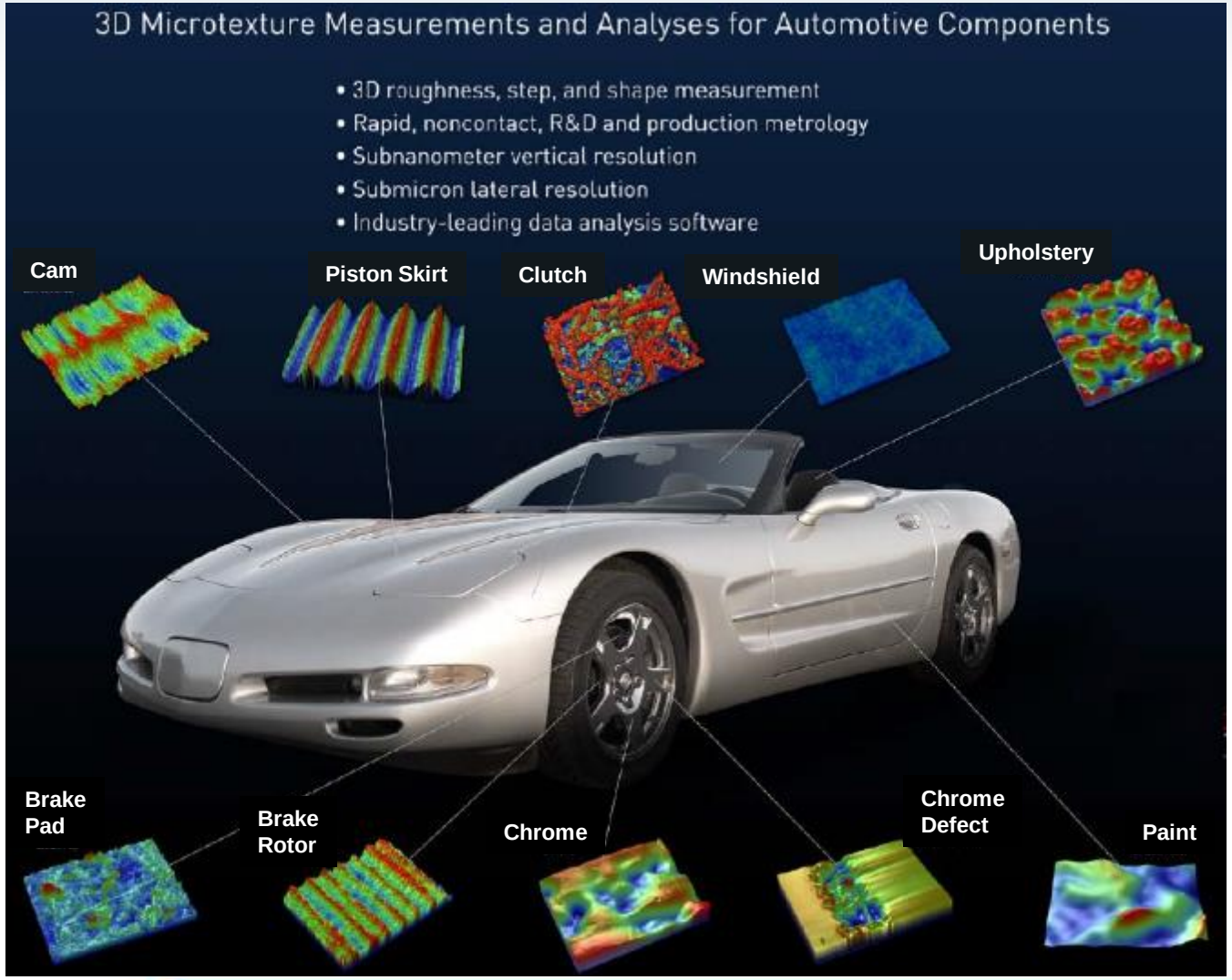
Automotive Applications using
White Light Interferometry



Introduction

Overview of several Automotive Applications *using White Light Interferometry*



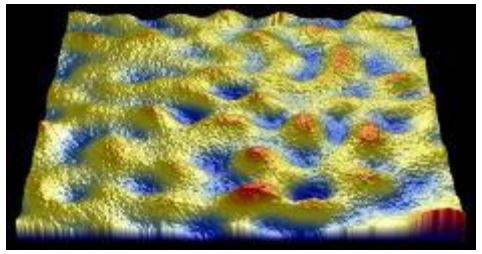
- 3D quantification provides profound insights into part performance
- Repeatable non-contact measurements does not deform or damage surfaces
- High vertical resolution captures optical-grade surface roughness
- Vertical range enables measurement of large steps, surface excursions, and film thicknesses
- Comprehensive data analysis offers in-depth understanding of surface performance

What Optical Profiling Do for the Automotive Industry

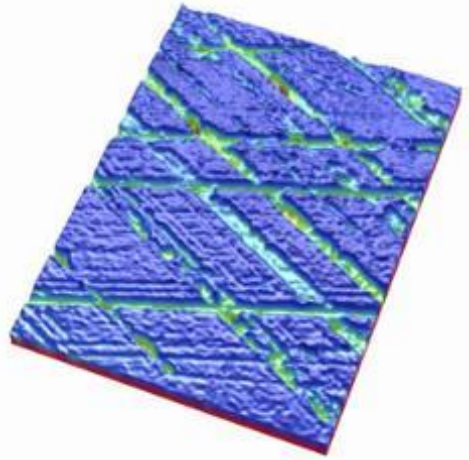
3D, High-Speed, Microtextured Measurement and Analysis

Quantify Wear…

- Failure analysis investigation
- Design for longer life



Paint finish



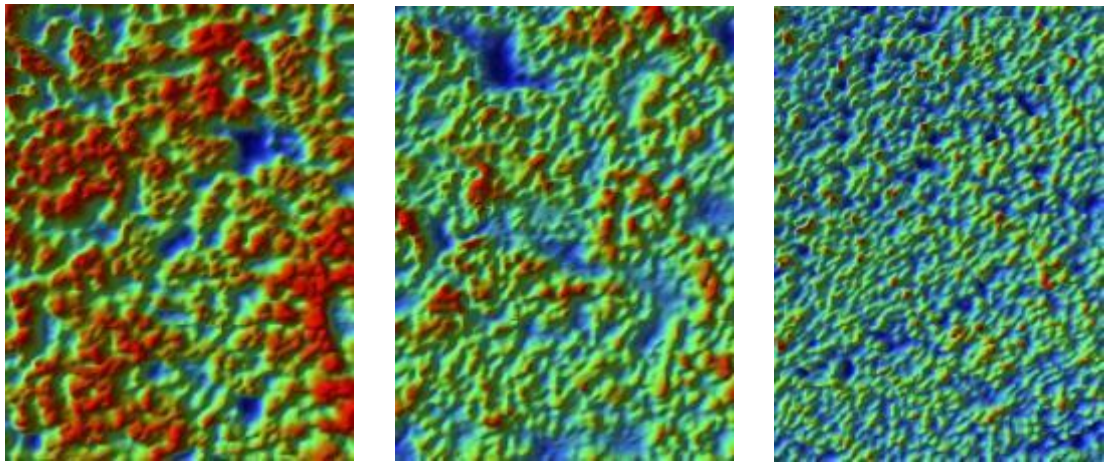
Wear on cylinder wall

Quantify Texture…

- Design the Surface for Performance

Quantify/Monitor Manufacture Process…

- Monitor production
- Quality control
- Improve production

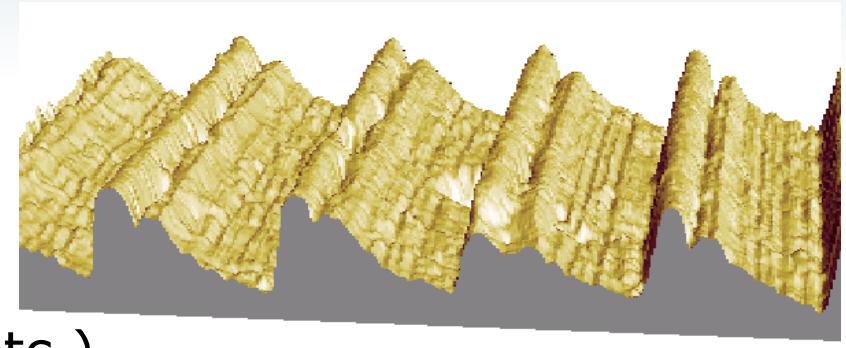


Different Metal Surface Preparations

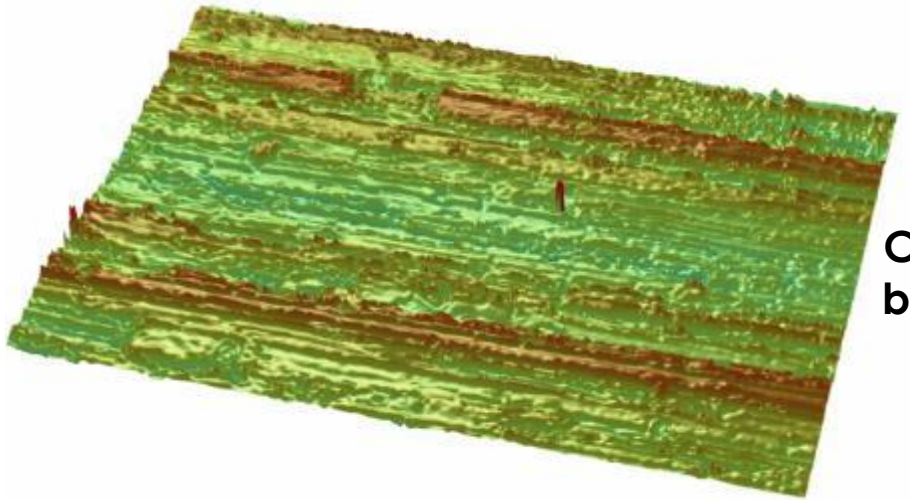
Automotive Applications
Surface Texture Characterization

Optical profiling gathers critical data on:

- Component Wear (Rings, Piston Skirt, Gear, etc.)
- Friction (Clutch Plates, Rings, Pistons, Gears, etc.)
- Fluid Handling/Sealing Surface (Valves, Seals, etc.)
- Noise, Vibration, Harshness (Brakes, Gears, Clutches, etc.)
- Sensor Failure (Fuel level Sensor, Air Bag Sensor, etc.)
- Coatings/Textile (Adhesion, Appearance, etc.)

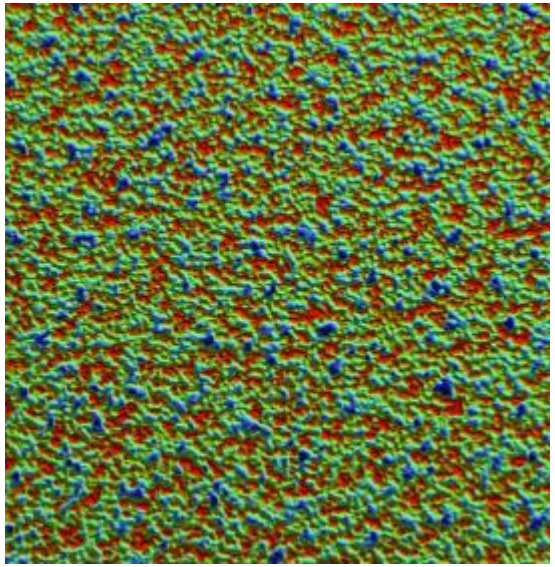


Brake rotor surface texture



Connecting rod bearing surface wear pattern

Failed surface preparation for paint



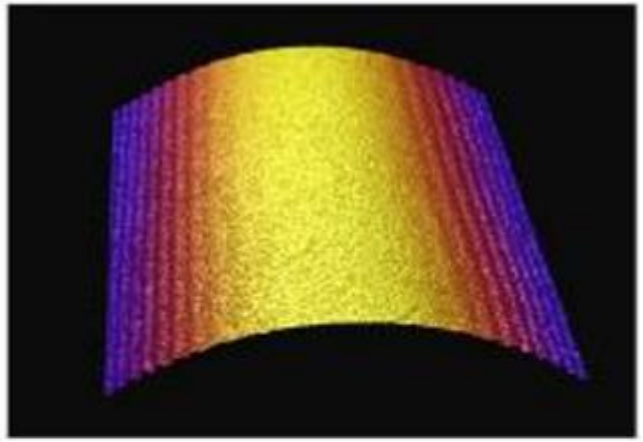
Confidential

Automotive Applications
Film Thicknesses

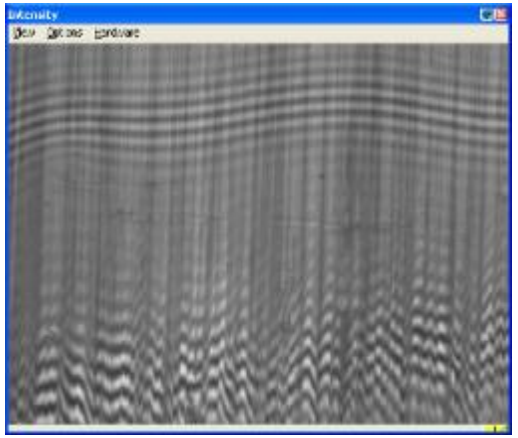
- Lubricant thickness
- Anodization layers
- Polymer coatings

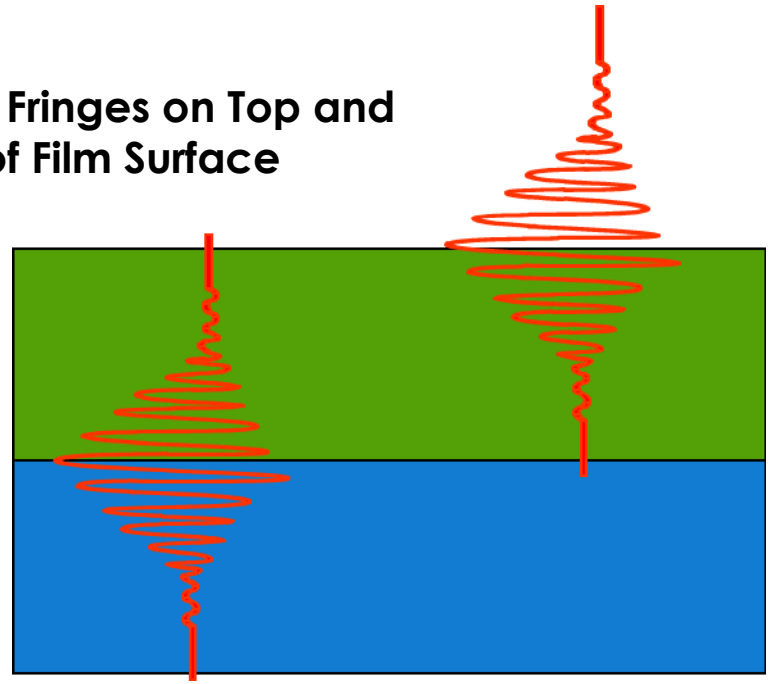
Thickness Avg: 4.95 um
Thickness Rt: 1.30 um
Thickness Rp: 5.45 um
Thickness Rv: 4.15 um

Top Surface

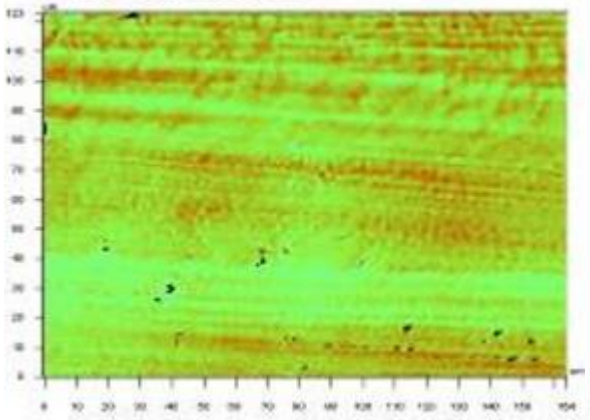


Measurement Fringes on Top and Bottom of Film Surface

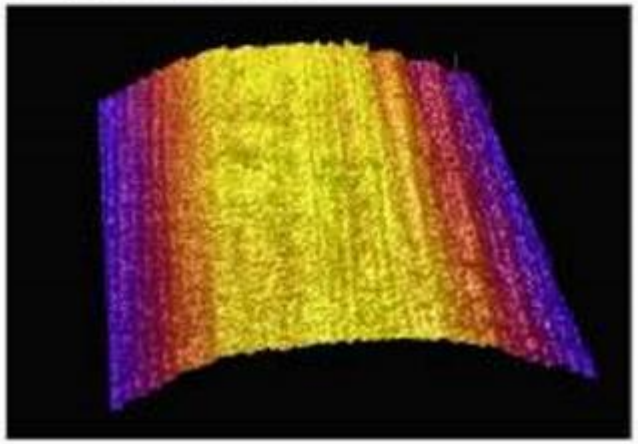




Film Thickness



Bottom Surface



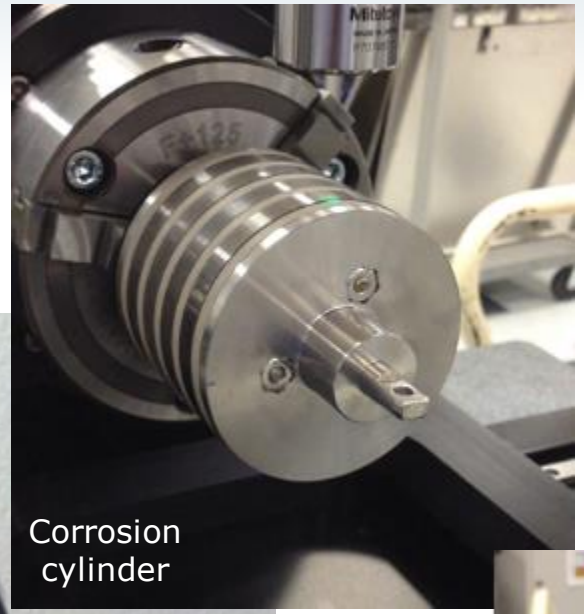
NPFlex – Made for Automotive

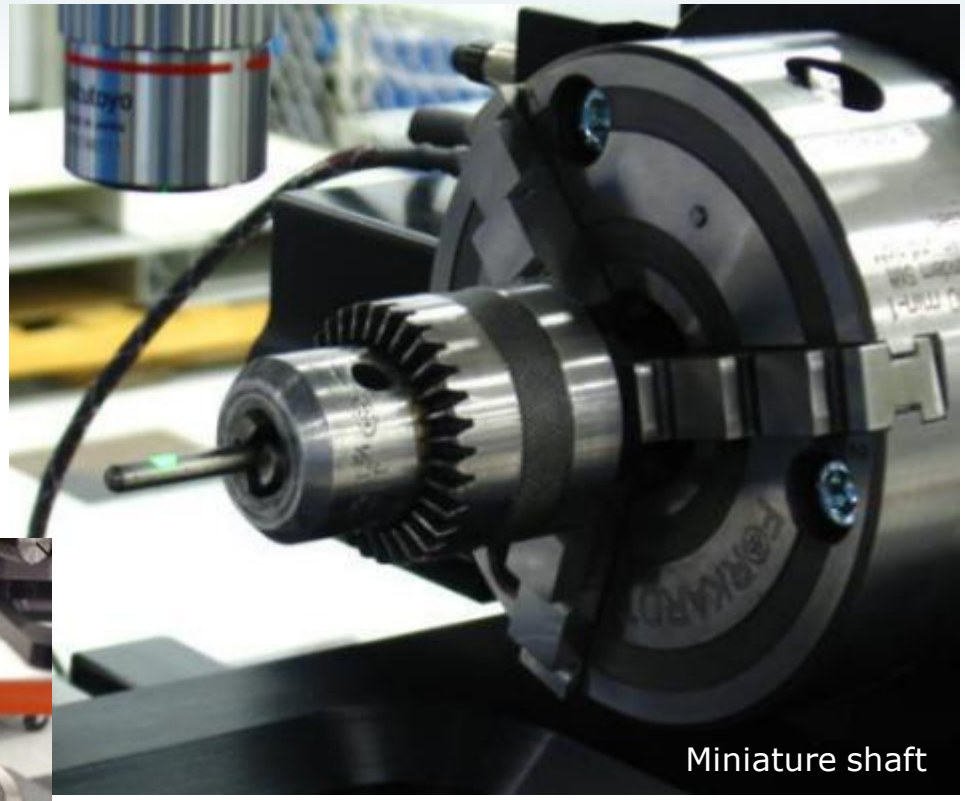
Versatility of measurable parts

Inherent Flexibility and Accuracy

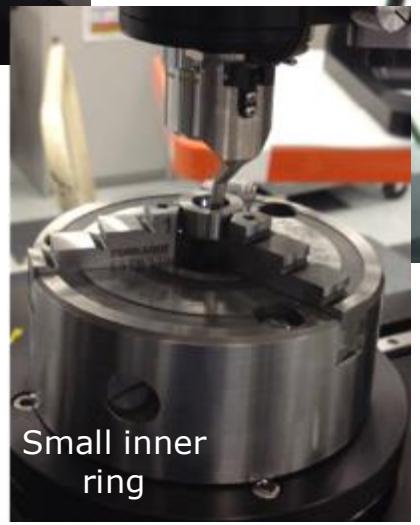
Versatility of Measurable Locations

Optional rotational stage


Corrosion cylinder


Miniature shaft


Slip Yoke shaft


Small inner ring

Versatility on accessibility

SLWD objective and fold Mirror

SLWD = Super Long Working Distance
34mm working distance

Piston head

Fold mirror gives side access

Piston
Connecting Rod

Versatility of measurable locations

Optional swivel head and deep fold mirror

Inner Cylinder Sleeve Bore

Swivel head ± 45°

Steering Wheel Column

Bruker Bench Top Measurement
ContourX White Light Interferometers

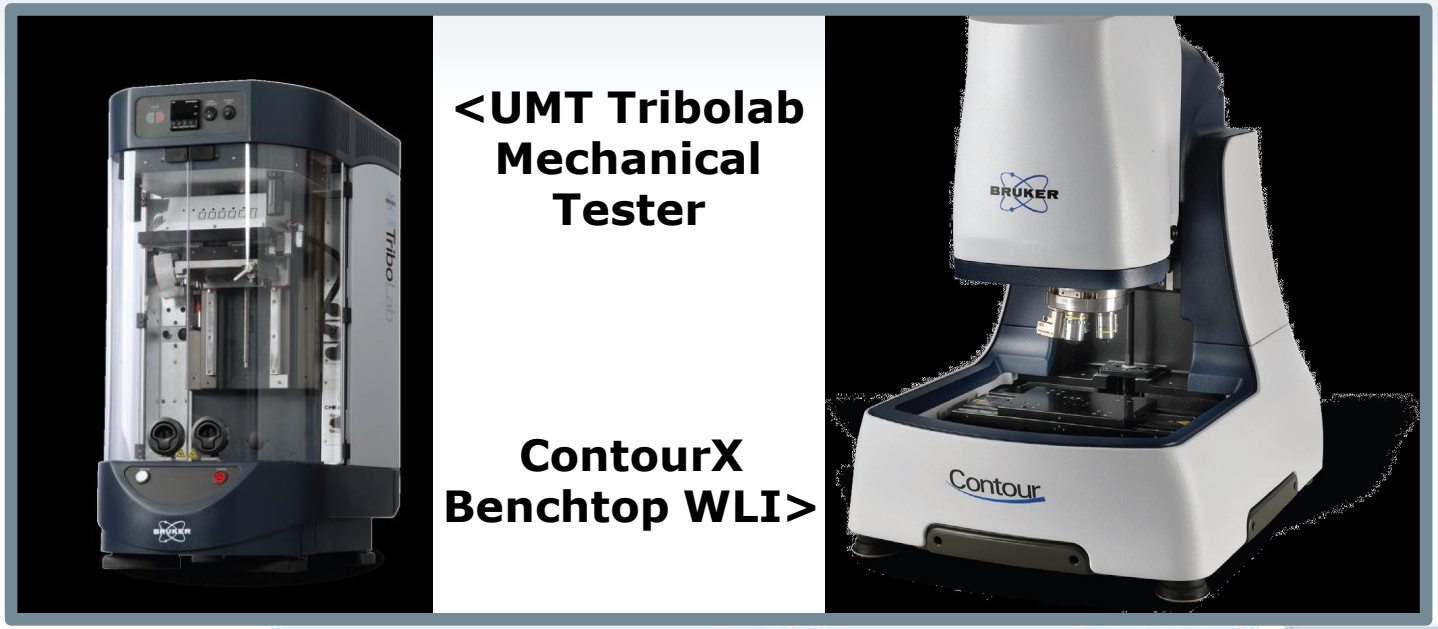
ContourX-100

ContourX-200

ContourX-500

Bruker Bench Top Tribology

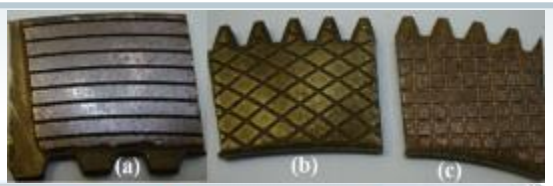
Offering Wear Testers to Measurements

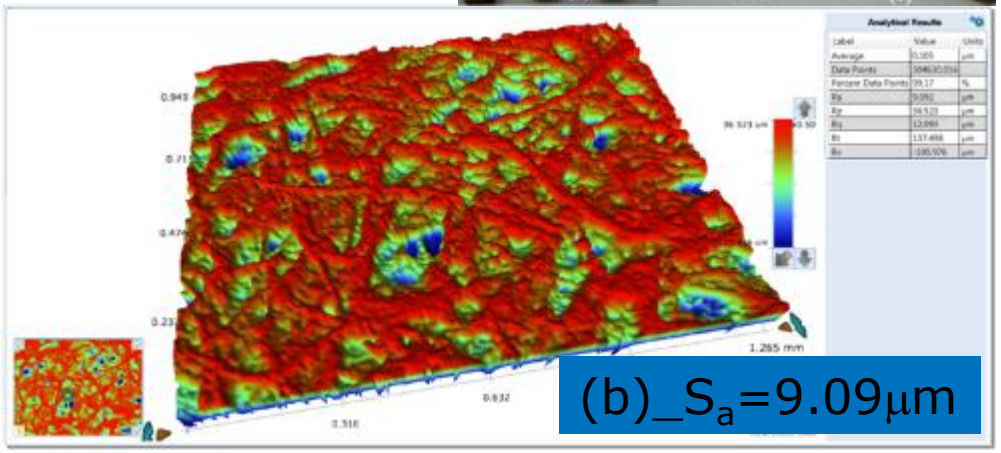


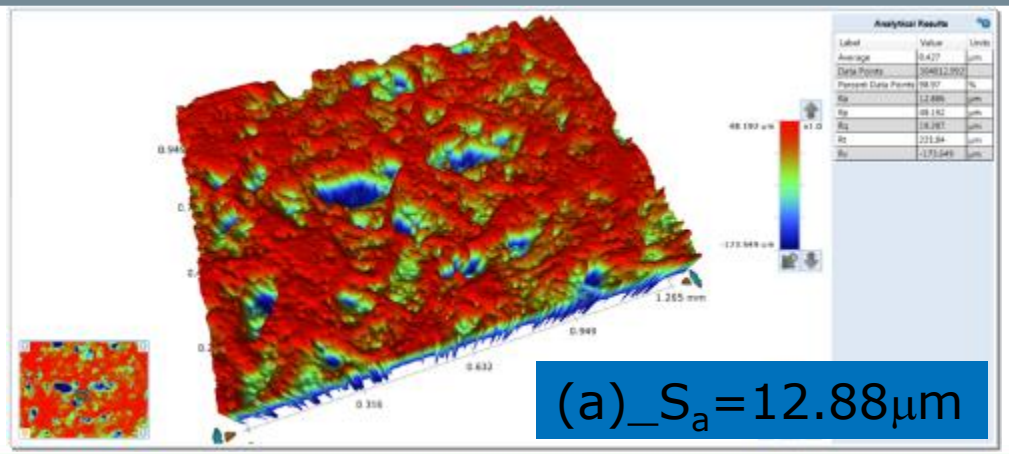
<UMT Tribolab Mechanical Tester

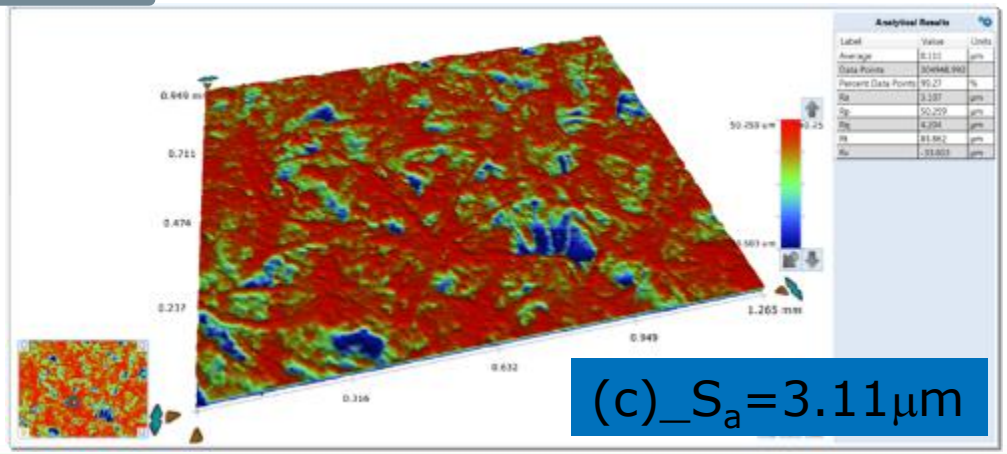
ContourX Benchtop WLI>

Wet Clutch Wear Testing





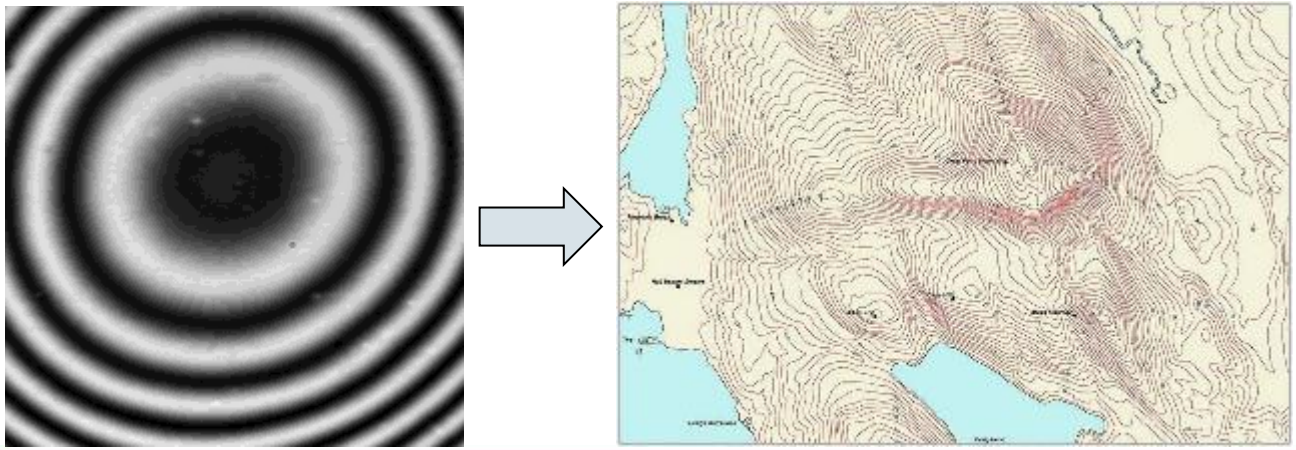


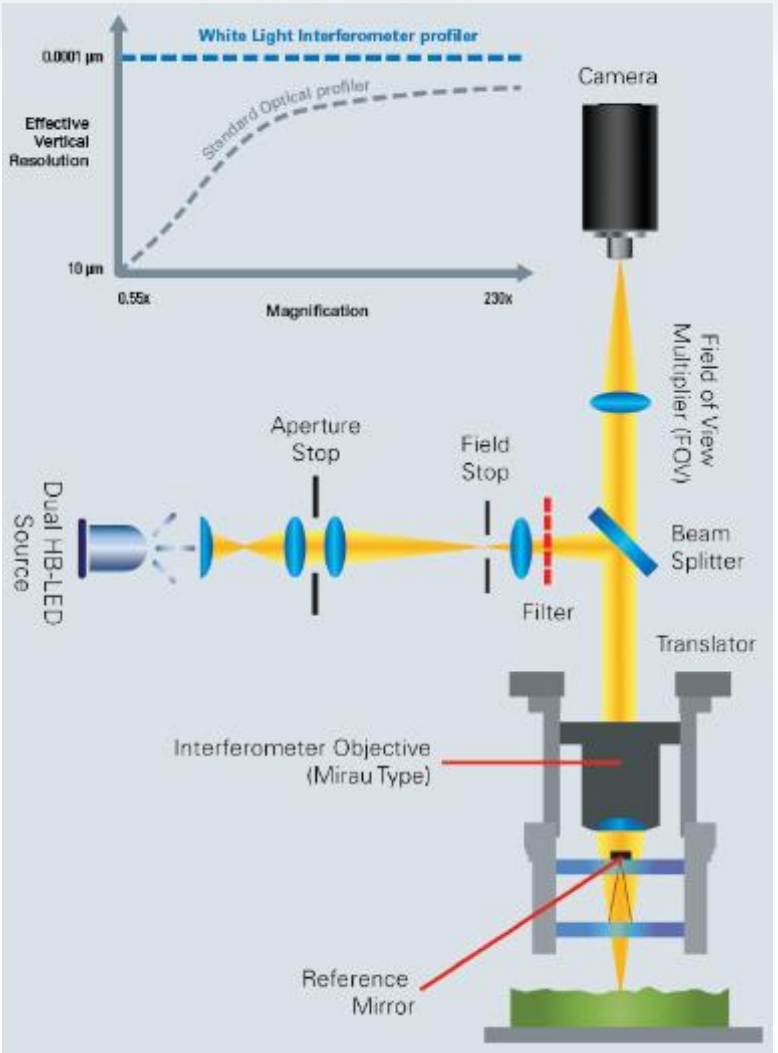


What is White Light Interferometry

White Light Interferometry
A Specialized High-End Microscope

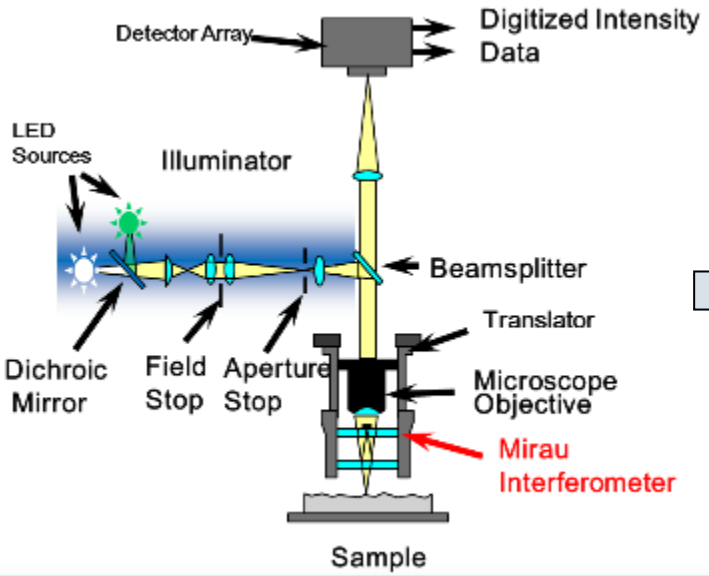
- White Light Interferometry, also know as Coherence Scanning Interferometry, scans thru focus using specialized interferometric objectives which creates a fringe pattern thru that focus
- Using this pattern at known heights create a topographic map of the surface

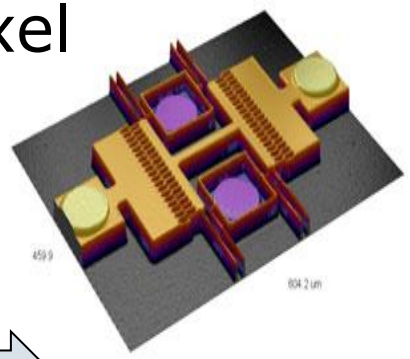


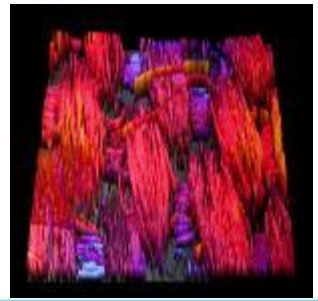


White Light Interferometry
A Specialized High-End Microscope

- Microscopes with interferometric objectives with internal mirror used to provide sample height data with the created fringe pattern
- Optics scanned vertically so that the sample is passed through focus
- Computer system computes up to sub-nanometer height information from this focus scan data for each camera pixel



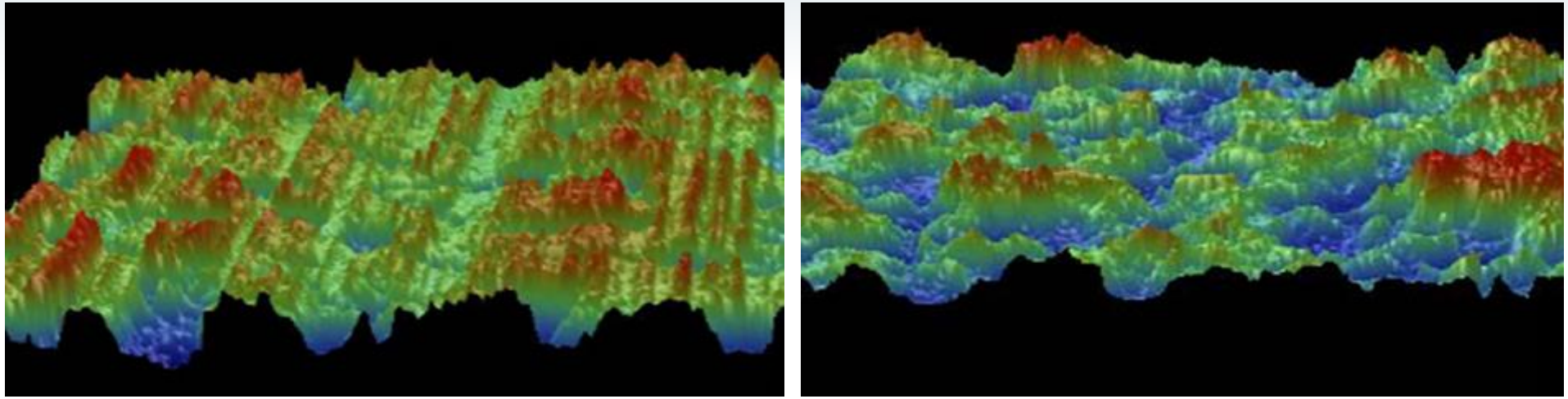




MEMS (air bag)
Cotton Weave
Quarter

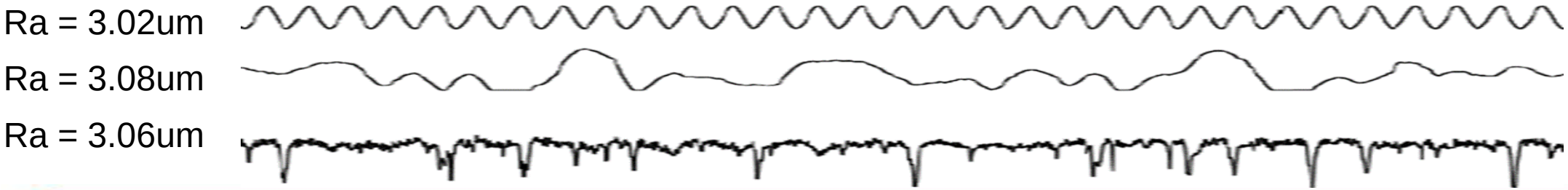
Surface Characterization using S-Parameters

Automotive Definitions
Is Ra (Sa) Enough?



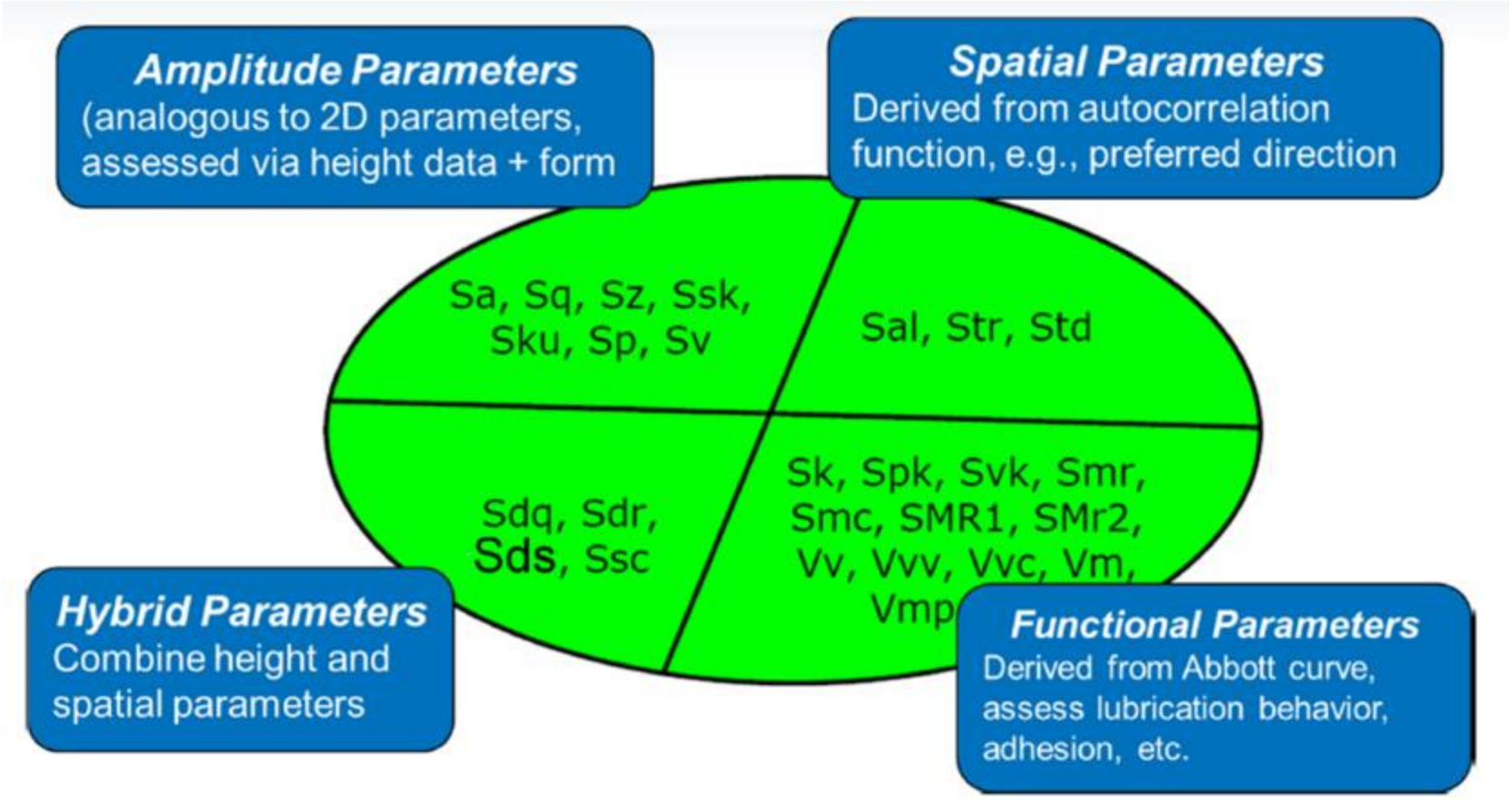
- These surfaces have identical Ra (Sa) value
- But these surfaces are different functionally (fluid retention, friction, etc.)

3D areal parameters (S-parameters) have been developed to capture and quantify differences



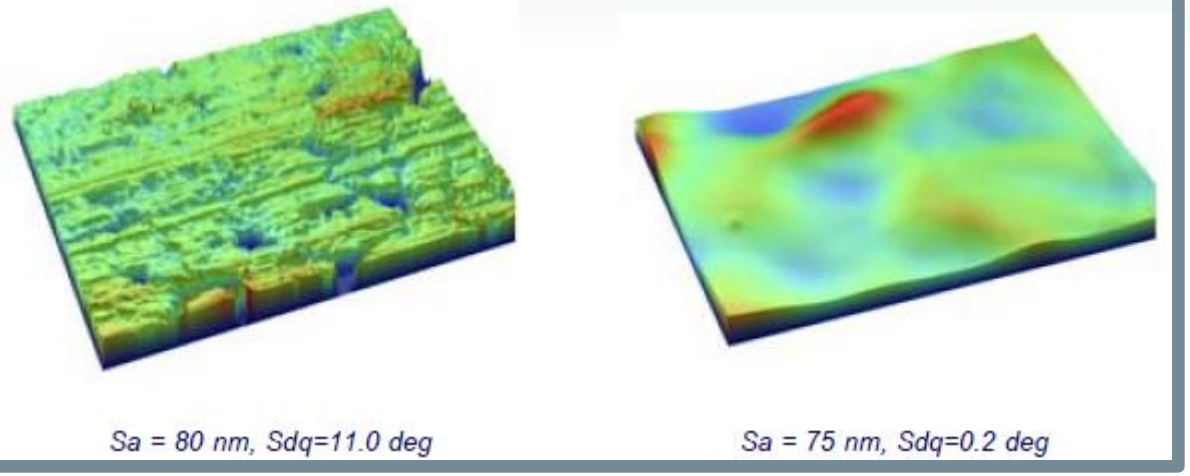
Automotive Definitions

S-Parameters provide missing details



Automotive Definitions
S-Parameters

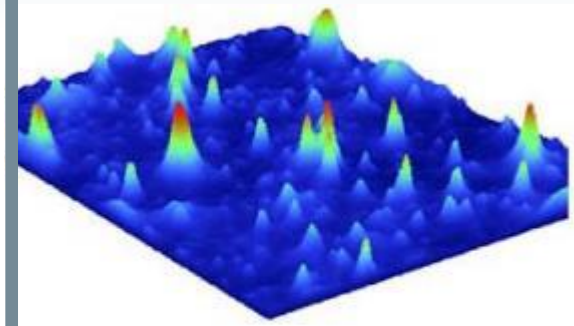
Sdq = Root Mean Square Surface Slope (sealing, cosmetic, appearance)



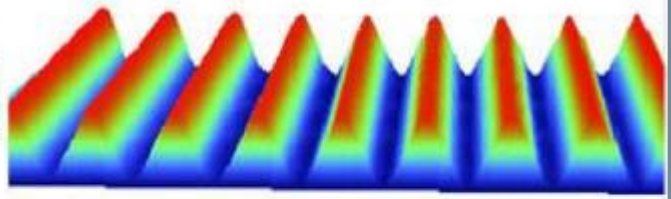
Sa = 80 nm, Sdq=11.0 deg

Sa = 75 nm, Sdq=0.2 deg

Ssk = Skewness-symmetry (sealing, cosmetic, appearance)

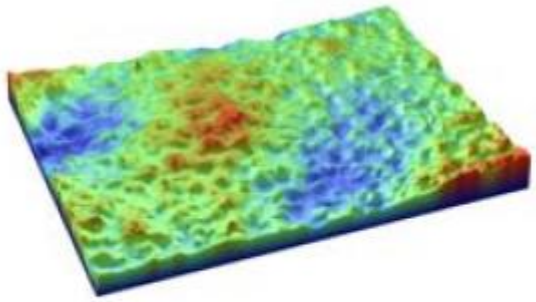


Surface with multiple peaks Ssk = 3.20 Sku = 18.71

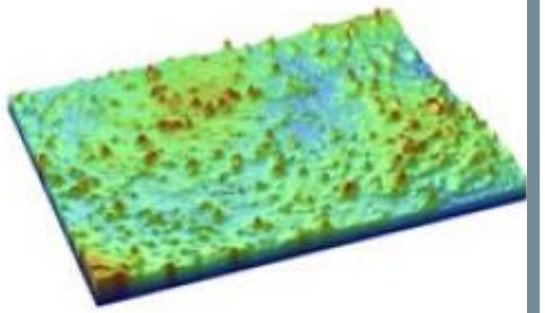


Periodic Texture Ssk = 0.16 Sku= 1.63

Sdr = Developed Interfacial Area Ratio (coatings, fluids, adhesion)

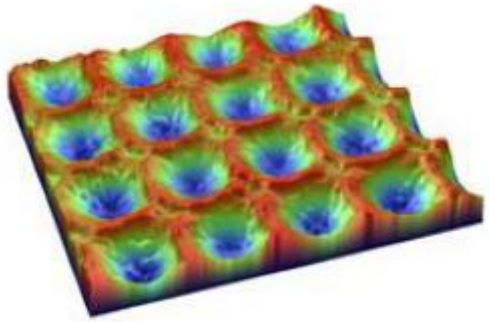


Sa= 0.52 um , Sdr=0.0023%

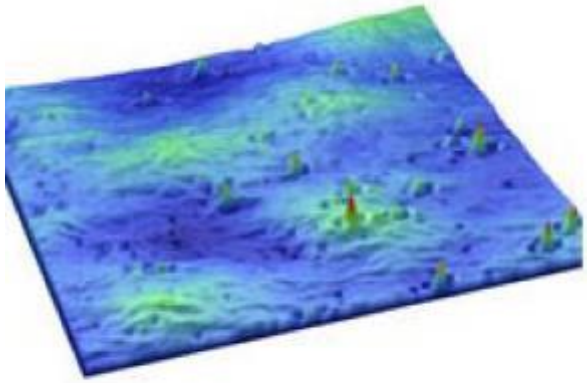


Sa= 0.33 um , Sdr=0.0623%

Sv & **Sp** = Evaluate the absolute highest and lower peaks



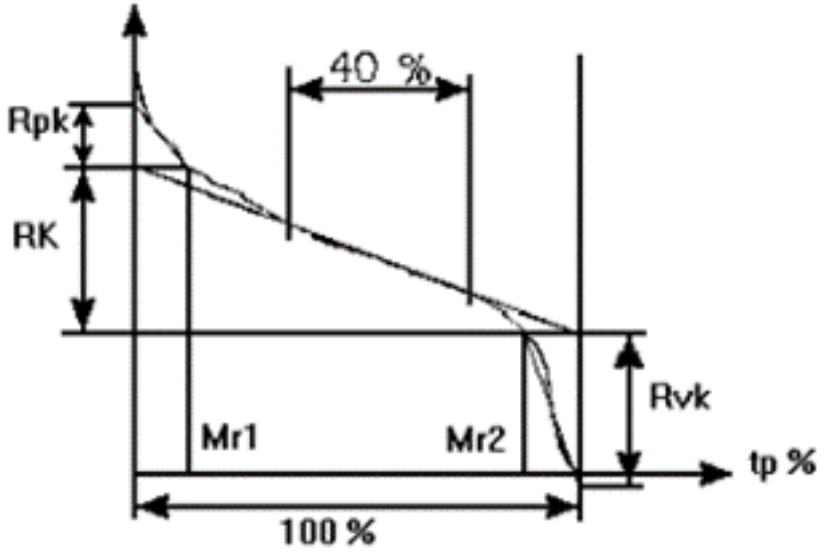
A surface used in the printing industry characterized by deep valley structures with Sv being ~ -15um

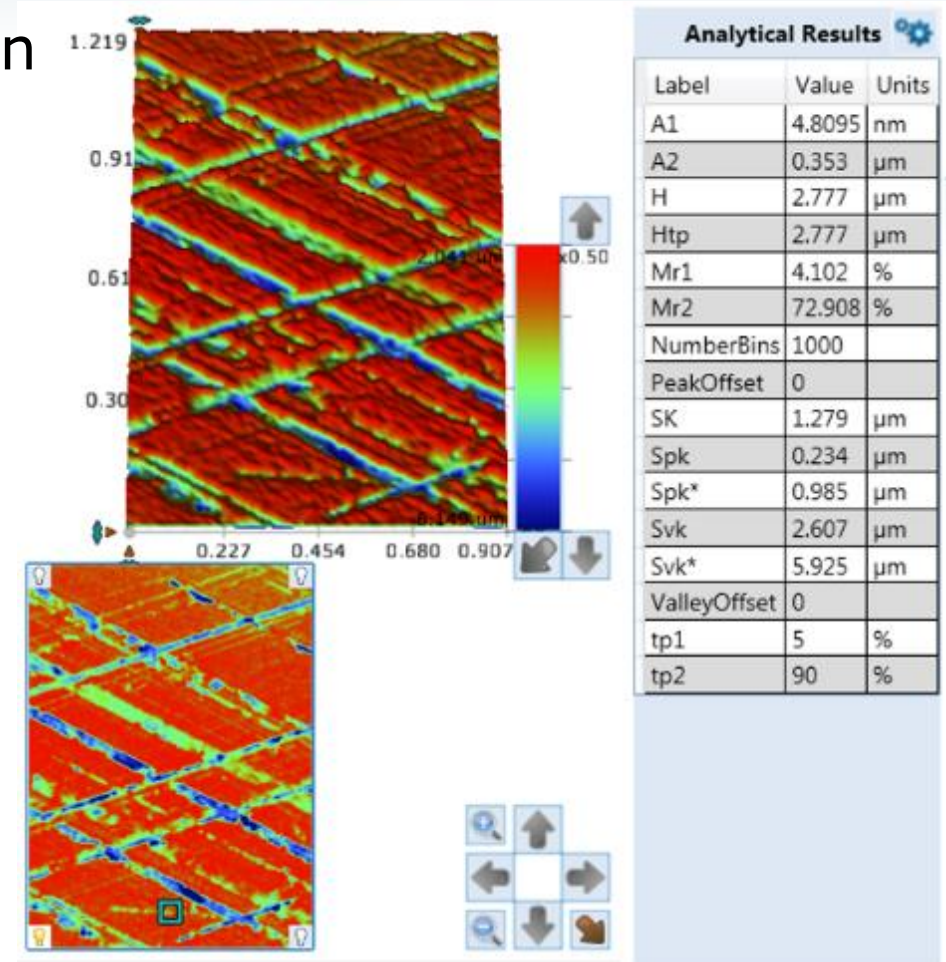


A polymer surface prepared with asperities as measured by Sp being ~0.90 um

Automotive Definitions
V-Parameters Bearing Curve Ratio (1)

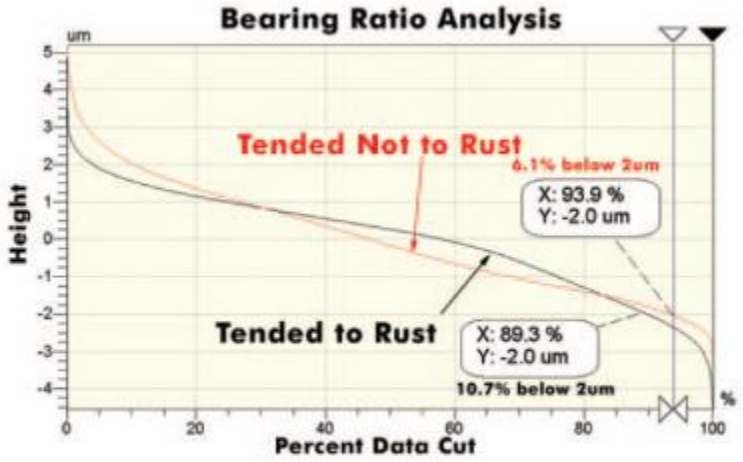
- Parameters can predict surface wear and retention
  - Peak areas that erode first are quantified (Spk)
  - Load bearing surface is identified (SK)
  - Valley areas that contain lubricates (Svk)



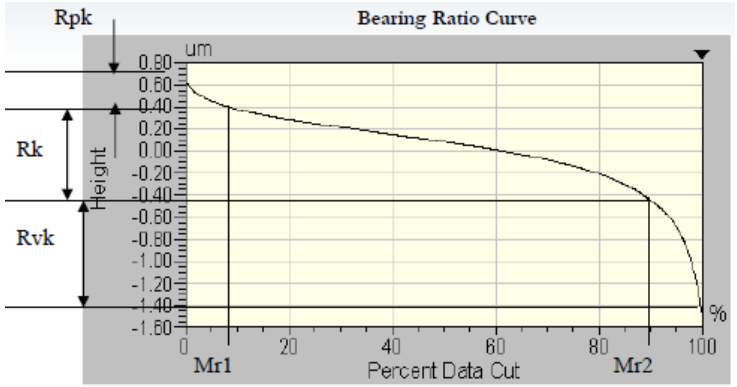


Label	Value	Units
A1	4.8095	nm
A2	0.353	µm
H	2.777	µm
Htp	2.777	µm
Mr1	4.102	%
Mr2	72.908	%
NumberBins	1000	
PeakOffset	0	
SK	1.279	µm
Spk	0.234	µm
Spk*	0.985	µm
Svk	2.607	µm
Svk*	5.925	µm
ValleyOffset	0	
tp1	5	%
tp2	90	%

Automotive Definitions
V-Parameters Bearing Curve Ratio (2)



Bearing ratio analysis of the two surfaces in Figure 2. The stock that eventually corroded showed a greater percentage of valleys deeper than 2 microns.



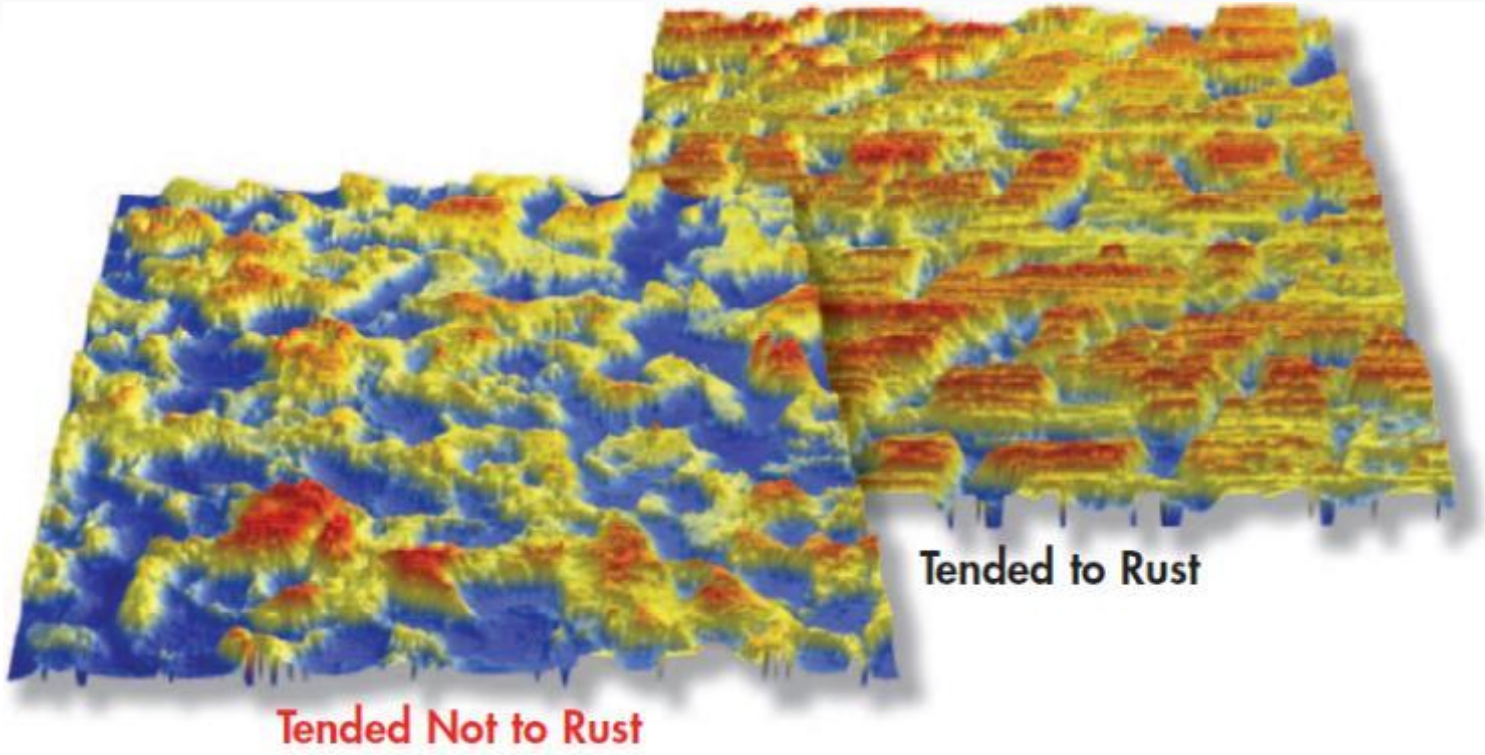
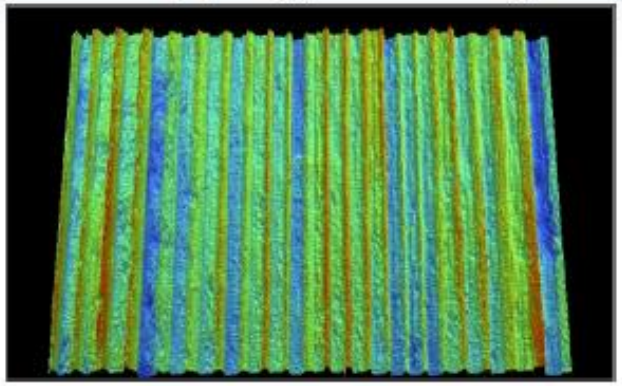


Figure 2. Stock either maintained an acceptable surface finish (left image) or corroded (right image) following processing. 3D parameters helped trace the difference to a predominance of deep valleys which Ra did not discern.

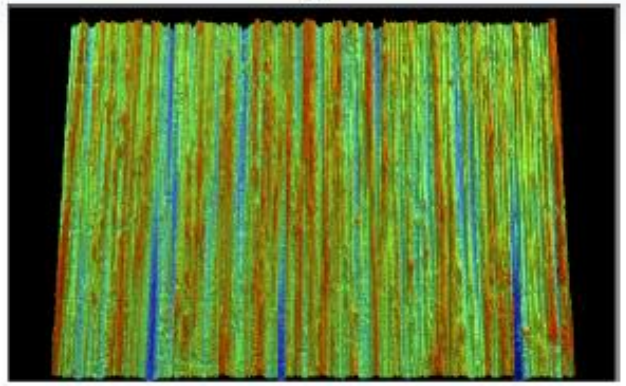
Different Machining Processes

S-Parameters can characterize these surfaces

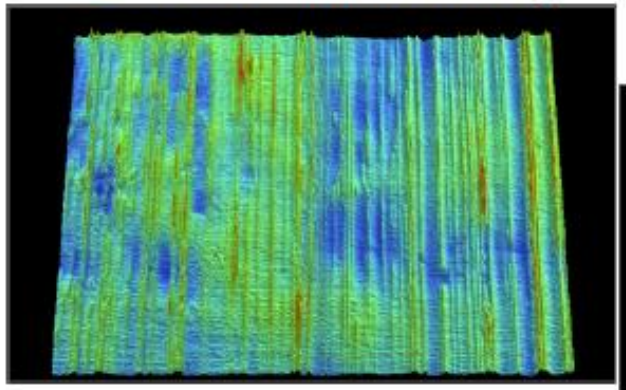
- Flat lapping/Reaming



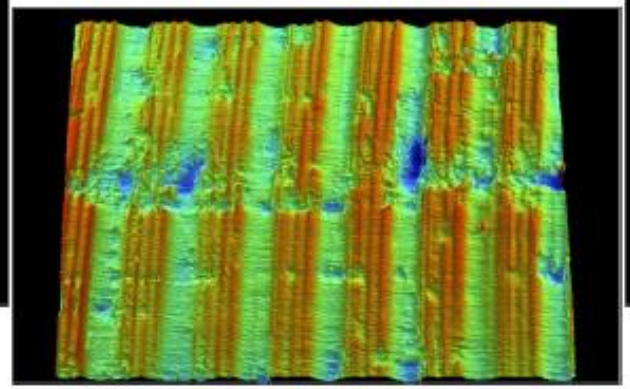
- Grinding



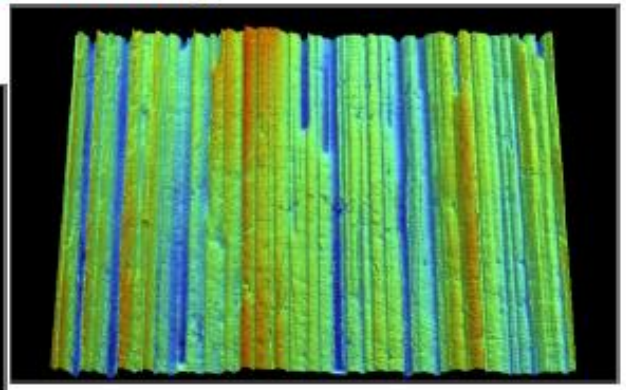
- Horizontal Milling



- Vertical Milling



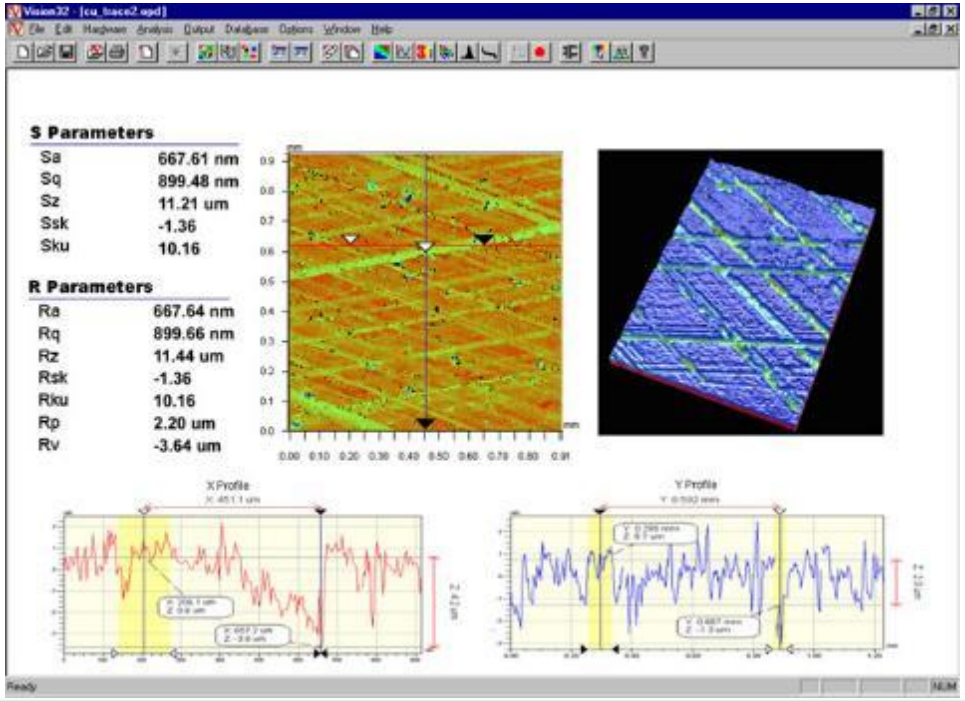
- Turning



Wear/Corrosion Characterization

Wear of Cylinder Components
Quality Control and Failure Analysis

- **Bruker profilers have characterized drive train components**
  - Shaft, cam, rod, valve roughness and wear
  - Cylinder bore machining



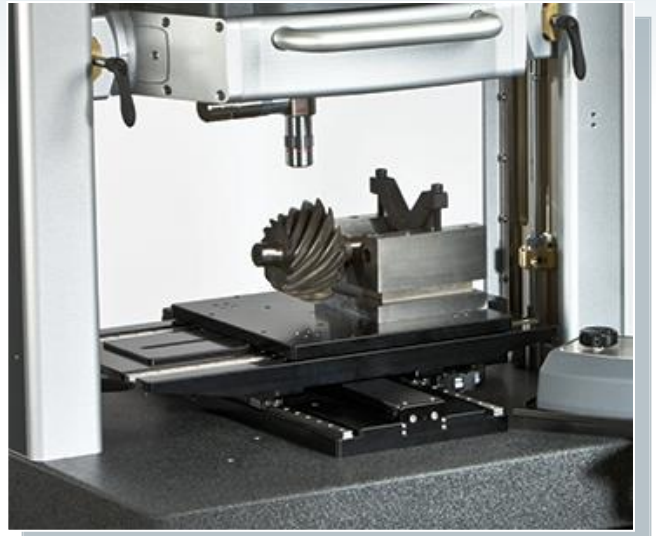
Quantifying cylinder bore finish and wear

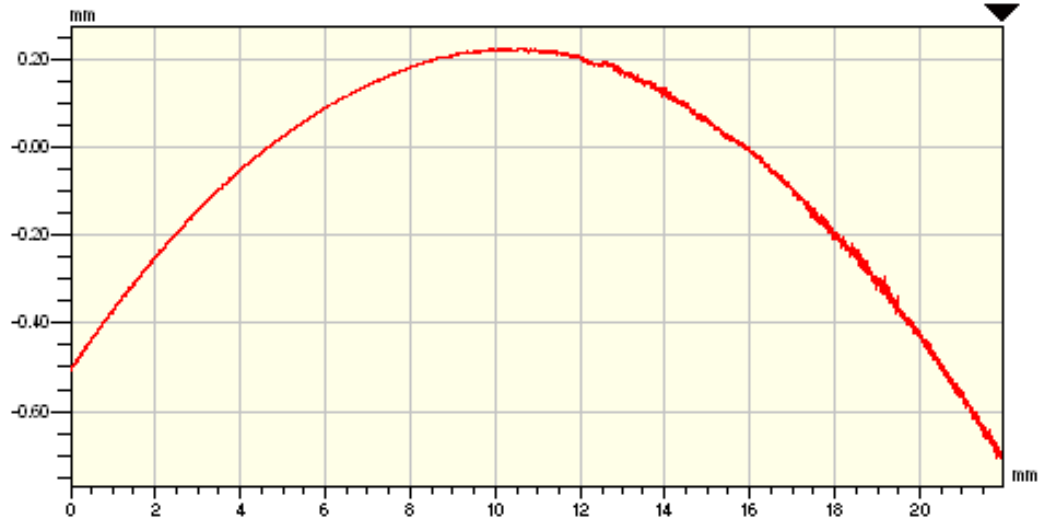
2D and 3D plots of honed cylinder wall showing volume of material lost over time, ratio of peaks to valleys, directionality of wear, etc.

Hypoid Pinion Gear Wear (1)

Ability to Measure Shaft and Tooth-One Setup

- Hypoid tooth shape preferred to apply more torque over a smaller "contact patch" area
- Currently used contact technique or cut down on parts
- Form & roughness using stitching of multiple images due to large contact patch





Rq	0.25 mm
Ra	0.22 mm
Rt	0.95 mm
Rp	0.22 mm
Rv	-0.73 mm

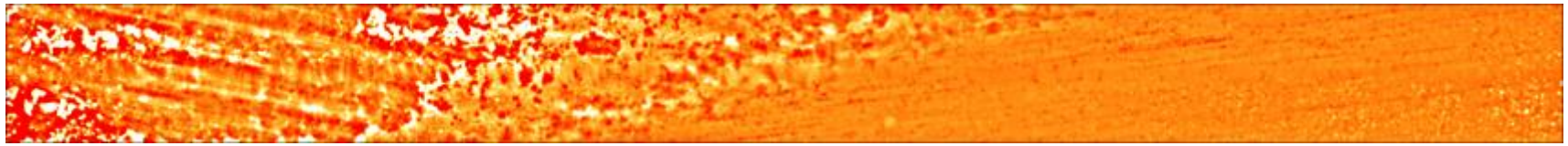
Angle	-9.33 mrad
Curve	-73.44 mm
Terms	None
Avg Ht	-0.06 mm
Area	-1.39 mm2

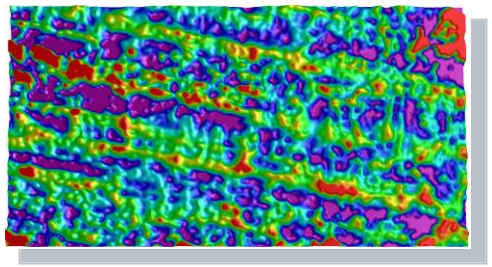
Tooth bow x-section shows range of z-height.

Hypoid Pinion Gear Wear (2)
Using Volume and Areal Surface Parameters

- Volume measurements quantify the amount of wear in the contact zone and show the displacement of material toward the OD of the gear
- 20mm stitch of hypoid gear tooth

Material Deposited ← Material Removed

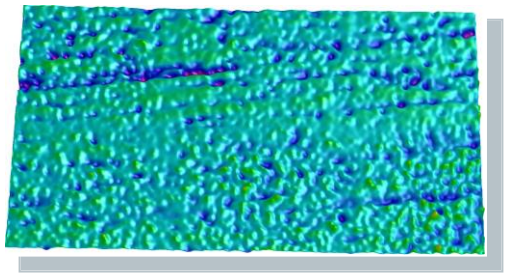




Unworn area
Sa= 3.48um

Volume Calculations

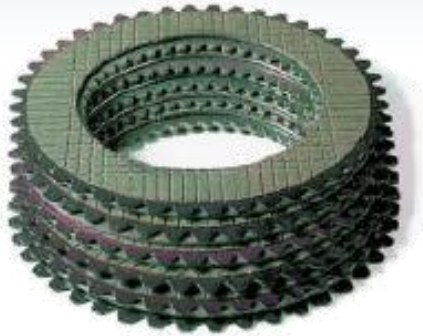
Volume Options	Normal
Natural Volume	251763504.00 um3
Normal Volume	4.70 um3
Negative Volume	20941616.00 um3
Positive Volume	21643120.00 um3
Net Missing Volume	-701504.00 um3
Total Displaced Volume	42584736.00 um3



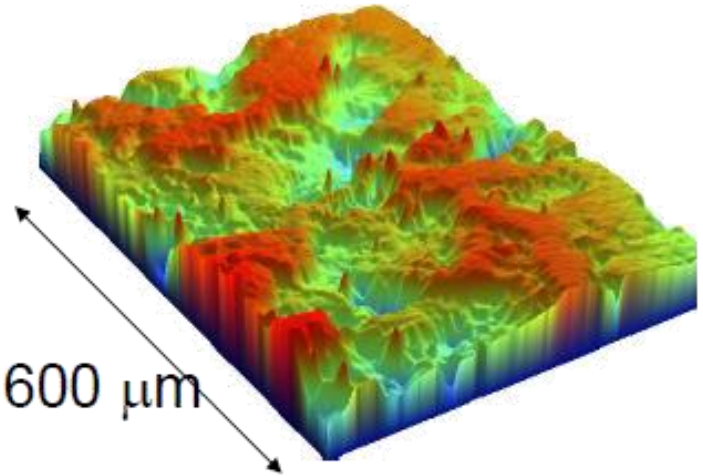
Worn area
Sa= 0.78µm

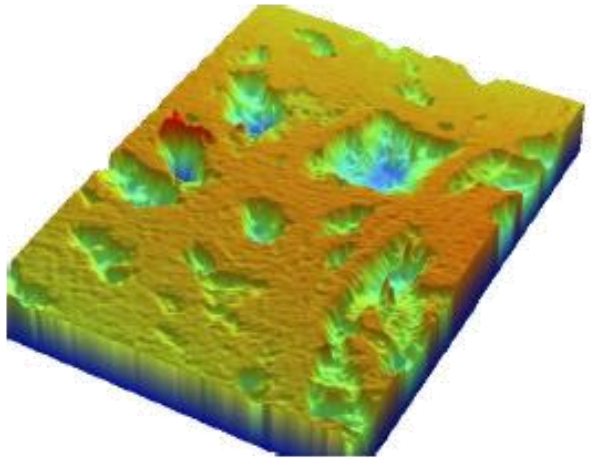
Automotive Application

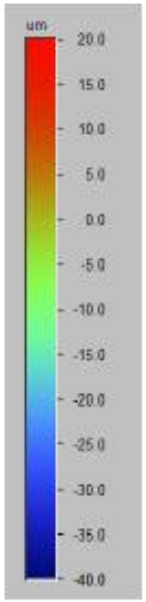
Wear Measurement on Clutch Plates



Friction Plates







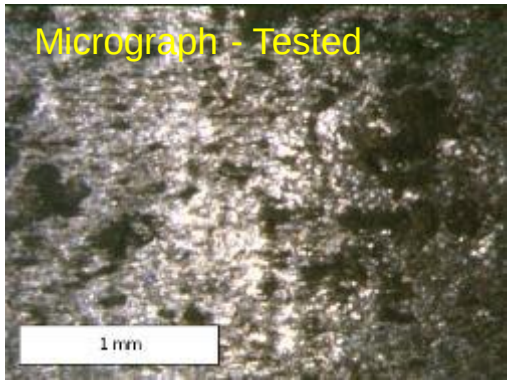
Paper Clutch Plate (slightly worn)

Paper Clutch Plate (highly worn)

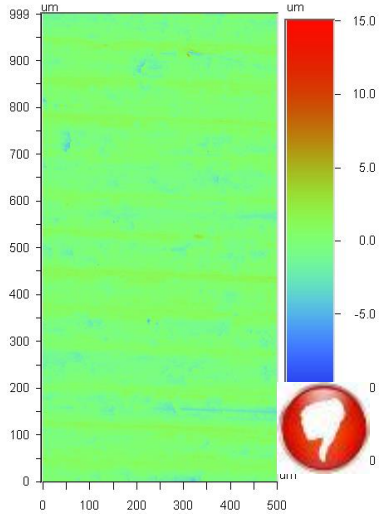
Cam Cap Wear Study

Supplier Selection Testing Study

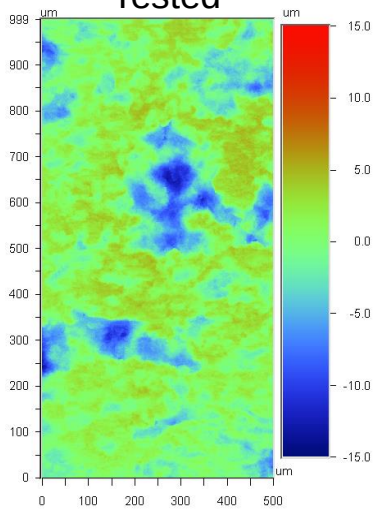
Supplier A



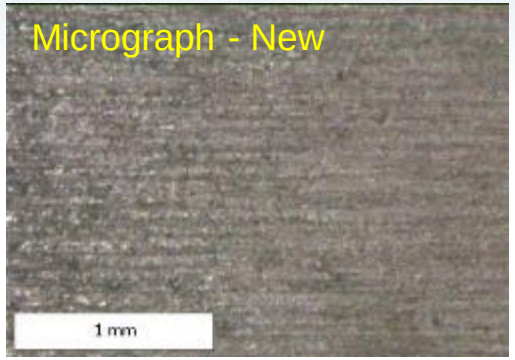
New

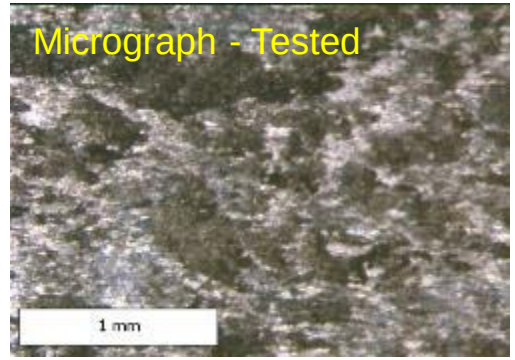


Tested



Supplier B





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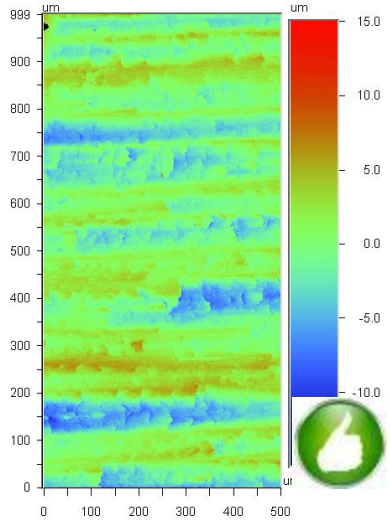
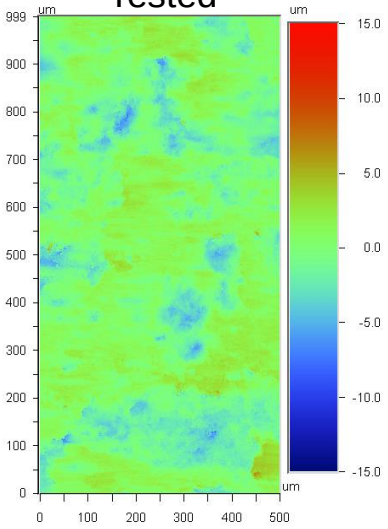


Tested



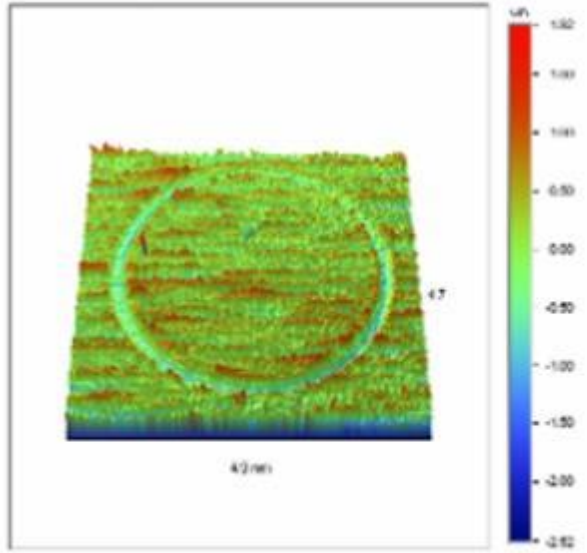
Quantify Wear
Depths, Volume Loss/Gain Analysis

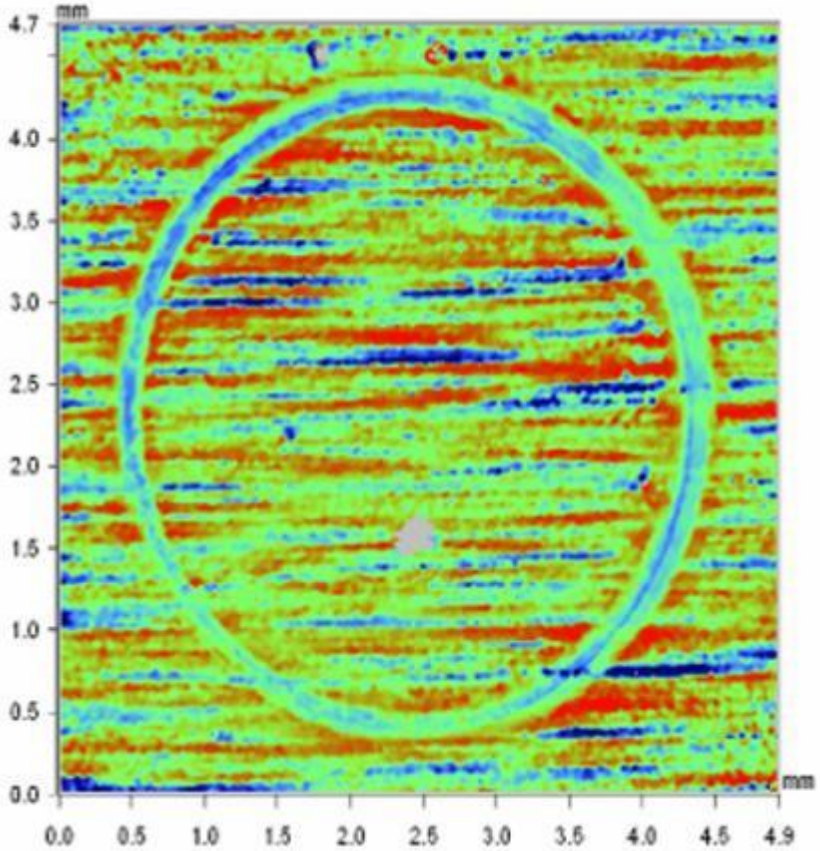
- **Pin and Ball Wear Study**

- Quantify material characteristics with wear studies
- Quantify material removal in terms of volume
- Evaluate negative, positive and missing volumes

Volume Calculations

Volume Options	Normal
Natural Volume	20013972.00 um3
Normal Volume	0.56 um3
Negative Volume	4020140.00 um3
Positive Volume	1110722.25 um3
Net Missing Volume	-90582.25 um3
Total Displaced Volume	8130862.00 um3

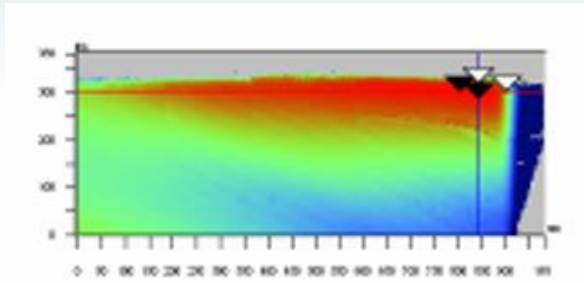


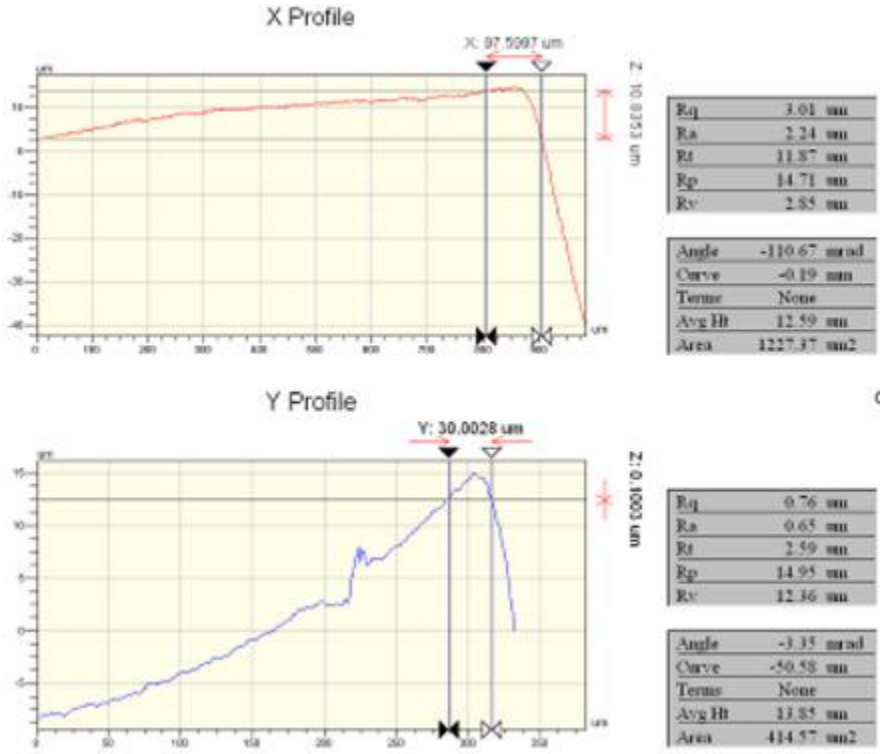


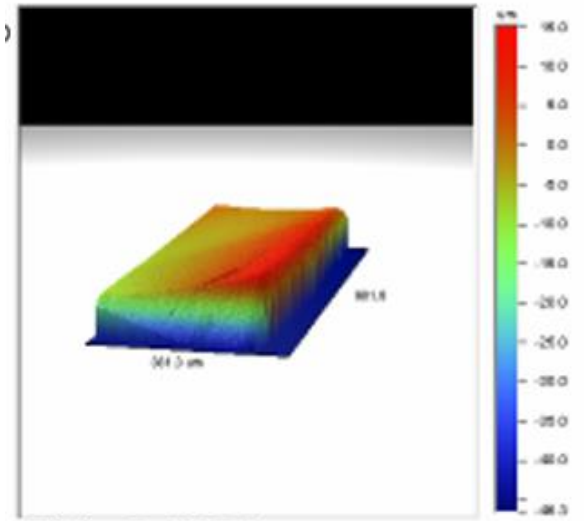
Quantify Wear
Depths, Volume Loss/Gain Analysis

- Measure inside surfaces!
  - The cutting edge that wears, not the outer circumference
- Machining bits
  - Roughness, radii of curvature, angles
- High-speed machining
- Quantify wear and set conditions on replacement

Cutting Surfaces 1







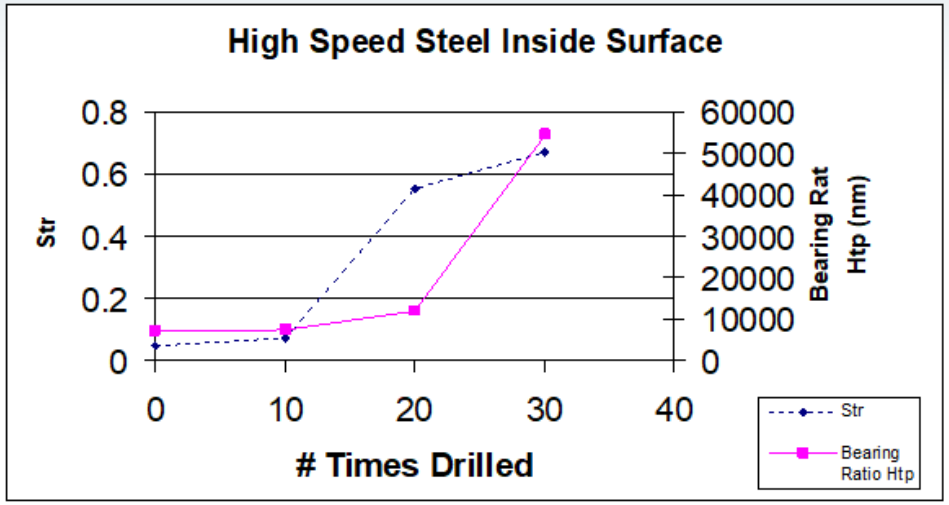
Title: Drill Bit

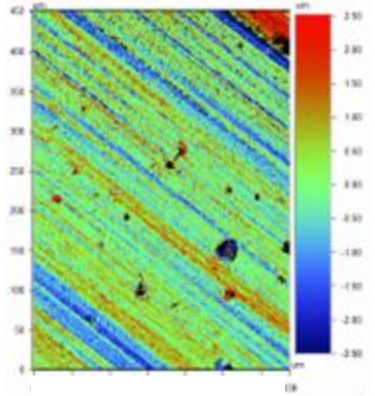
Note: Tip Shape and Wear

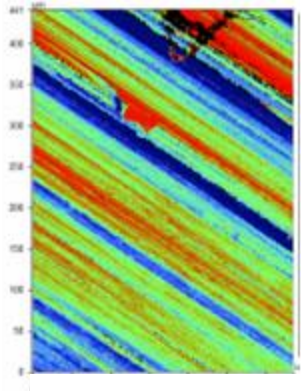
Quantify Wear
Depths, Volume Loss/Gain Analysis

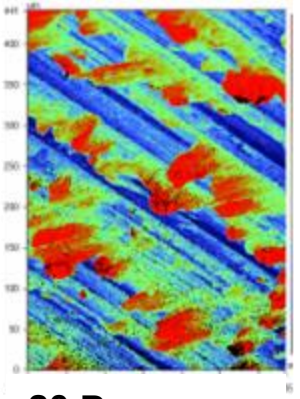
- Study wear with usage
  - Cutting bit roughness changes over the course of 30 uses
  - Material redeposit on surface significantly affects topology
- Radii of curvature, edge quality unaffected

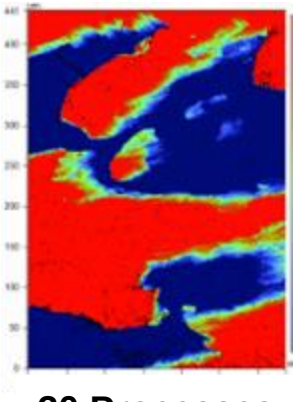
Cutting Surfaces 2




NEW

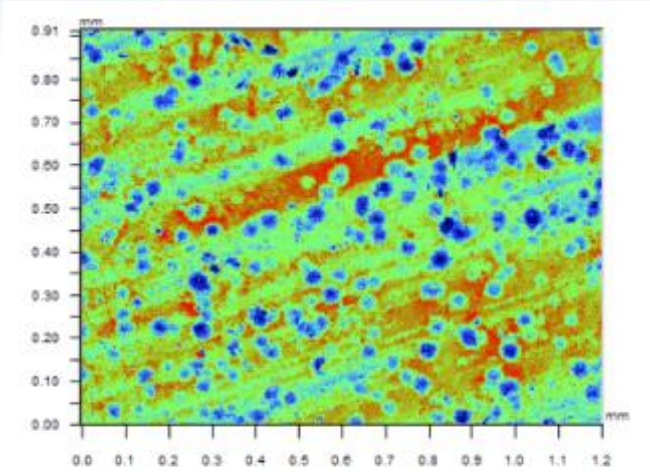

10 Processes

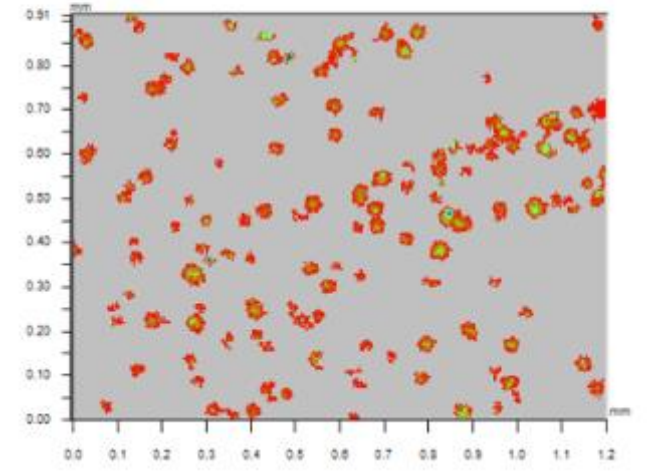

20 Processes


30 Processes

Quantify Corrosion
Depths, Volume, Size Analysis

- Corrosion
  - Automatic detection and characterization of corrosion and defects on surface
  - Recipe saved for each type process and analysis

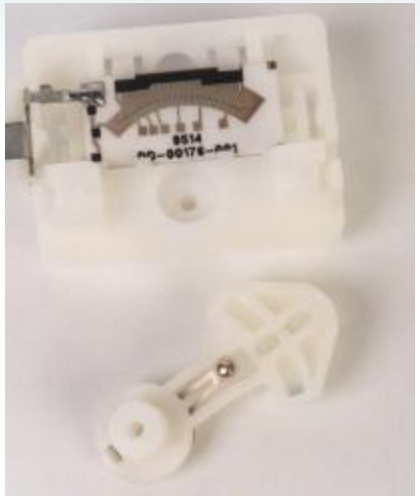




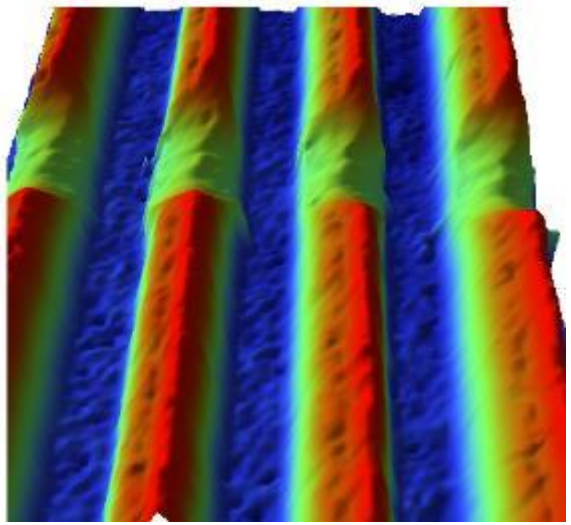
Region	Mean (um)	Diameter (um)	Area (mm2)	Rv% (um)	Volume (um3)
84	-3.002	38.054	0.001	-4.567	-1799.938
85	-2.916	44.755	0.001	-4.375	-3096.113
86	-2.517	54.458	0.001	-3.537	-2860.571
87	-2.067	27.525	0.000	-2.598	-722.797
88	-2.379	143.674	0.005	-3.852	-12003.441
89	-2.003	24.869	0.000	-2.567	-650.465
90	-2.054	35.194	0.000	-2.556	-769.561
91	-2.004	25.604	0.000	-2.423	-725.695
92	-2.161	29.756	0.000	-2.983	-836.811
93	-2.330	48.645	0.001	-3.859	-2503.165
94	-2.311	72.611	0.002	-3.787	-3550.267
95	-2.560	40.735	0.001	-3.866	-2461.870
96	-2.243	30.417	0.000	-4.048	-1008.718
97	-2.880	54.525	0.002	-4.353	-5034.870
98	-2.812	110.301	0.003	-4.695	-8884.792
99	-2.133	52.653	0.001	-2.824	-1838.387
100	-2.512	74.810	0.002	-4.067	-5176.191
101	-2.428	31.592	0.000	-3.704	-1000.648
102	-2.401	31.592	0.001	-3.314	-1589.020
103	-2.412	40.894	0.001	-3.665	-2349.824
104	-2.523	30.301	0.001	-3.528	-1354.902
105	-2.281	55.304	0.001	-3.409	-2193.438
106	-1.961	57.487	0.001	-2.433	-2840.395
107	-2.570	95.290	0.002	-4.130	-3980.248
108	-2.152	36.305	0.001	-3.075	-1155.807
Average	-2.349	44.681	0.001	-3.551	-2184.592
Std Dev	0.290	20.851	0.001	0.782	1849.531
Range	1.555	120.458	0.005	4.583	11362.362

Title: Process A

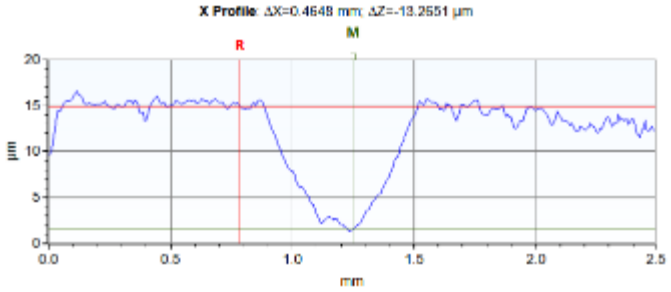
Quantify Wear
Depths, Volume Loss/Gain Analysis



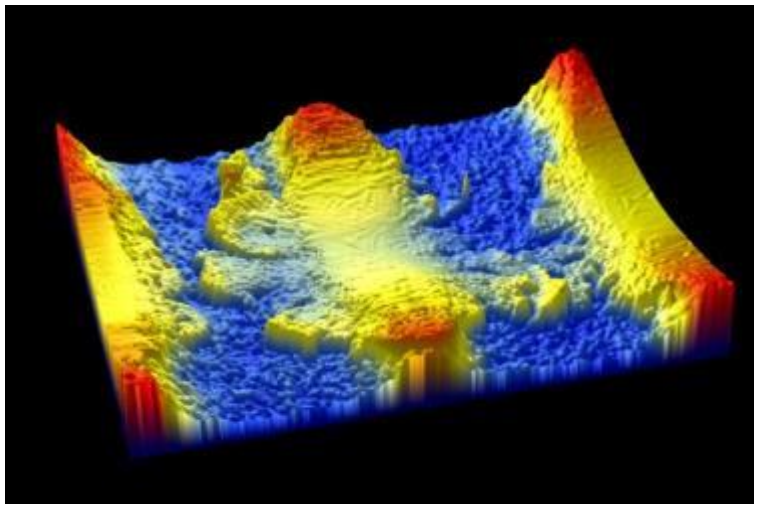
- **Bruker profilers have measured wear rate on fuel level sensors**
  - Wear mechanisms can change over time
  - Failure Analysis Done
  - Lifetime testing of before and after components



Nominal Wear



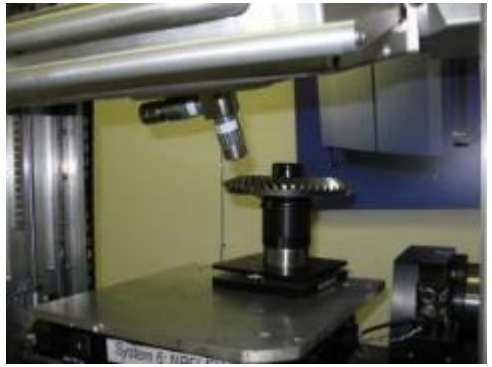
Profile along worn contact



Failed Component

Surface Finish – Gear Teeth using SLWD Objective

Tooth roughness
SLWD *Objective*

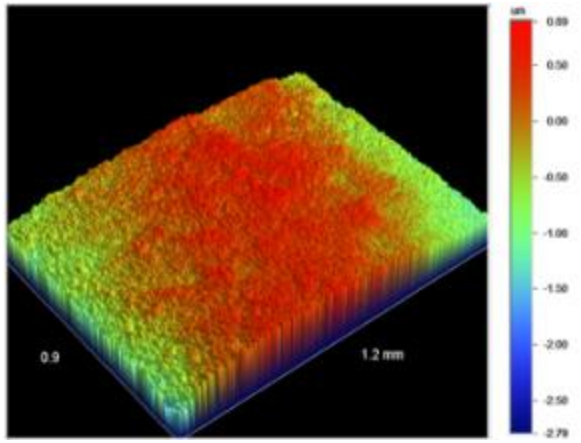


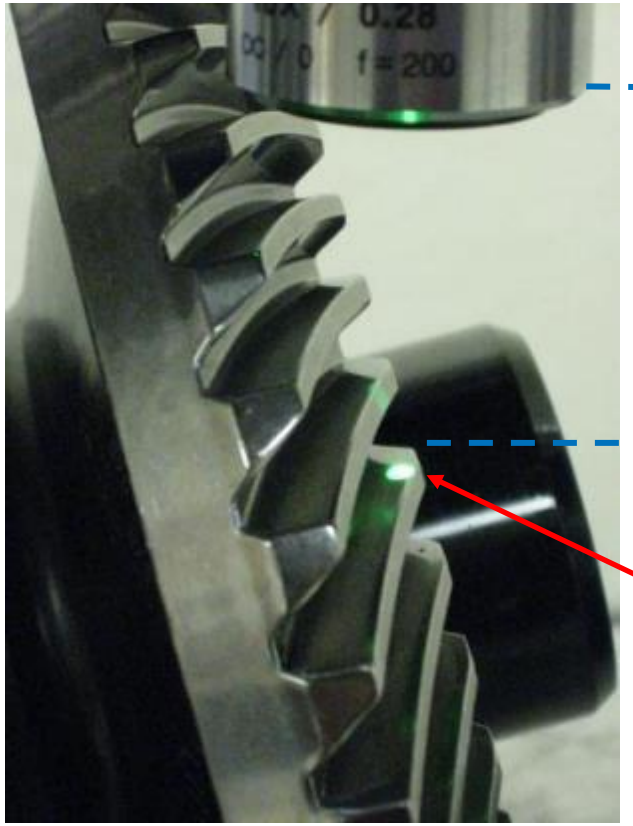
Surface Stats:

Ra: 335.41 nm

Rq: 405.66 nm

Rt: 3.69 um





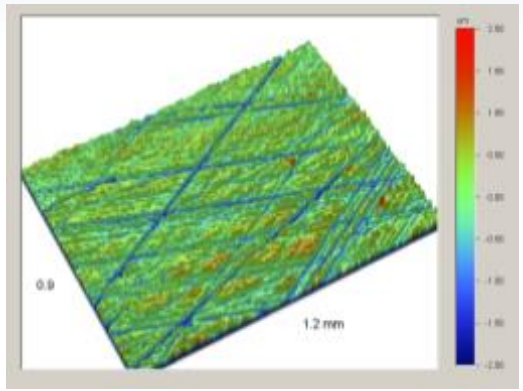
Super Long Working Distance objective allows for sidewall tooth inspection

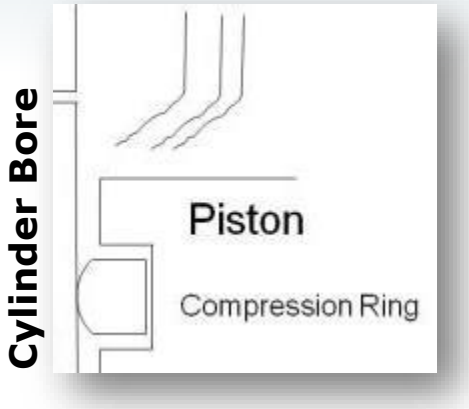
Cylinder Bore Inspection

Cylinder Bore Inspection

Complete Solution for Pre-Inspection

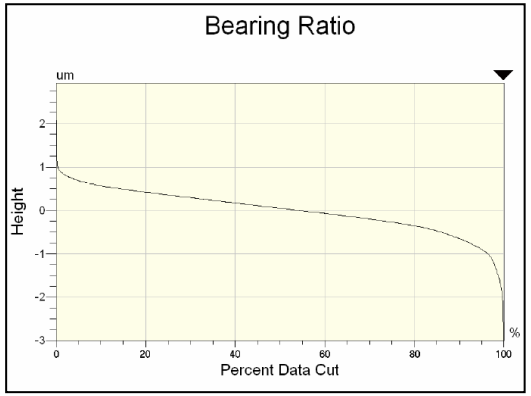
Cylinder bore texture





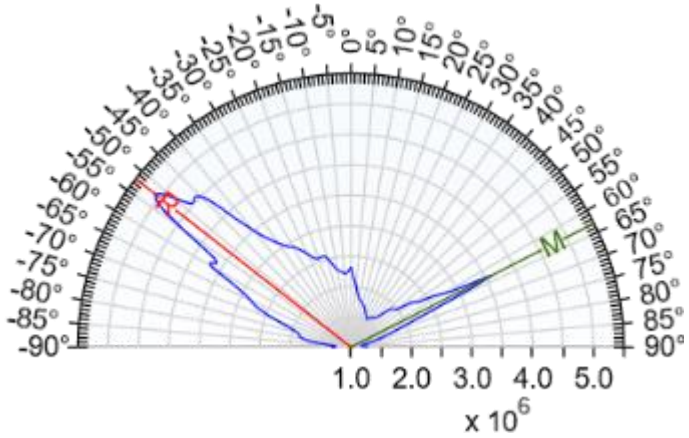
No	Region	A Diameter µm	Rv µm
1		16.408	-1.360
2		54.419	-2.560
3		23.310	-1.596

Automatic defect analysis



Plateau texture affects contact mechanics with rings

Valley affects oil retention



Cross hatch – deep valleys – affect gas/fluid flow and fluid retention

Bore-Scope objective collecting data 150 mm inside large metal engine cylinder liner.

Dynamic Sealing Interfaces and Surface Texture

Cylinder Bore / Rings

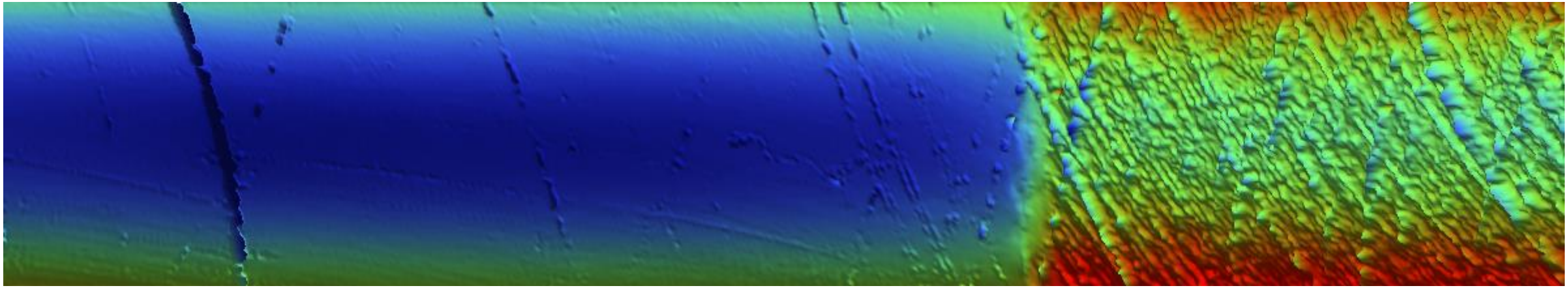
Cylinder Bore Surface Texture

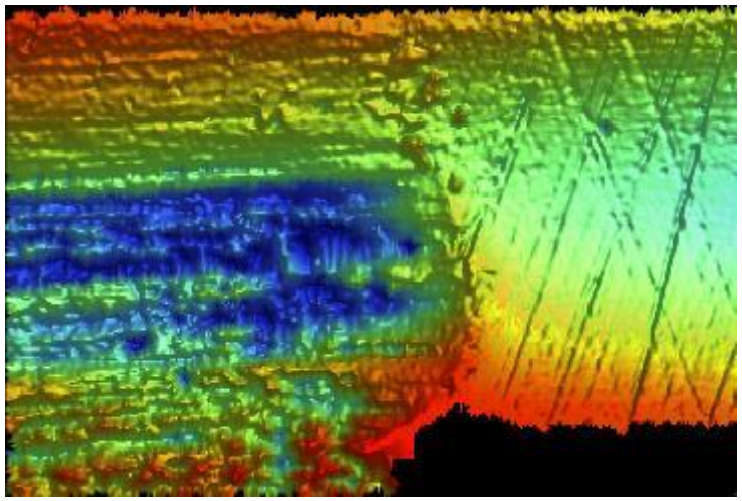
OVERALL Engine Performance

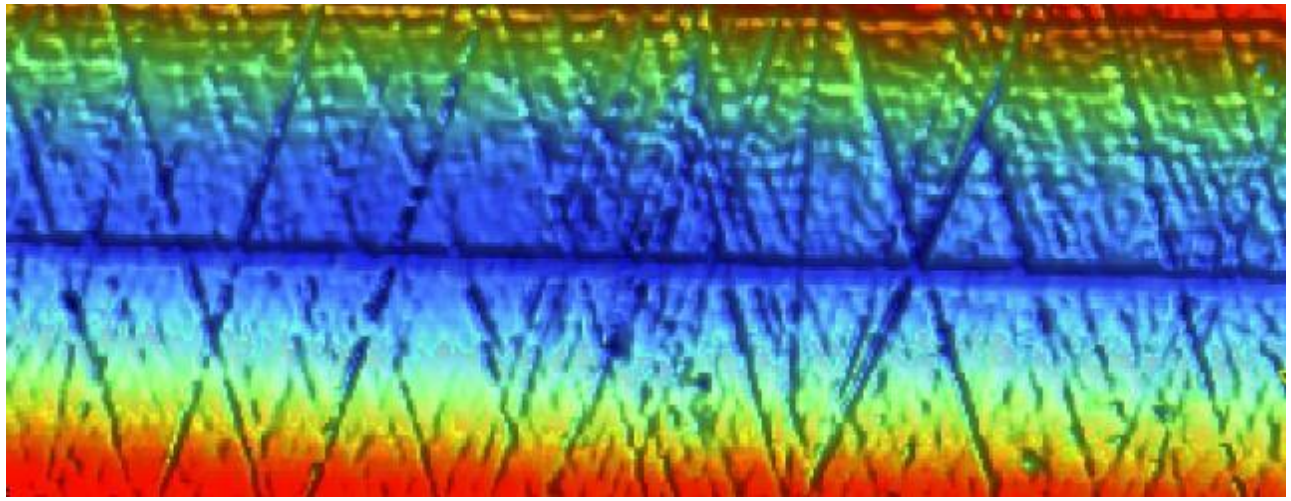
Cylinder Bore Inspection

Complete Solution for Post-Inspection

Severe Cylinder Wear and Catastrophic Damage







Brake

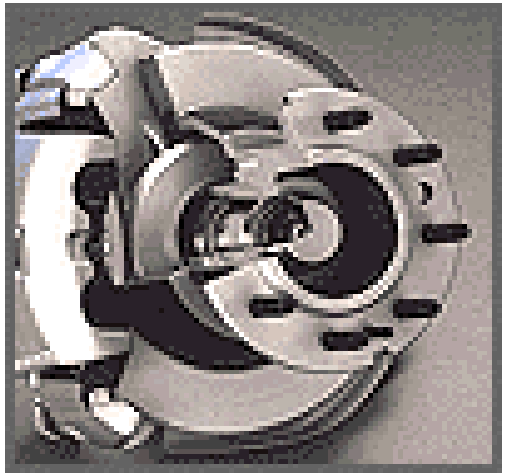
Brake Rotor
Characterization of Performance

- Brake rotor vibration
  - Enhanced process control of noise vibration harshness
  - Discern between tool life, material, pre/post machining operations, etc.

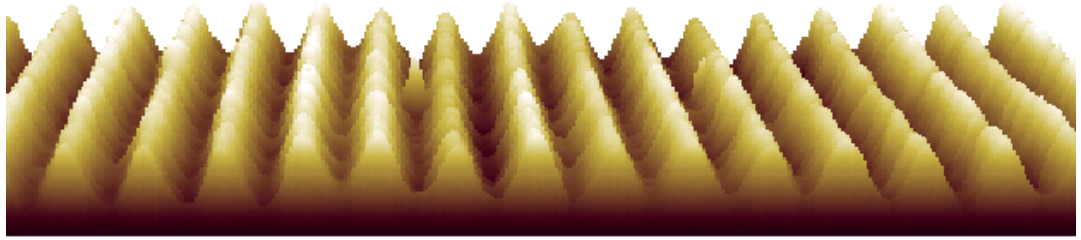
Quiet

Ra: In spec

Sdq: ***Low***



Noisy



Ra: In spec

Sdq: ***High***

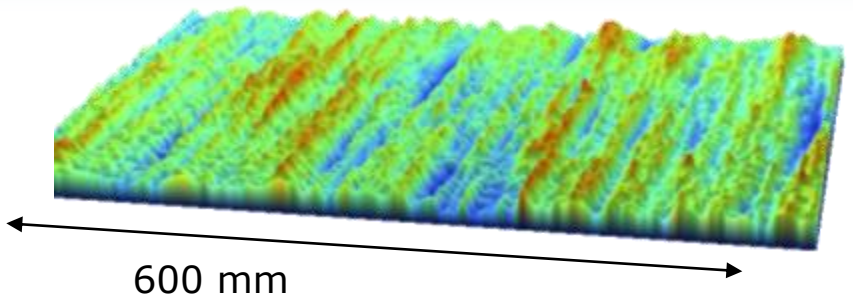
Cam and Crank shaft

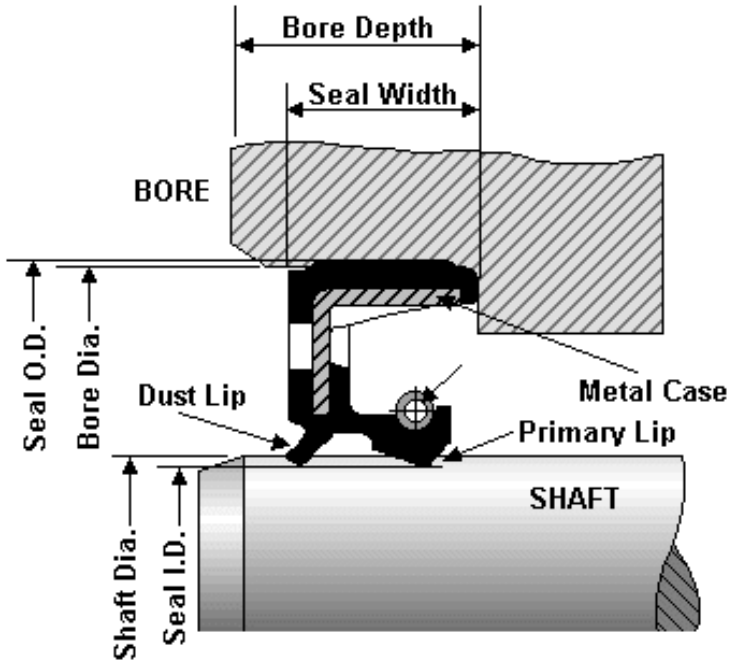
Shaft roughness

Leak Prevention with Sds/Ssc Parameters

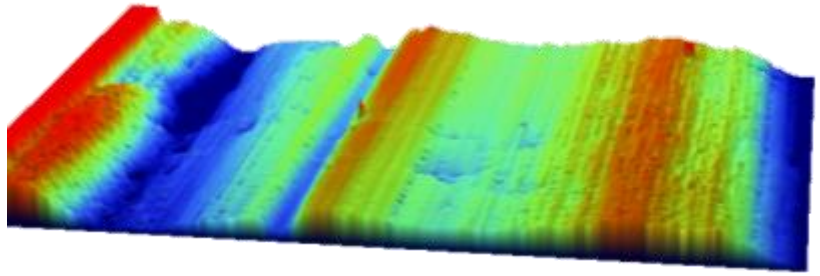
Sa	368nm
Sds	1130 /mm^2
Ssc	49 mm^{-1} (radius 20mm)

New shaft



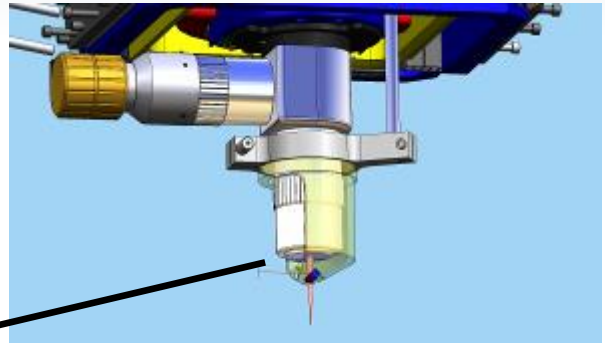


Used shaft

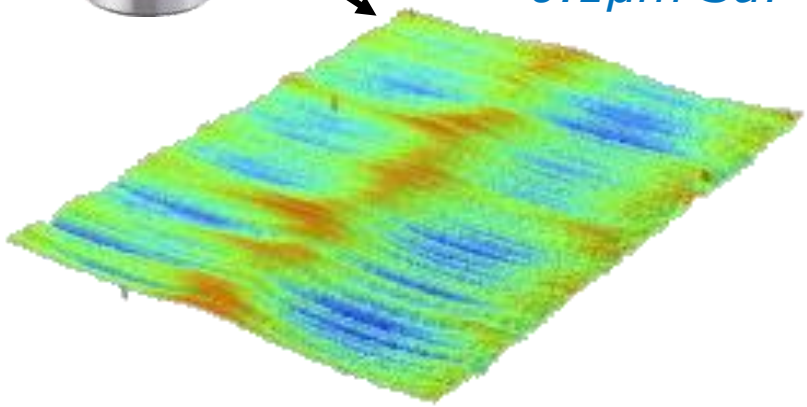


Sa	769 nm
Sds	247 /mm^2
Ssc	6 mm^{-1} (radius 166 mm)

Camshaft & Crank Shaft Roughness
Challenging Access Resolved with SLWD



0.1µm Sa!

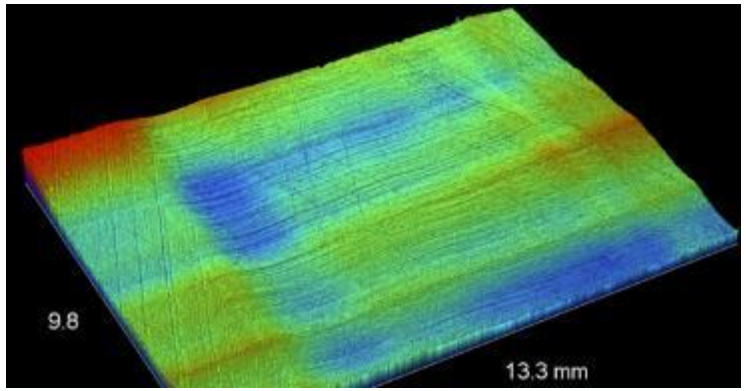


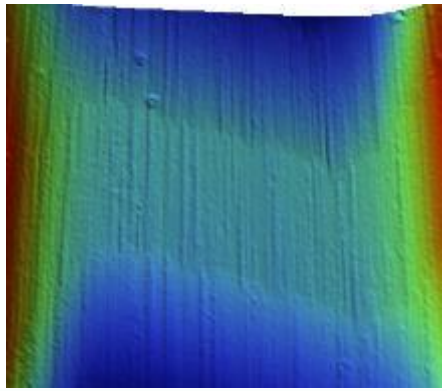
Lobing

Crank shaft

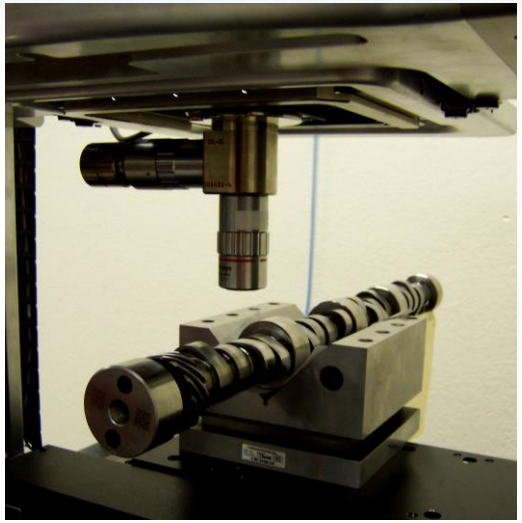
Wear Scar &

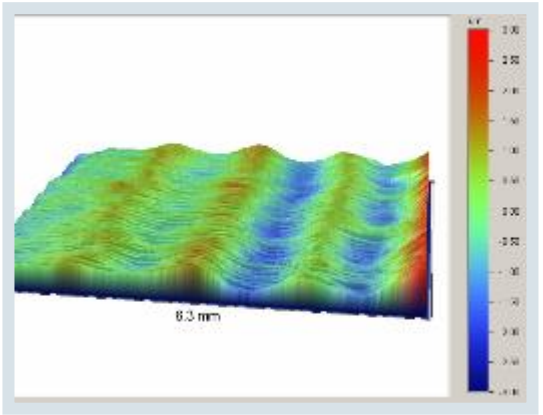
Flat Spot





Camshaft
Lobe Chatter

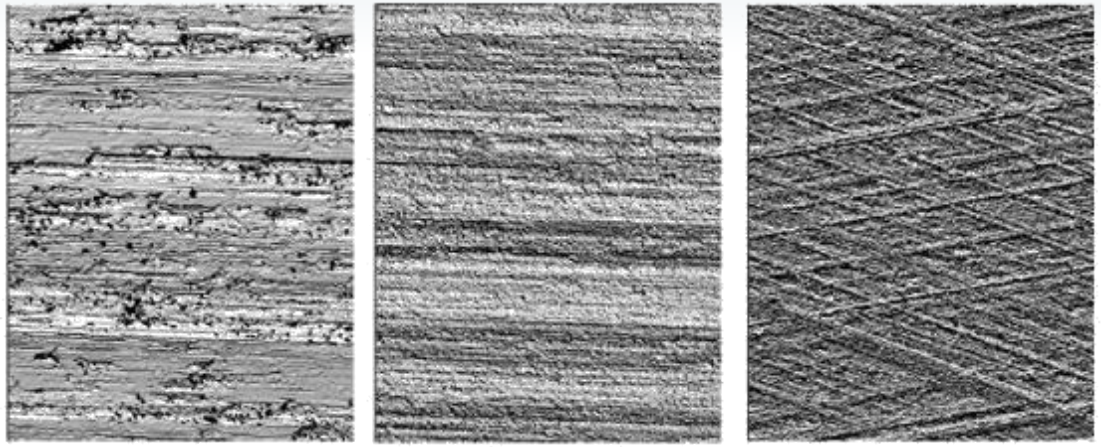




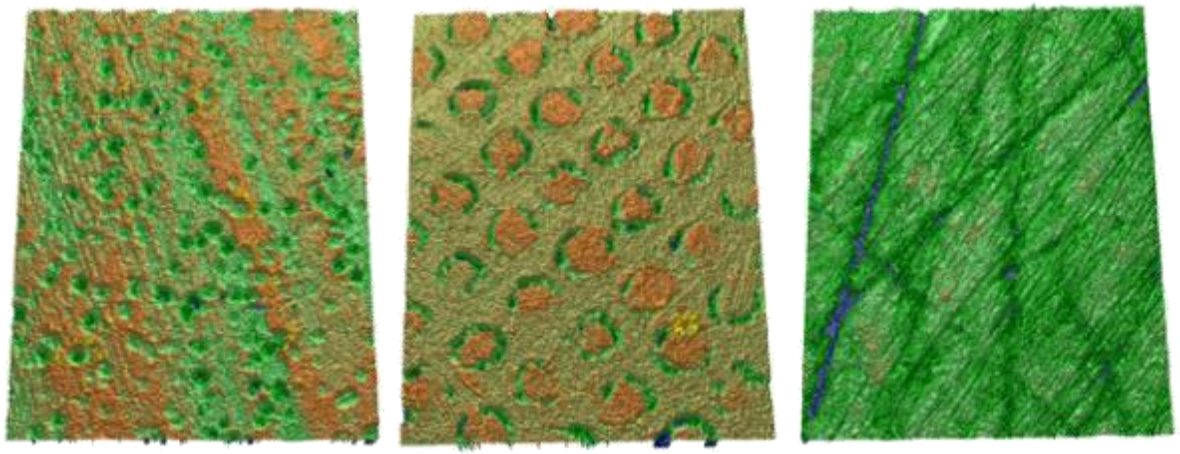
- Surface texture of camshaft lobe shows evidence of chatter
- Quantify periodicity with optical interferometry
- Metrology results in:
  - Better manufacturing and design of interfacing surfaces to avoid engine noise & failure
  - Better operation and timing for proper combustion and subsequent lower emissions

Material Surface Assessment

Influence of Texture & Processes
Surface Finish to Efficiency/Performance



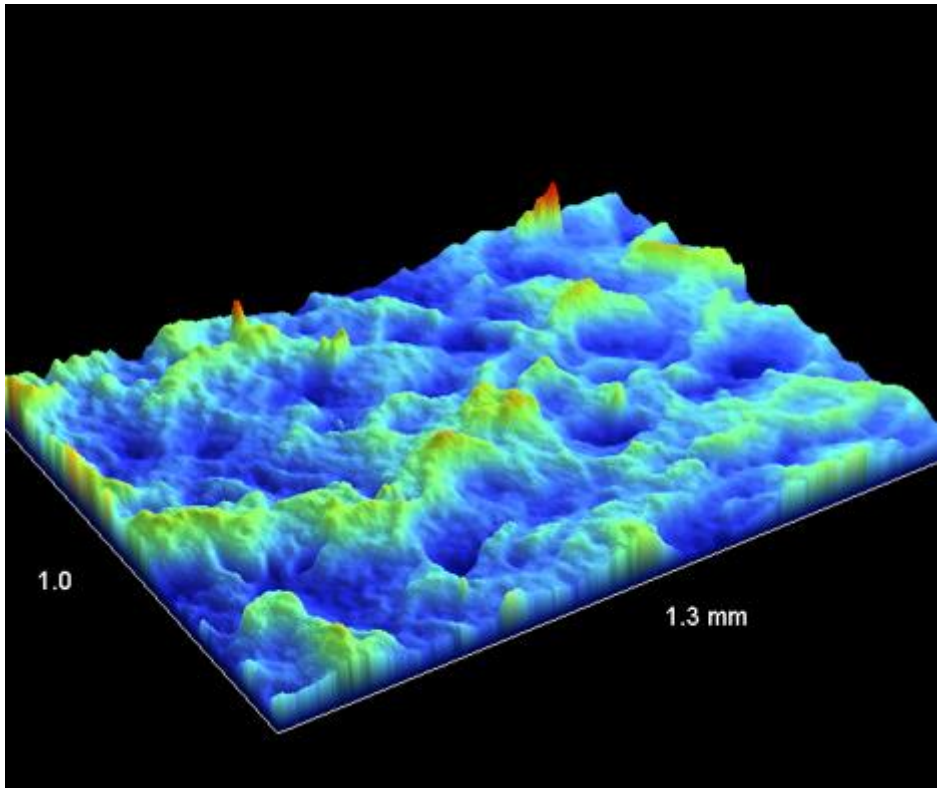
Cylinder bore machining
(Courtesy GM Powertrain)



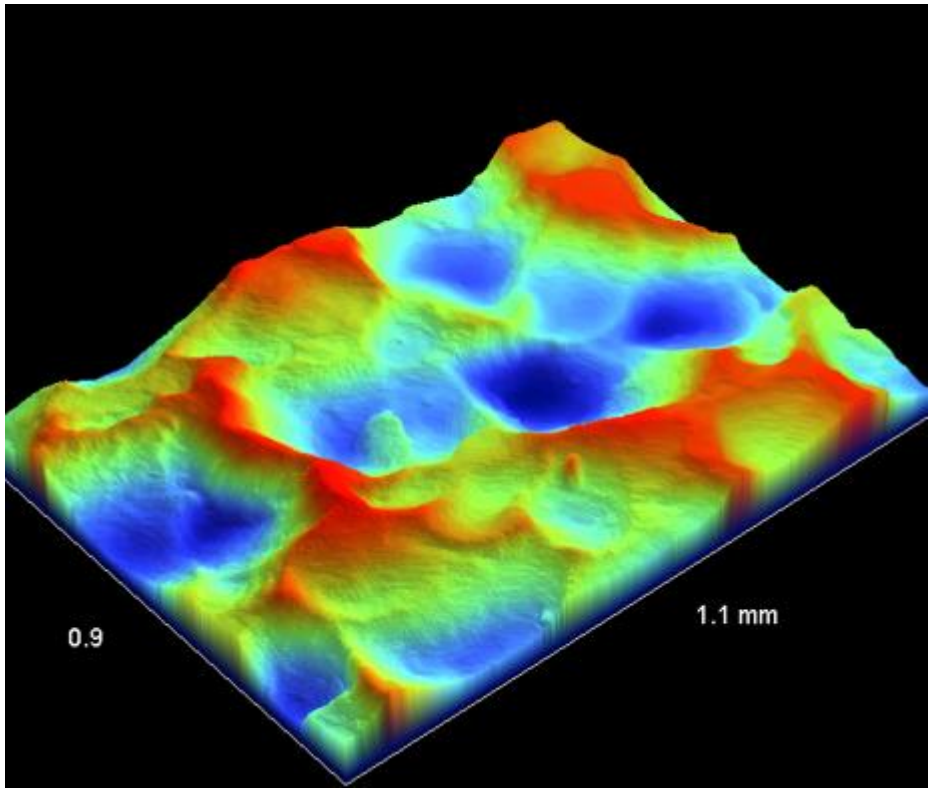
Experimental **Clutch plate** designs
(Courtesy Steel Parts)

Influence of Texture & Processes

Surface Finish to Process Results



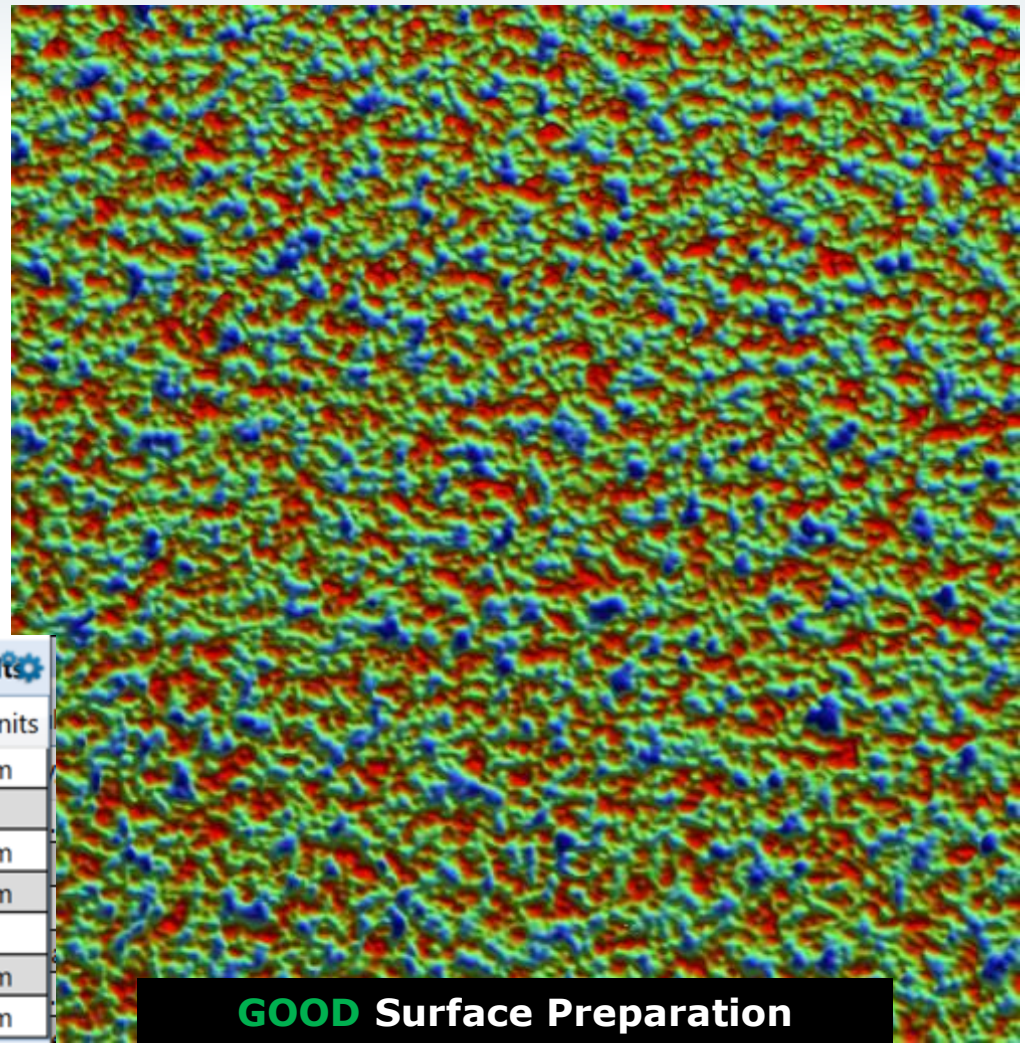
Shot Peened surface



Laser Peened surface

Influence of Texture & Processes

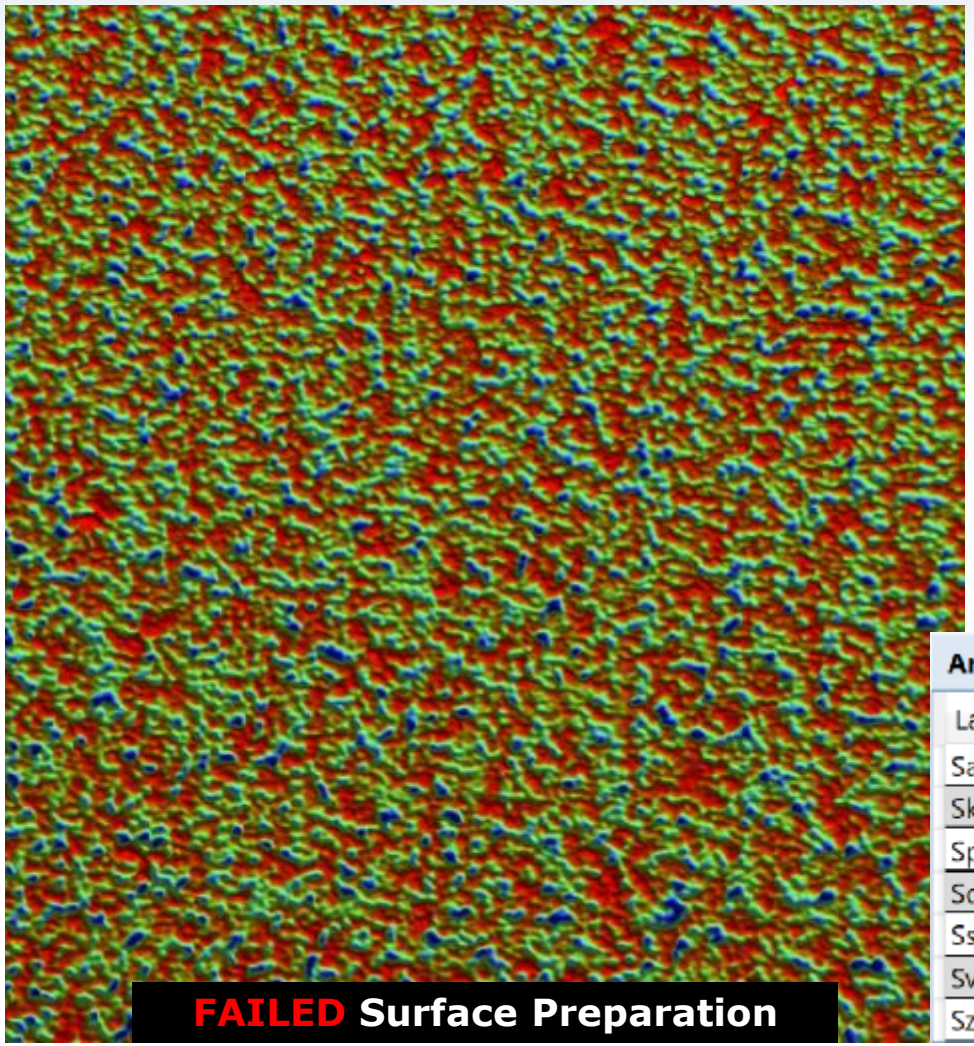
Pre-Paint Surface Finish to Final Visual Quality



GOOD Surface Preparation

Analytical Results

Labe	Value	Units
Sa	0.774	µm
Sku	3.898	
Sp	10.055	µm
Sq	0.982	µm
Ssk	-0.759	
Sv	-5.647	µm
Sz	15.702	µm



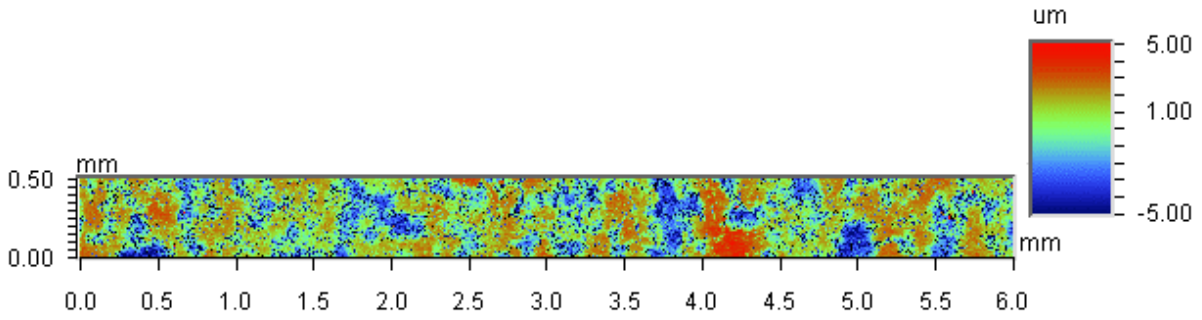
FAILED Surface Preparation

Analytical Results

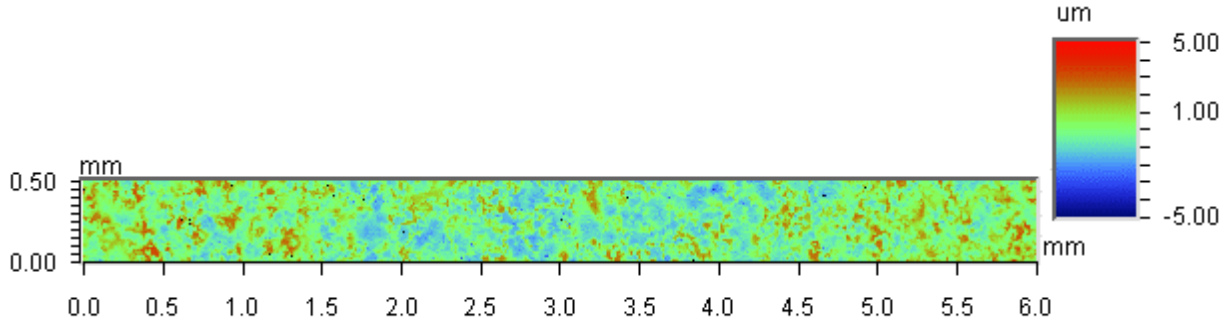
Labe	Value	Units
Sa	1.153	µm
Sku	2.803	
Sp	4.69	µm
Sq	1.425	µm
Ssk	-0.197	
Sv	-6.774	µm
Sz	11.464	µm

Influence of Texture & Processes
Various Preparation Processes

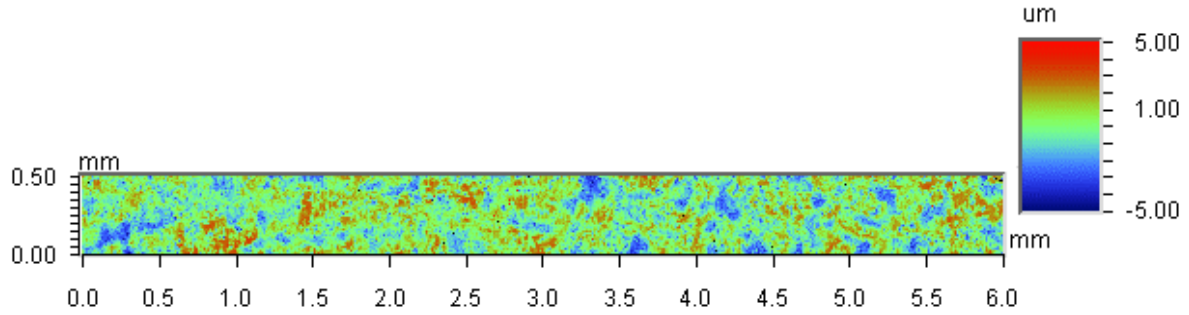
- The surface roughness and waviness of different steels was quantitatively tested



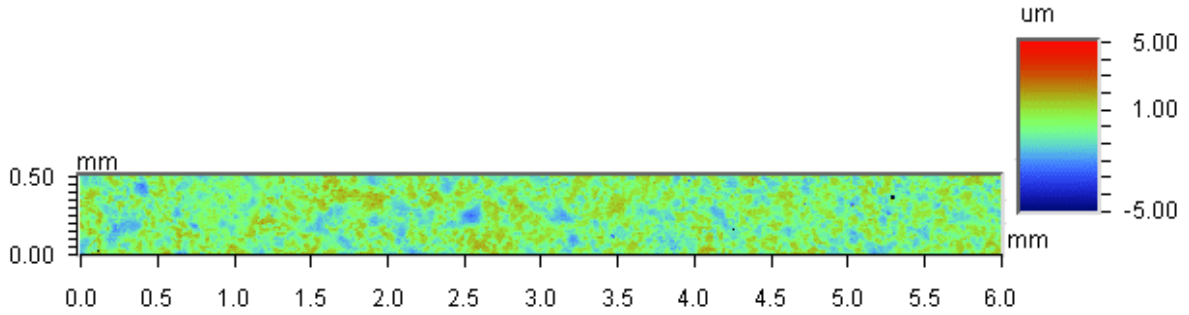
Hot Dipped Galvanneal



Electrogalvanic



Electrogalvanized

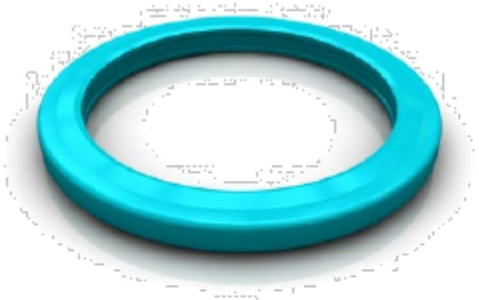


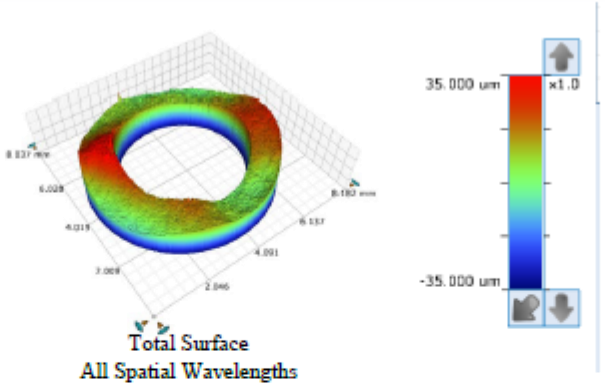
Cold Rolled Steel

Sealing Surfaces

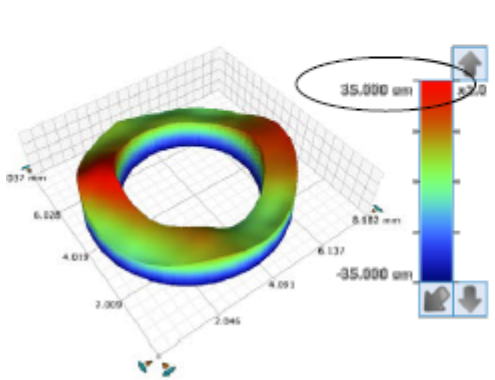
Flatness
From Seals to Fuel Injectors

Face Seal – "Form – Waviness – Roughness"

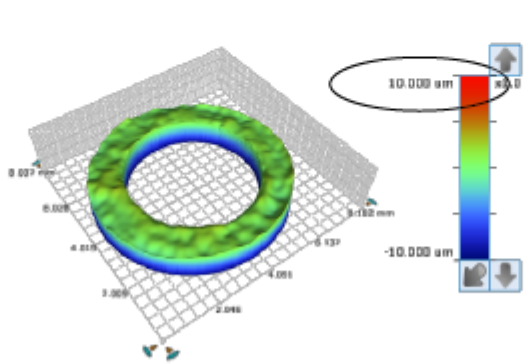




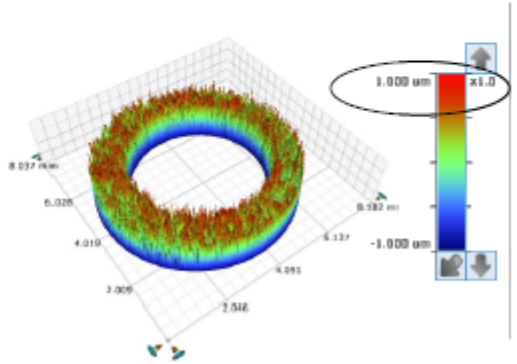
Total Surface
All Spatial Wavelengths



Form
Wavelengths > 1mm

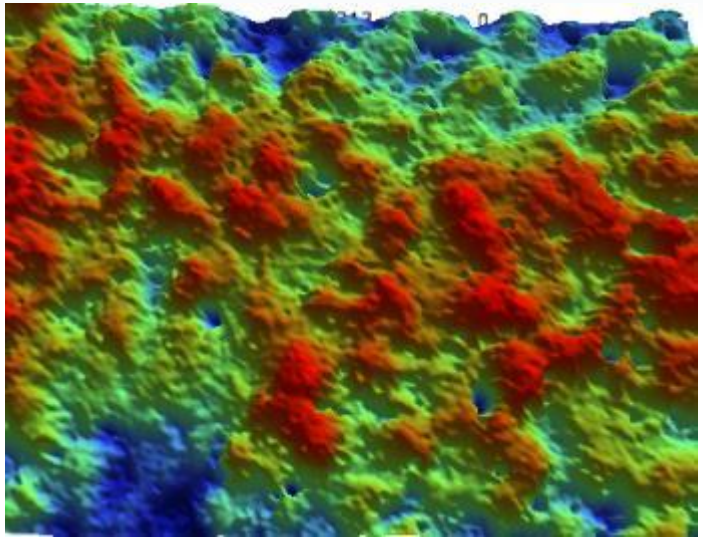


Waviness
0.5 mm < Wavelengths <1 mm

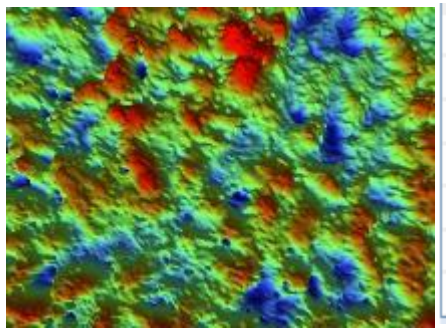


Roughness
Wavelengths < 0.5 mm

Rubber O-Ring



O-Ring Form Removed



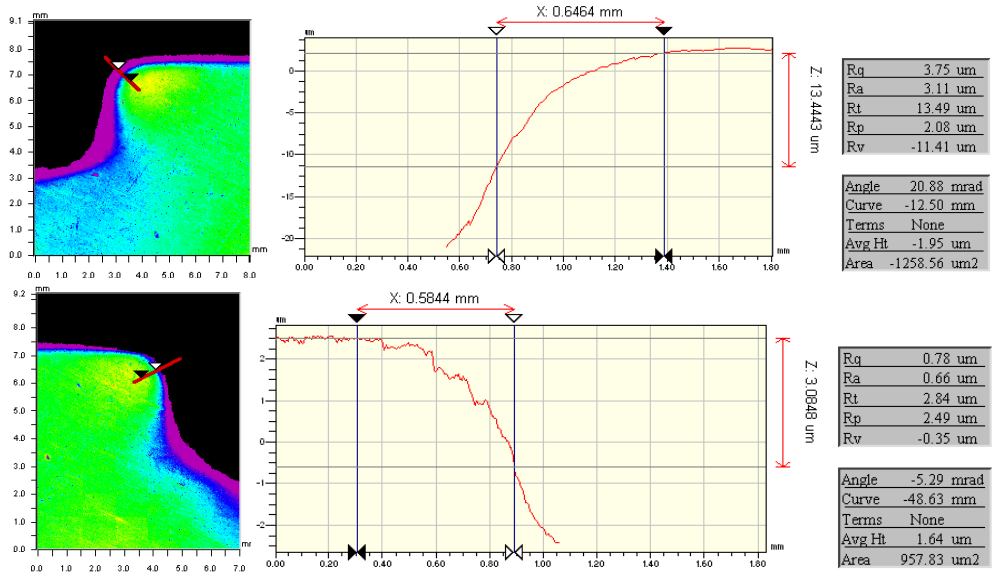
Sa	2.066	µm
Sku	3.675	
Sp	9.365	µm
Sq	2.63	µm
Ssk	-0.204	
Sv	-21.94	µm
Sz	31.305	µm

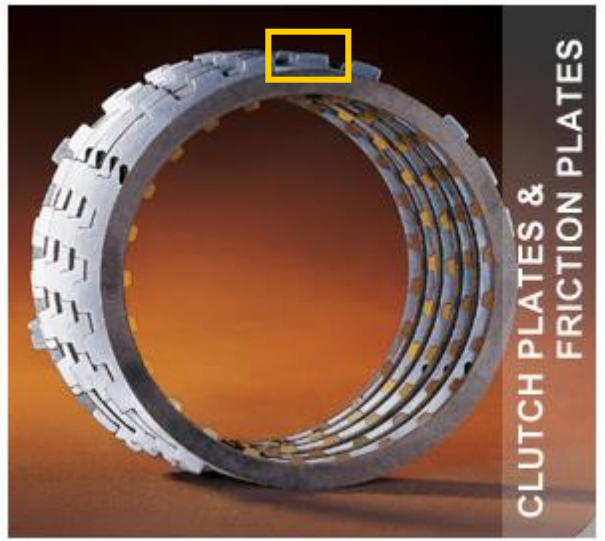
Clutch

Clutch Plate Tab Roll Off

Easy Acquisition and Analysis

- Metrology results in better clutch materials for improved performance
- Roll off limits movement of the whole plate- tabs stick to hub
- Friction causes chatter, premature wear, slippage, overheating



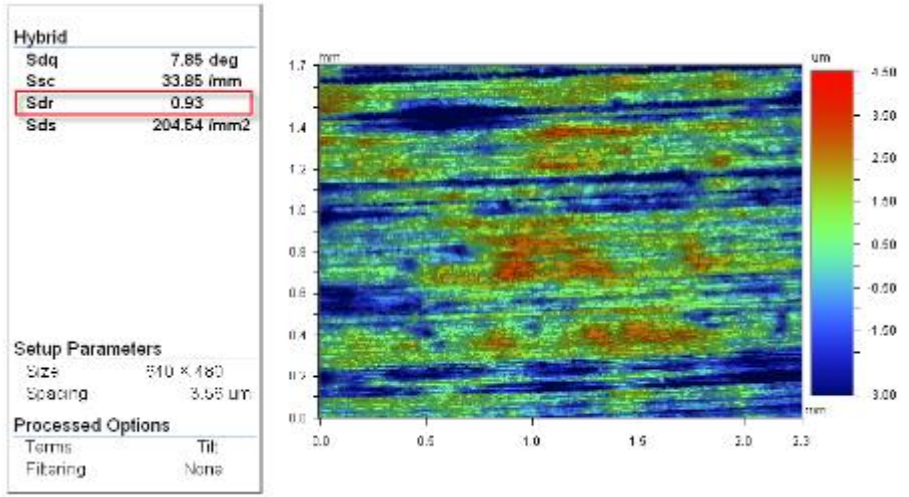


Radius of curvature: 12.50mm & 48.63mm

Rotor

Tribology of Rotors
New Areal Roughness Parameters

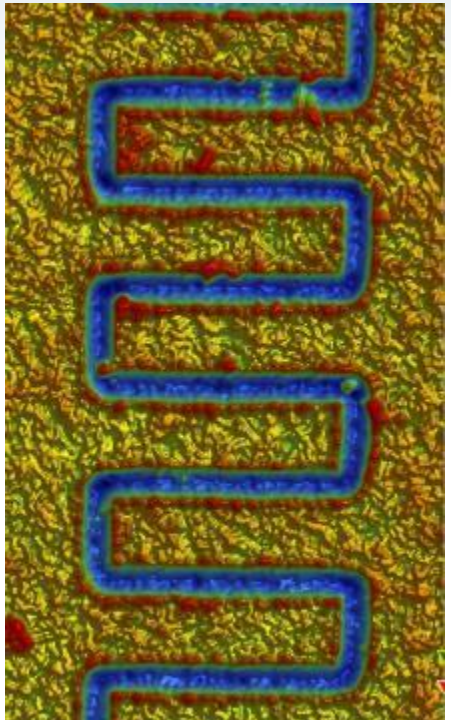
- Contact surface under significant load, friction, heat
- S Parameter Metrology provides:
  - Functional: surface wear, lifetime, performance, fluid retention information
  - Hybrid: directionality of surface texture

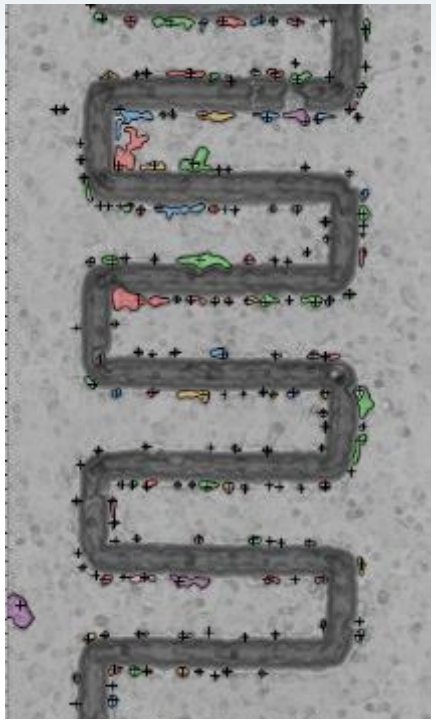


Sensors - Electronics

Electronic Measurements

Qualification and Failure Analysis



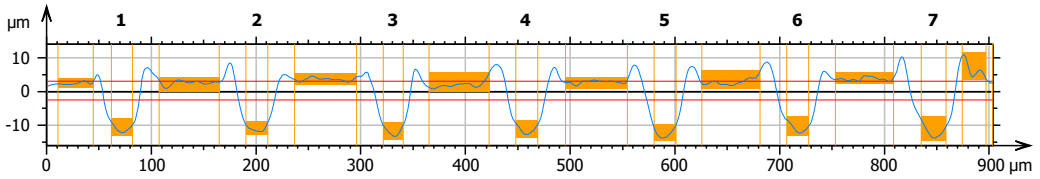


Engine Oxygen Sensor

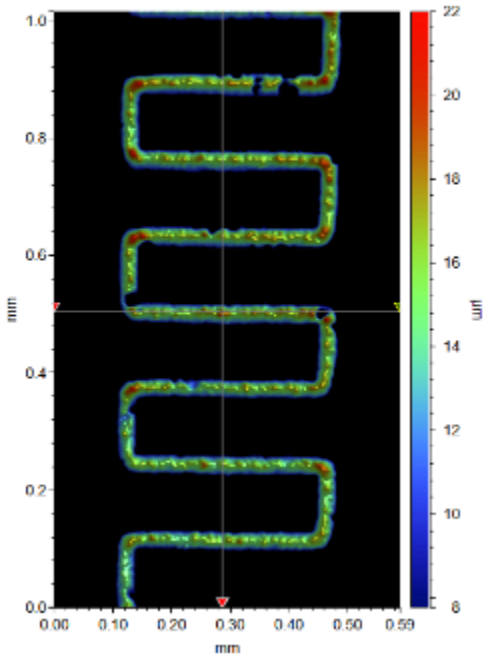
Analytical Results

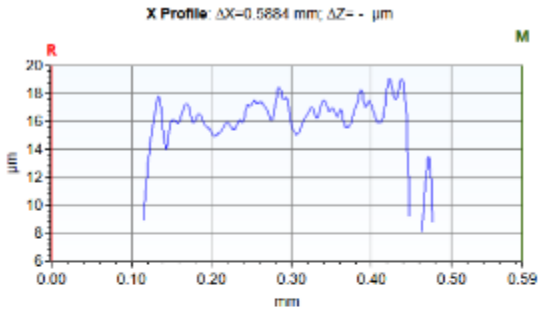
Label	Value	Units
Natural Volume	0.005	mm^3
Negative Volume	0.001	mm^3
Net Missing Volume	-12574.056	μm^3
Normal Volume	5.201	μm^3
Positive Volume	0.001	mm^3
Total Displaced Volume	0.003	mm^3

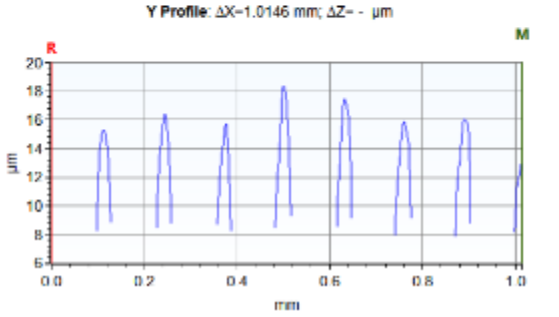
Extracted profile



Parameters	Unit	Mean	Min	Max	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Width	µm	20.95	19.13	23.68	20.04	20.95	19.13	20.95	20.95	20.95	23.68
Maximum depth	µm	15.89	14.95	16.83	15.27	14.95	16.34	15.77	16.77	15.33	16.83
Mean depth	µm	14.66	13.91	15.65	14.15	14.24	15.01	14.55	15.65	13.91	15.11





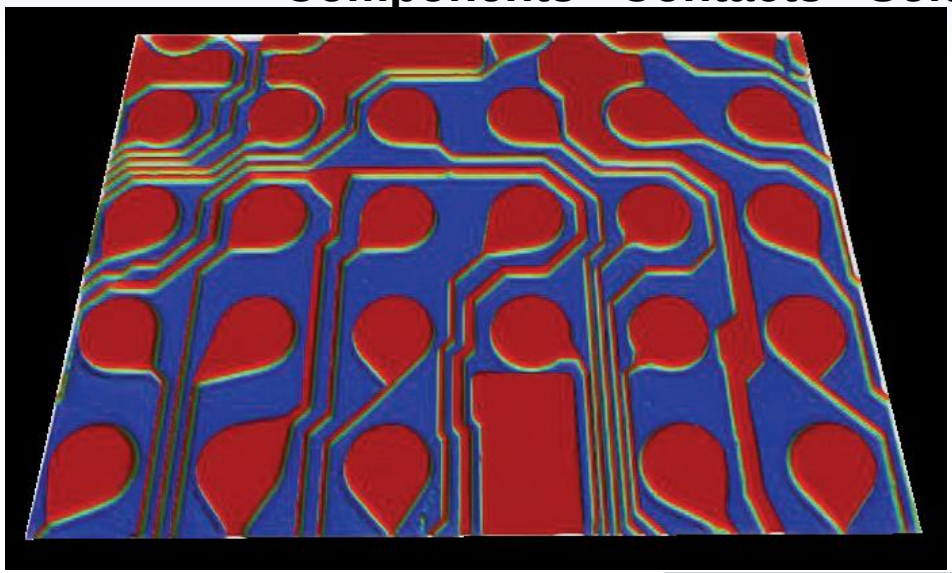


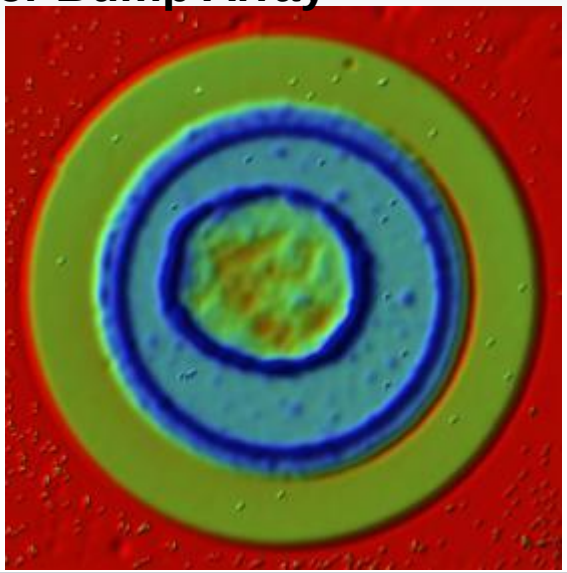
Analytical Results
General

Label	Value	Units
Height Avg	17.822	µm
No. Traces	1	
Space Ra	1.197	µm
Space Rq	1.935	µm
Space Rt	25.962	µm
Space Rz	25.617	µm
Trace 1 Height	17.822	µm
Trace 1 Width	0.115	mm
Trace 1 Width Max	0.362	mm
Trace 1 Width Min	9.073	µm
Trace 1 Width Stdev	0.14	mm
Trace 1 Width2	0.115	mm
Trace 1 Width2 Max	0.362	mm
Trace 1 Width2 Min	9.073	µm
Trace 1 Width2 Stdev	0.14	mm
Trace Ra	2.122	µm
Trace Rq	2.549	µm
Trace Rt	11.935	µm
Trace Rz	11.748	µm
Trace Width Avg	0.115	mm
Trace Width Avg2	0.115	mm
Trace Width Max	0.115	mm
Trace Width Min	0.115	mm
Trace Width Stdev	0	mm
Trace Width Stdev Avg	0.14	mm
Trace Width Stdev Avg2	0.14	mm

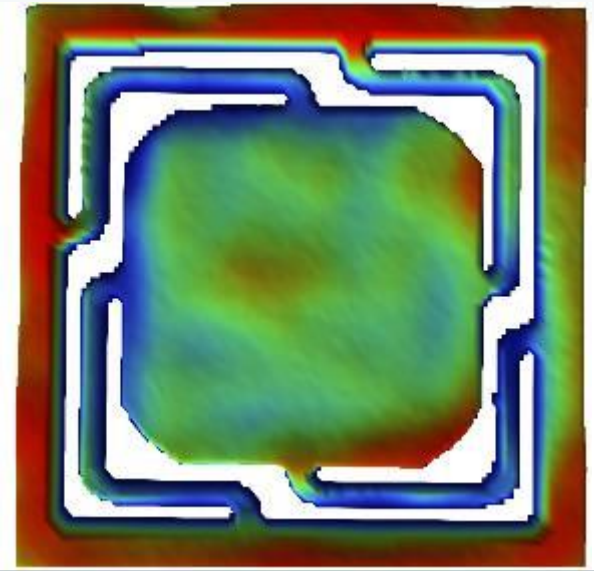
Electronic Measurements
Qualification and Failure Analysis

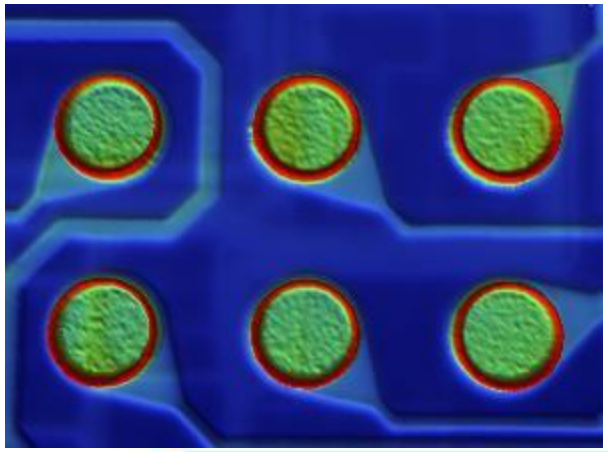
Components - Contacts - Solder Bump Array

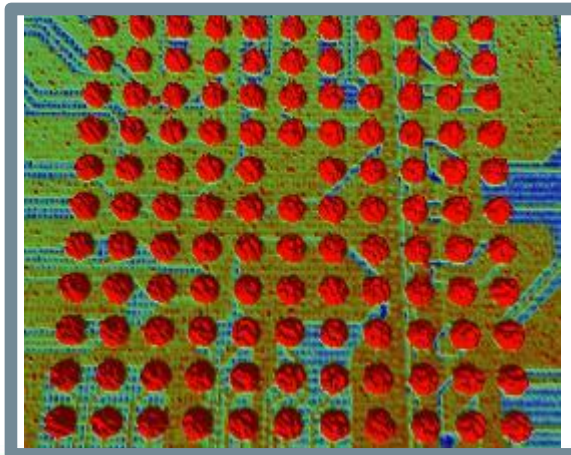




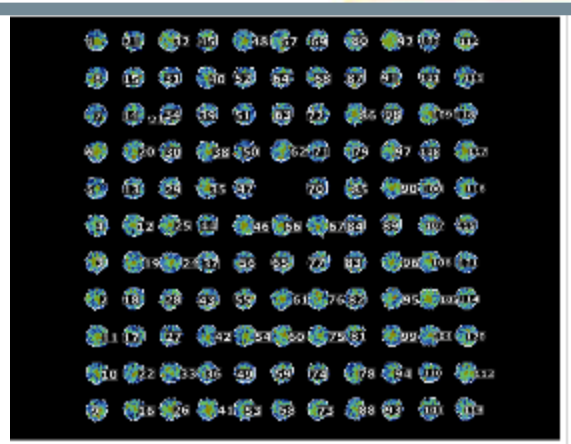
MEMS Sensors

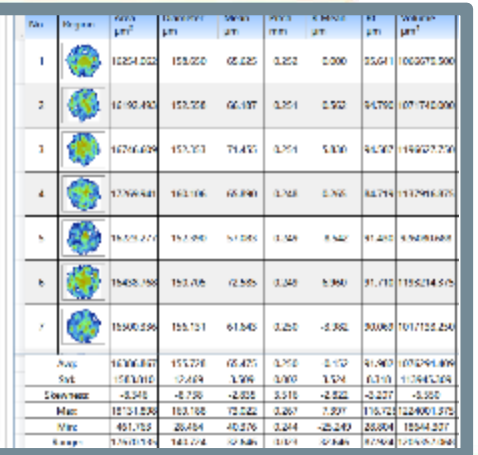






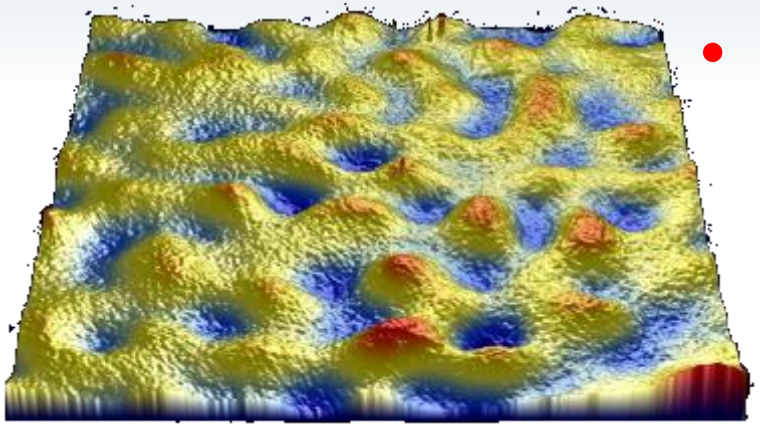
Raw and Analyzed





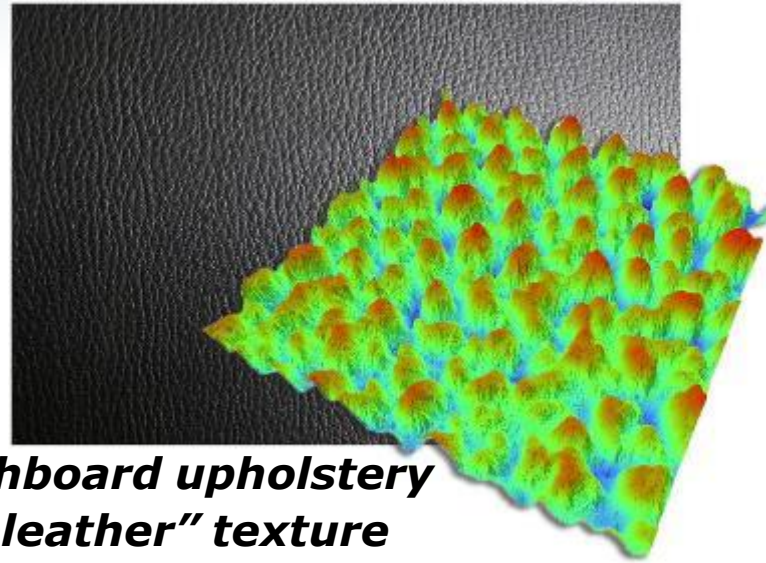
Visual Appearance - Upholstery/Paint

Quantify Appearance
New Areal Roughness Parameters

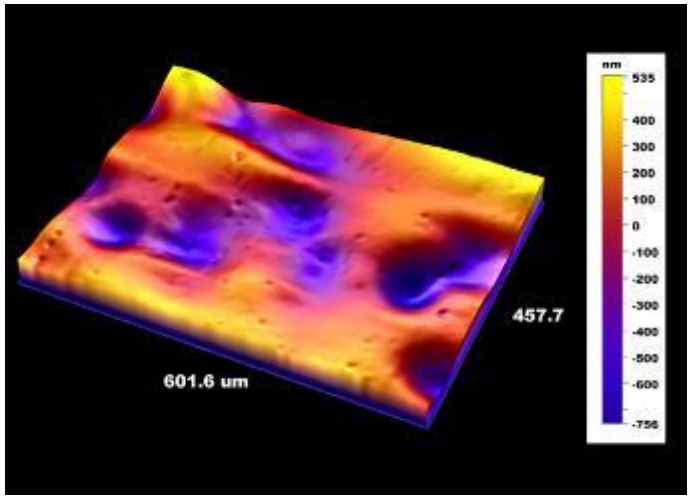


"Orange peel" in paint

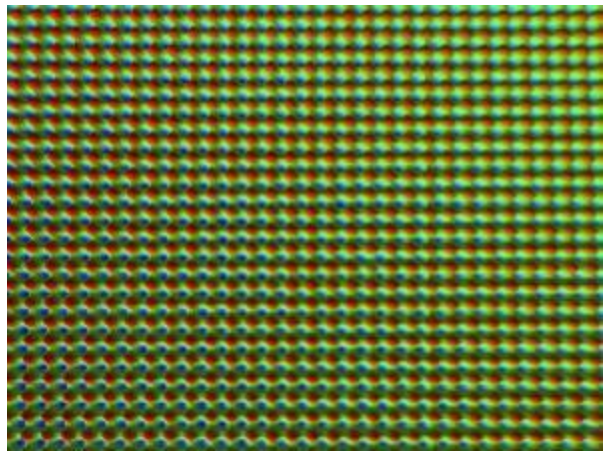
- Bruker profilers have characterized automotive surface finish
  - Cosmetic finishes
  - Surface-prep/cleaning
  - Paint
  - Plating
  - Anodizing
  - Polishing
  - Upholstery



Dashboard upholstery "pleather" texture



Electro-polished surface



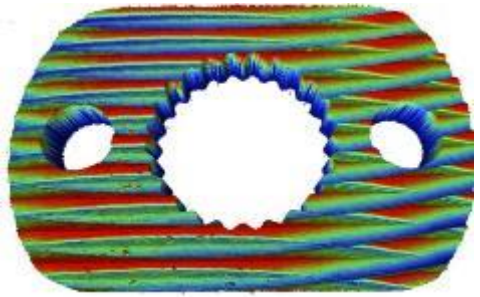
Lense - Reflector

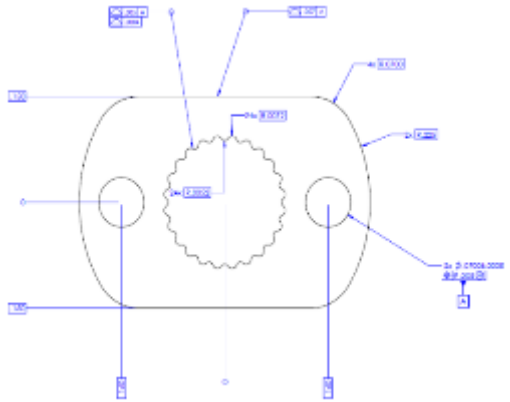
Dimensional Measurements

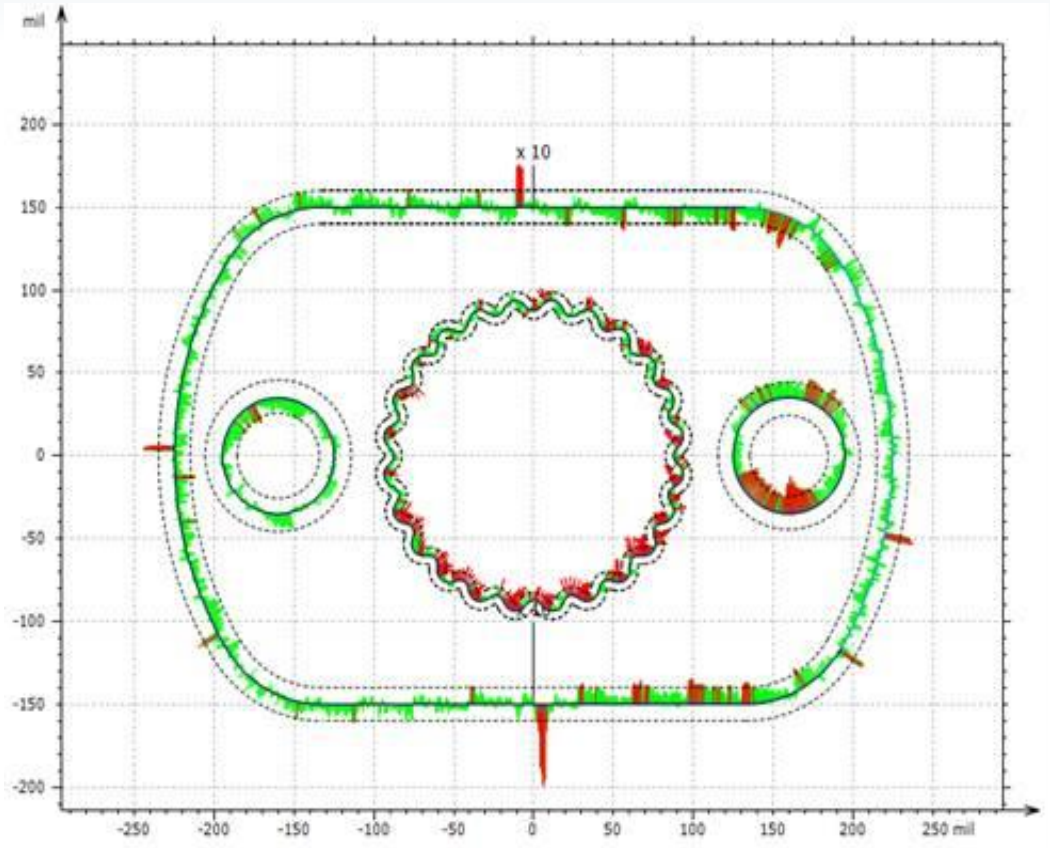
Dimensional Measurements

2D CAD Analysis w/ Vision MAP

Contour analysis





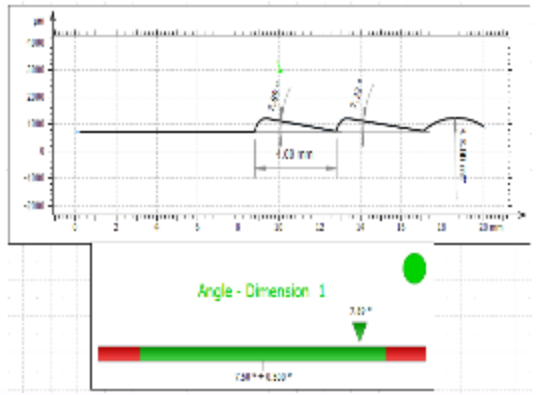


Part courtesy of

Mechanical workpiece

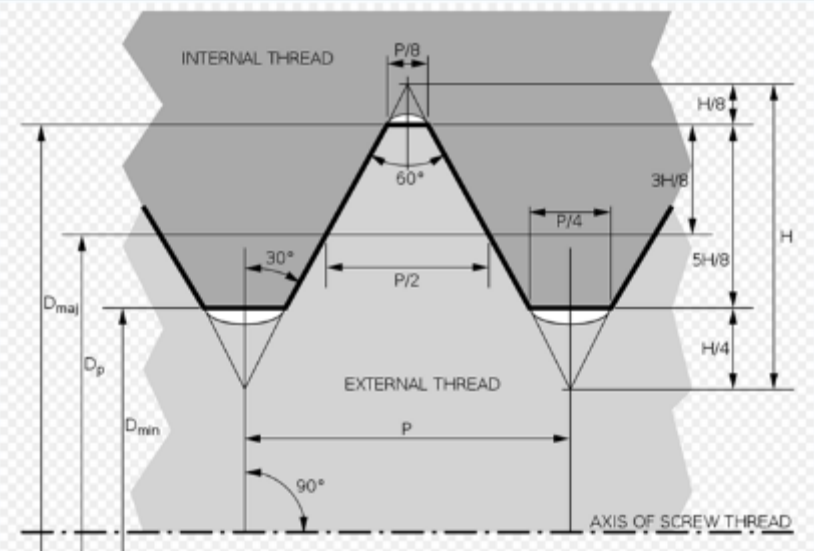
Dimensional analysis of geometrical profiles according to ISO 1101: sizes, angles, radii, diameters, form deviations.

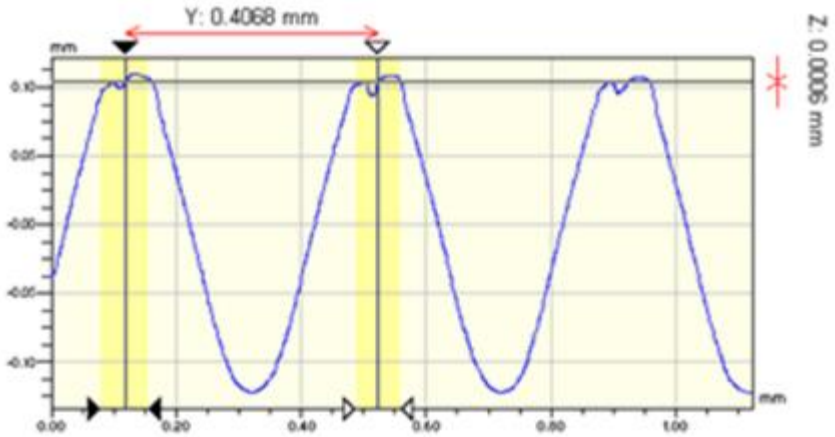
Compare against CAD model or user-defined tolerances



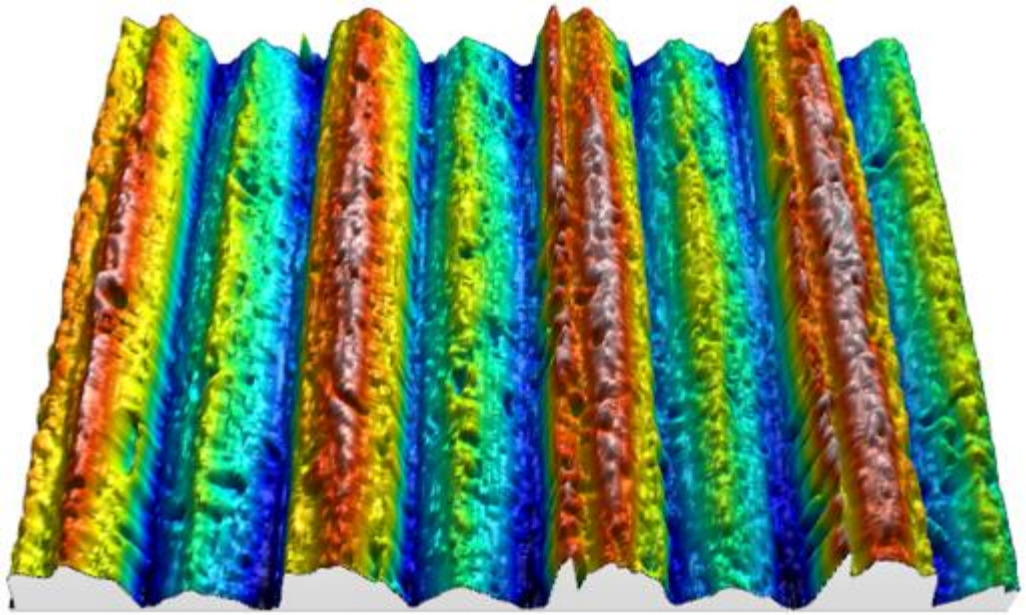
Dimensional Measurements

Thread Analysis w/ Vision MAP





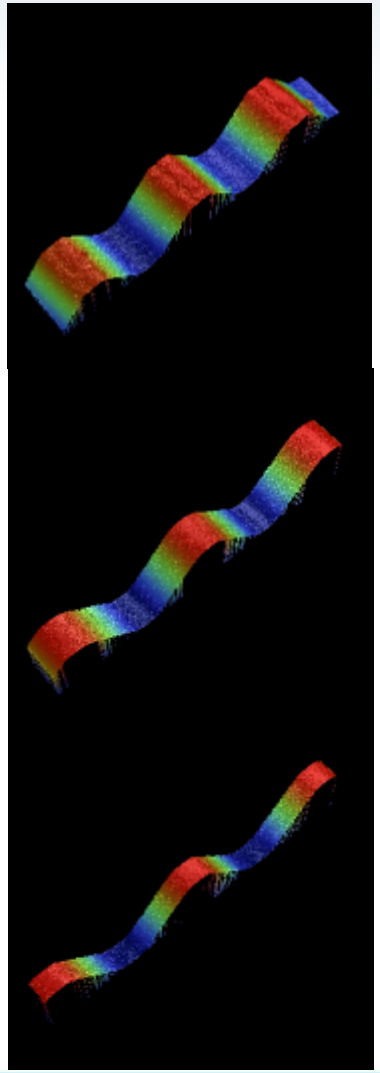
3D Thread Image



M2

M4

M8



Summary

Summary - *Characterization, Qualification and Failure Analysis*

- 3D optical profiling provides unprecedented, nondestructive insight into surface characteristics, functionality, and performance
- 3D profiling provides accurate surface data for:
  - R&D
  - Testing
  - Process development and control
  - Failure analysis
- Bruker Series of optical profilers offers the most comprehensive metrology platform available for quantifying wear, texture, manufacturing processes, and many other automotive applications with automated data capture and analysis

Innovation with Integrity