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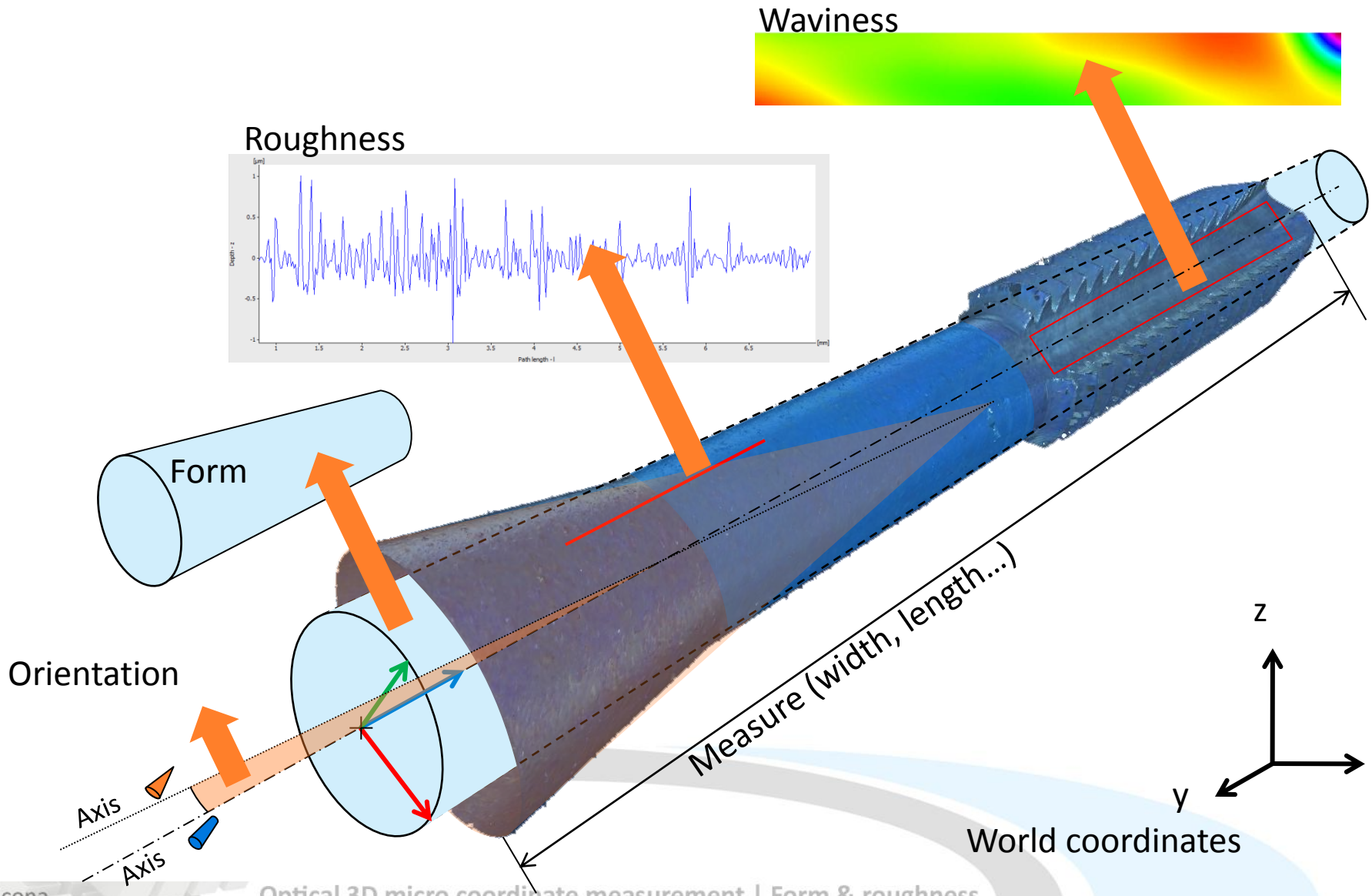
Roughness Measurements with InfiniteFocus

Pilsen, 18.10.2012

INTRODUCTION OPTICAL ROUGHNESS MEASUREMENT

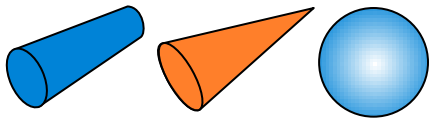
General Terms



Definitions

» **Form**

→geometric basic shapes



» **Roughness**

→high frequency wave length

» **Waviness**

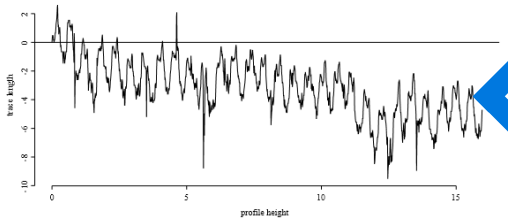
→low frequency wave length

» **Filtering**

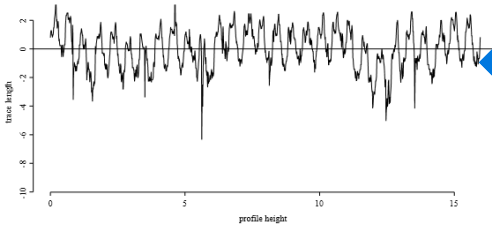
→the process of separating roughness and waviness

Form – Waviness – Roughness

Raw profile



Primary profile



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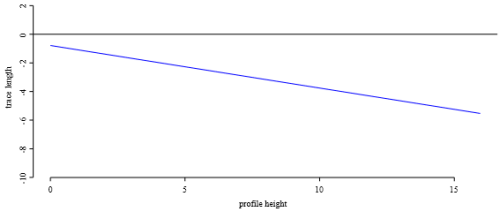
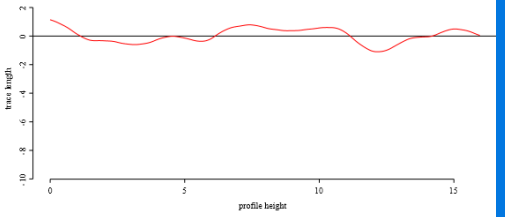


Form profile

Waviness profile



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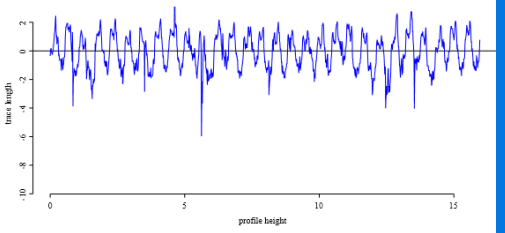
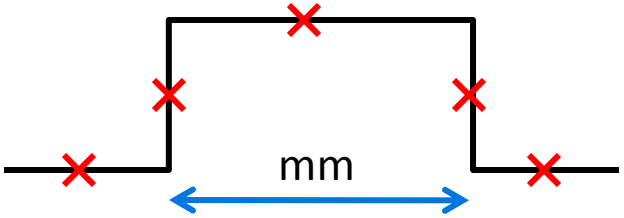
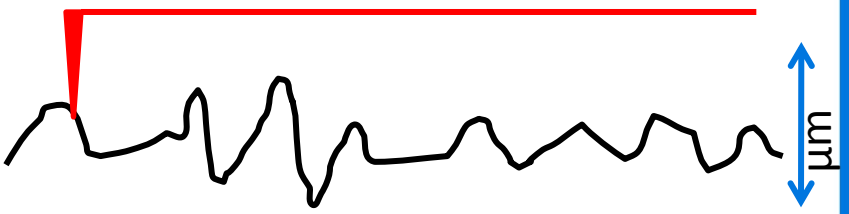
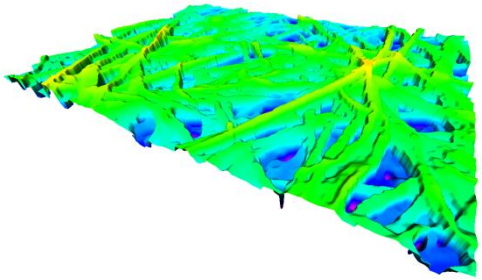


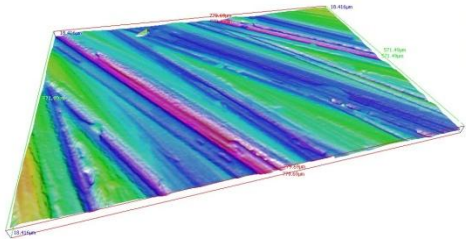
Roughness profile

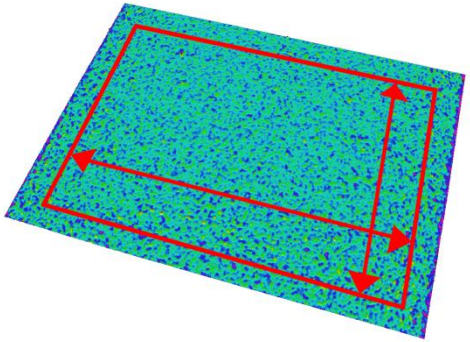
Form and Roughness Measurement

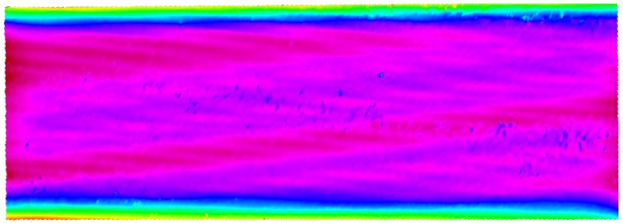
Form	Roughness
 × CMM measurement points	
Coordinate measurement device	**Profilometer**

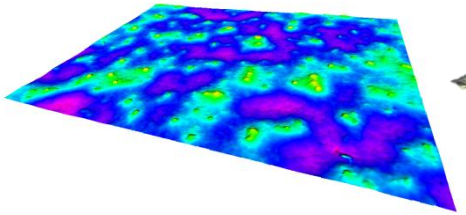
IFM combines roughness and form

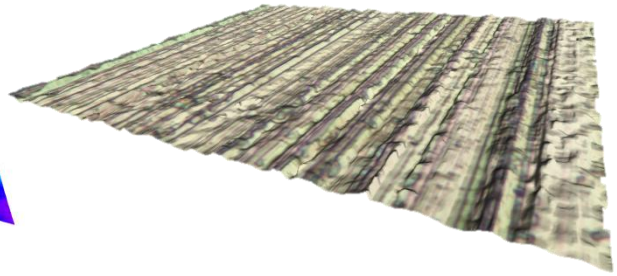


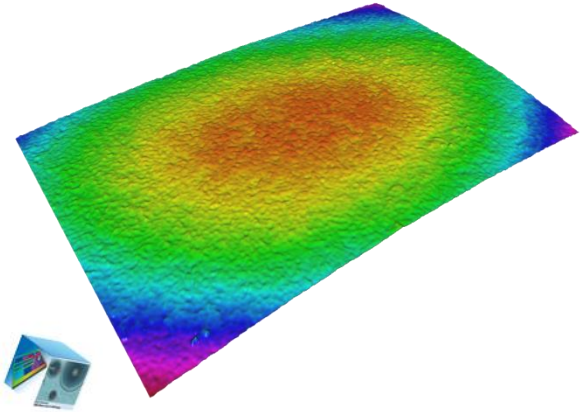


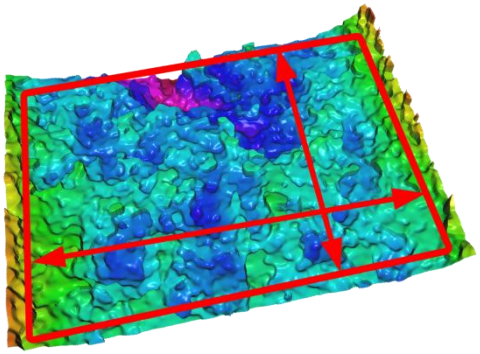


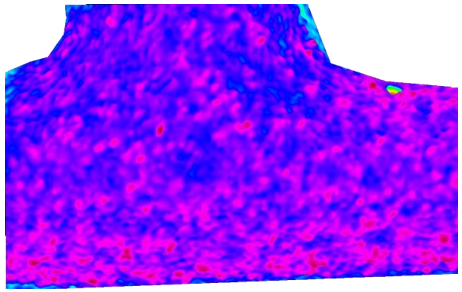












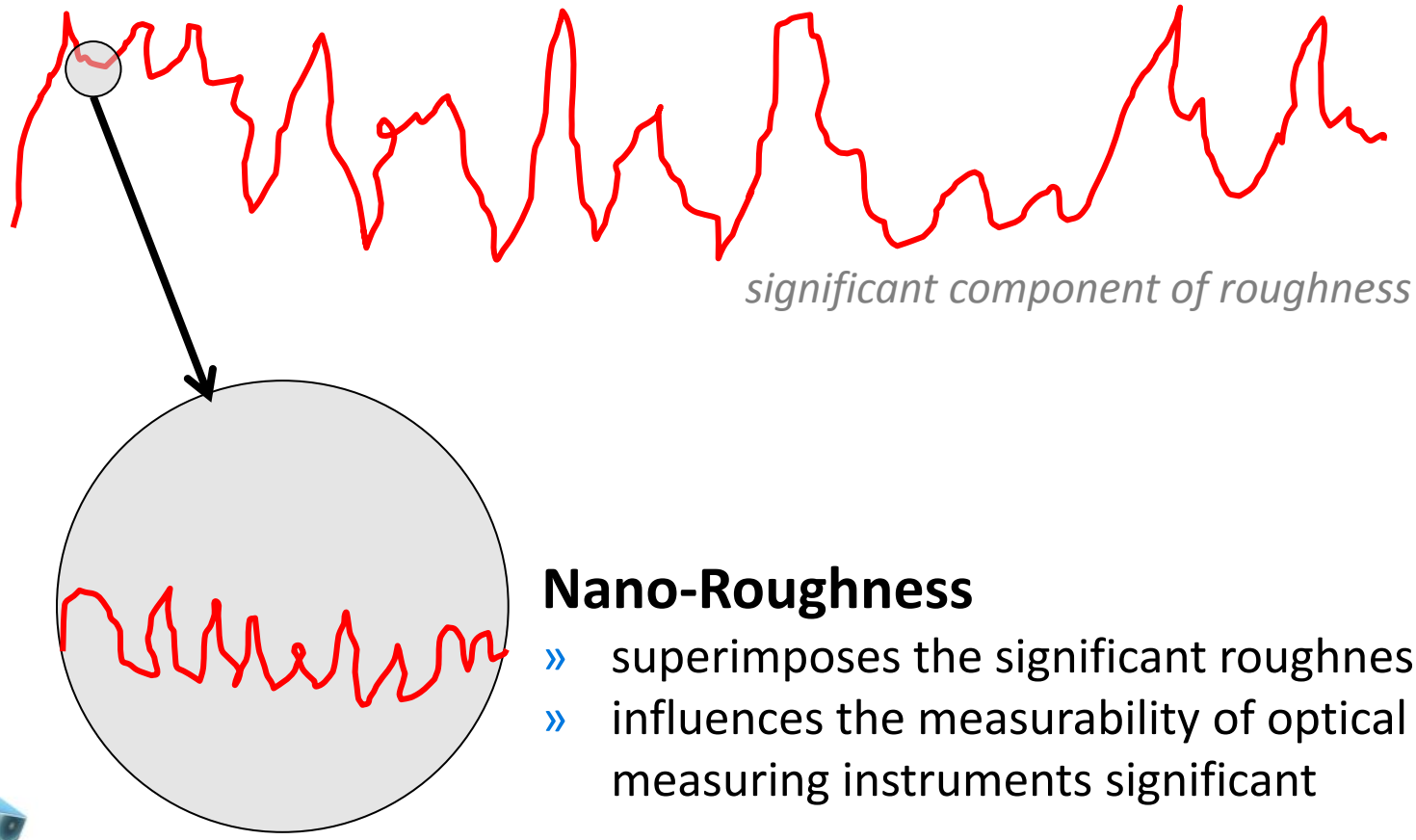
Typical Characteristics of Devices under Test for Roughness Measurements

- not transparent
- locally rough (hence they posses local „nano-roughness“)
- typical materials (metal, synthetic, ..)
- often: appropriate flanks

  --> Large scan range

  --> Large working distance necessary

Roughness Profile



Nano-Roughness

- » superimposes the significant roughness
- » influences the measurability of optical measuring instruments significant

Methods to Evaluate if the Roughness Measurement is Correct

Possible Methods

- MSA (Measurement System Analysis: Method 1-6)
- GUM (Guide to the expression of Uncertainty in Measurement)
- Gage R&R Study
- …

All these methods use calibrated comparison standards to demonstrate that a measurement device is capable of measuring a specimen.

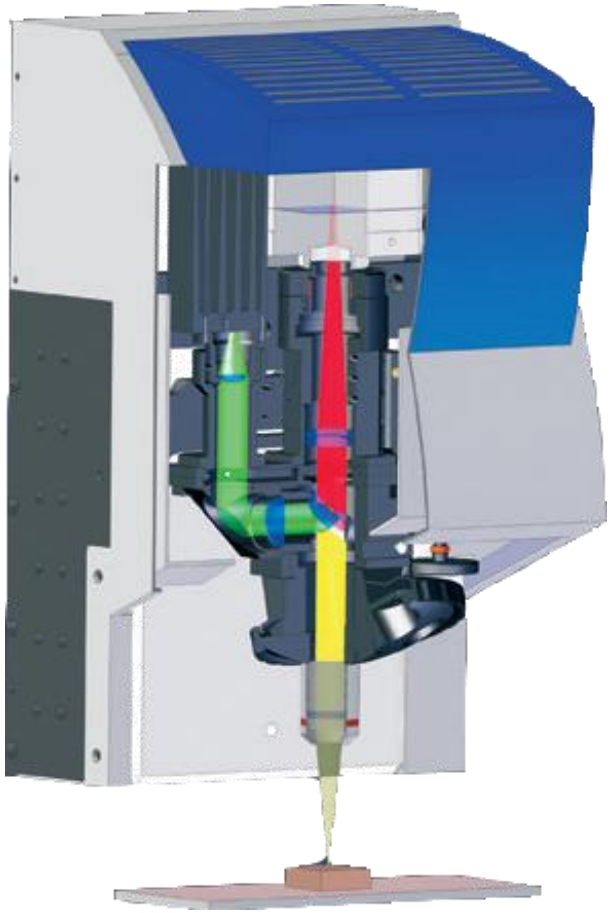
Agenda

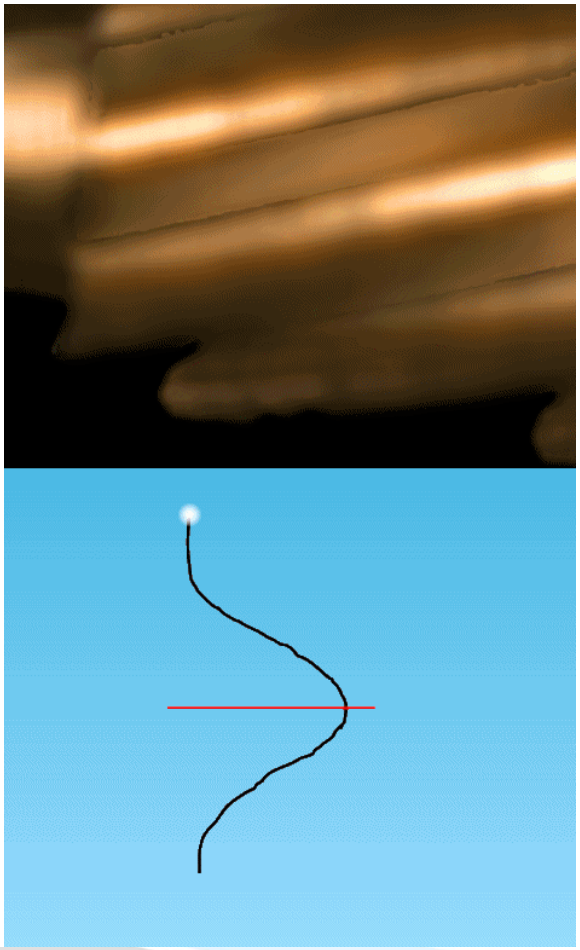
1. Focus-Variation explained
2. Why does focus variation work for roughness measurement
3. Why does the InfiniteFocus work for roughness measurement
4. Traceability and calibration
5. Practical results
6. Optical versus Tactile
7. Classification

1.

Focus Variation and InfiniteFocus Explained

Focus-Variation as Measurement Technique





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Focus-Variation
Technical Specifications

Optical 3D-surface metrology
based on a color focus sensor

Vertical resolution	**>10nm**
Lateral resolution	**>400nm**
Scan height	**<22mm**
Scan area	**100mm x 100mm**

Surface measurements in less than 16 sec.
(2 million measurement points, 11.6Mb)

Benefits of Focus-Variation

+ Form and roughness in one measurement

- + Rough and smooth surfaces
- + Color information
- + Steep flanks
- + Diversity of materials
- + Large measurement areas

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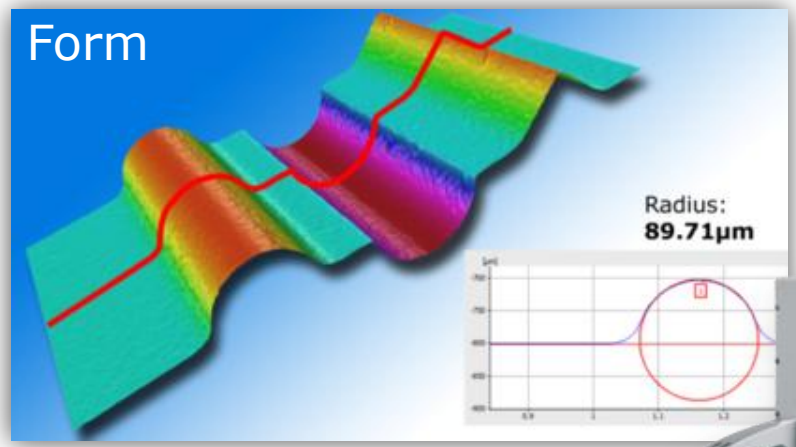
Technology Focus-Variation



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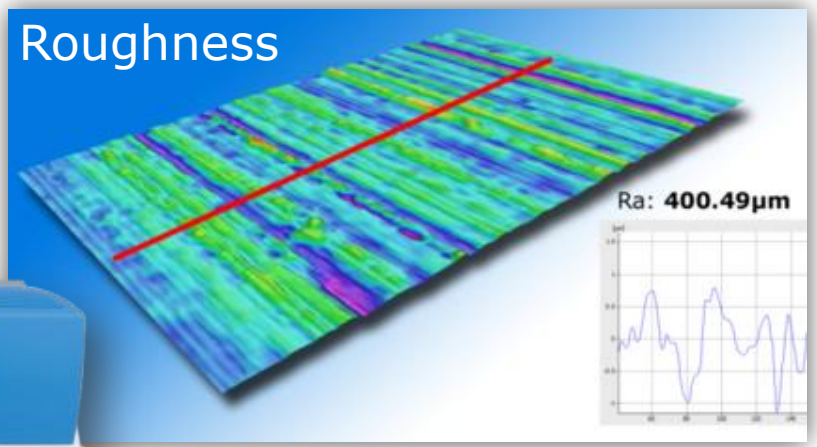
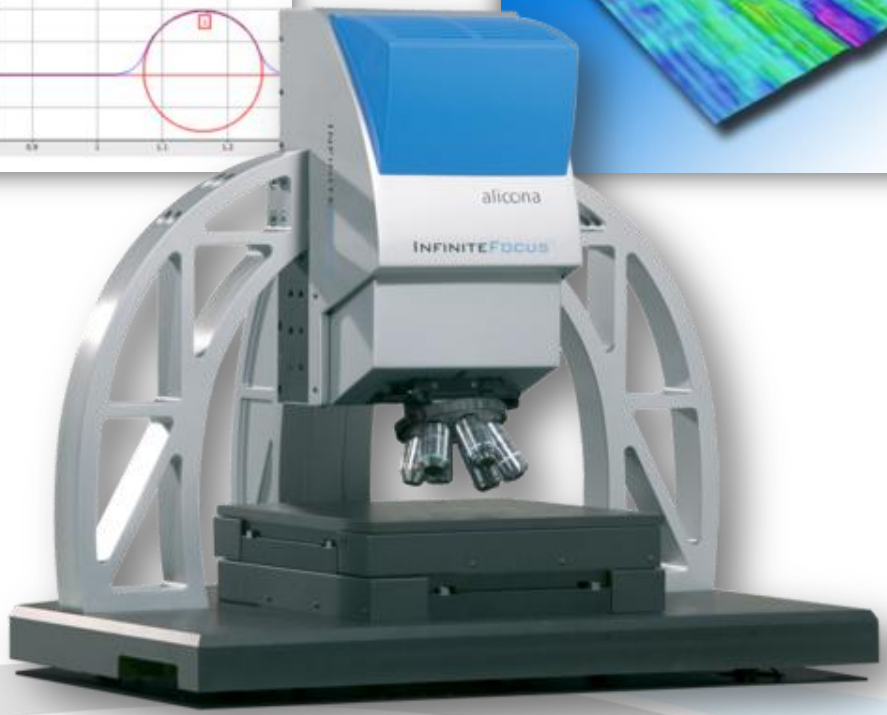




2.

Why does Focus-Variation work for roughness measurement?

Roughness Performance

- Ra of down to 0.05µm traceable and repeatable
- Measurement range beyond the typical piezo travel range
- Vertical resolution of 10nm
- Lateral resolution of less than 1µm
- Capable of measuring steep slope
- Capable of handling various materials through smart flash and polarization

- These are sales arguments and specs, why do we achieve those?

What we use and what we take care of

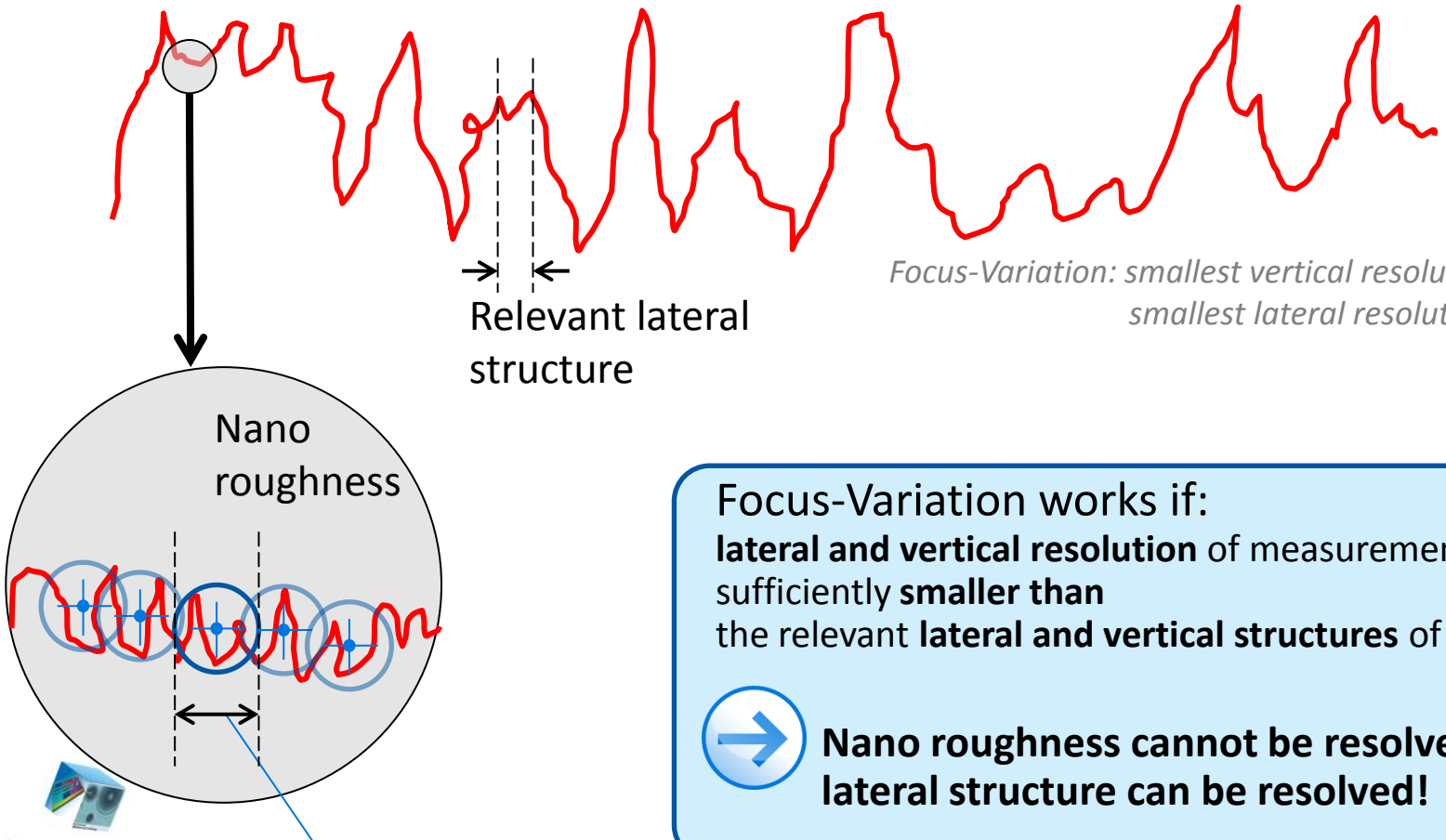
- Granite sensor basis
- 2nm glass scale
- Stage with high quality, low flatness and straightness, pitch and yaw
- Specially designed optics
- Low noise, high resolution, high speed CCD sensor
- Minimized temperature contribution
- Optimized vibration isolation
- High effort on system adjustment and calibration utilizing PTB and DKD standards

Why can roughness be measured with Focus-Variation?

11 year of effort with now 28 people in R&D with competence in:

- 5 PhD, 18 Masters,…
- 6 year of work in ISO, VDI and ÖNORM
- Strong cooperation with NPL and PTB
- Competence in optics, metrology, mathematic, software development, computer vision

Why does Focus-Variation work for roughness measurement?

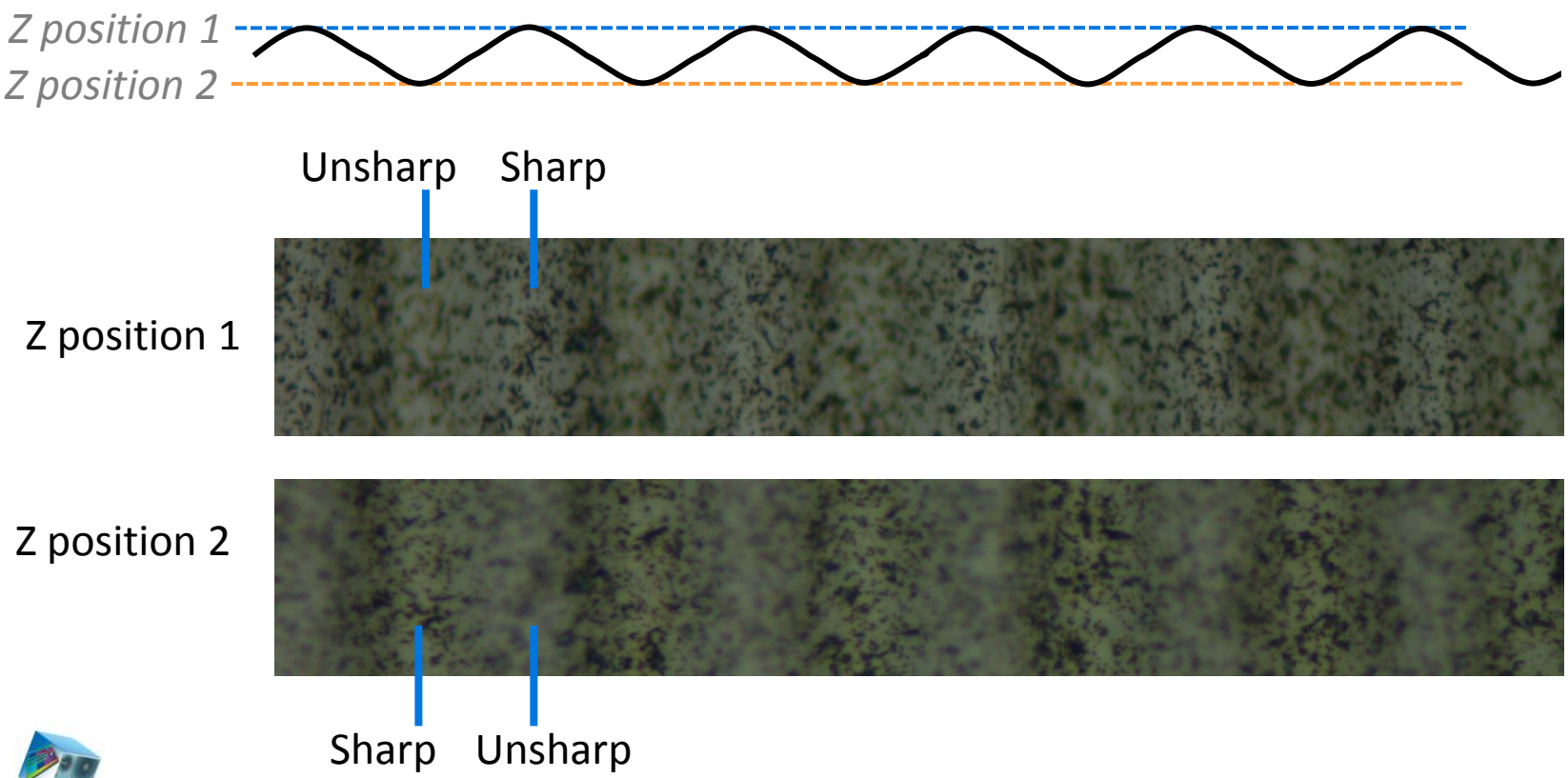


Focus-Variation: smallest vertical resolution: 10nm
smallest lateral resolution: ~0.5µm

Focus-Variation works if:
lateral and vertical resolution of measurement is sufficiently **smaller than**
the relevant **lateral and vertical structures** of the sample

Nano roughness cannot be resolved BUT the lateral structure can be resolved!

Why does Focus-Variation work for roughness measurements?



Since the human eye can distinguish sharp and unsharp areas the system can as well.

3.

Why does the InfiniteFocus work for roughness measurement?

Agenda

Advantages of InfiniteFocus for Roughness Measurement

- Measurement of small structures
  example: IF-RoughnessTool100
- Measurement of samples with small random structures
  example: Random Roughness Standard
- Large scan height > 400µm possible
  example: applicable samples
- Large working distance possible
  example: injection nozzle, tap - nut

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MEASUREMENT OF SMALL STRUCTURES

IF-RoughnessTool100

Problem

Often small roughness (e.g. 100nm) on small samples with very small lateral structures (<10µm) have to be measured.

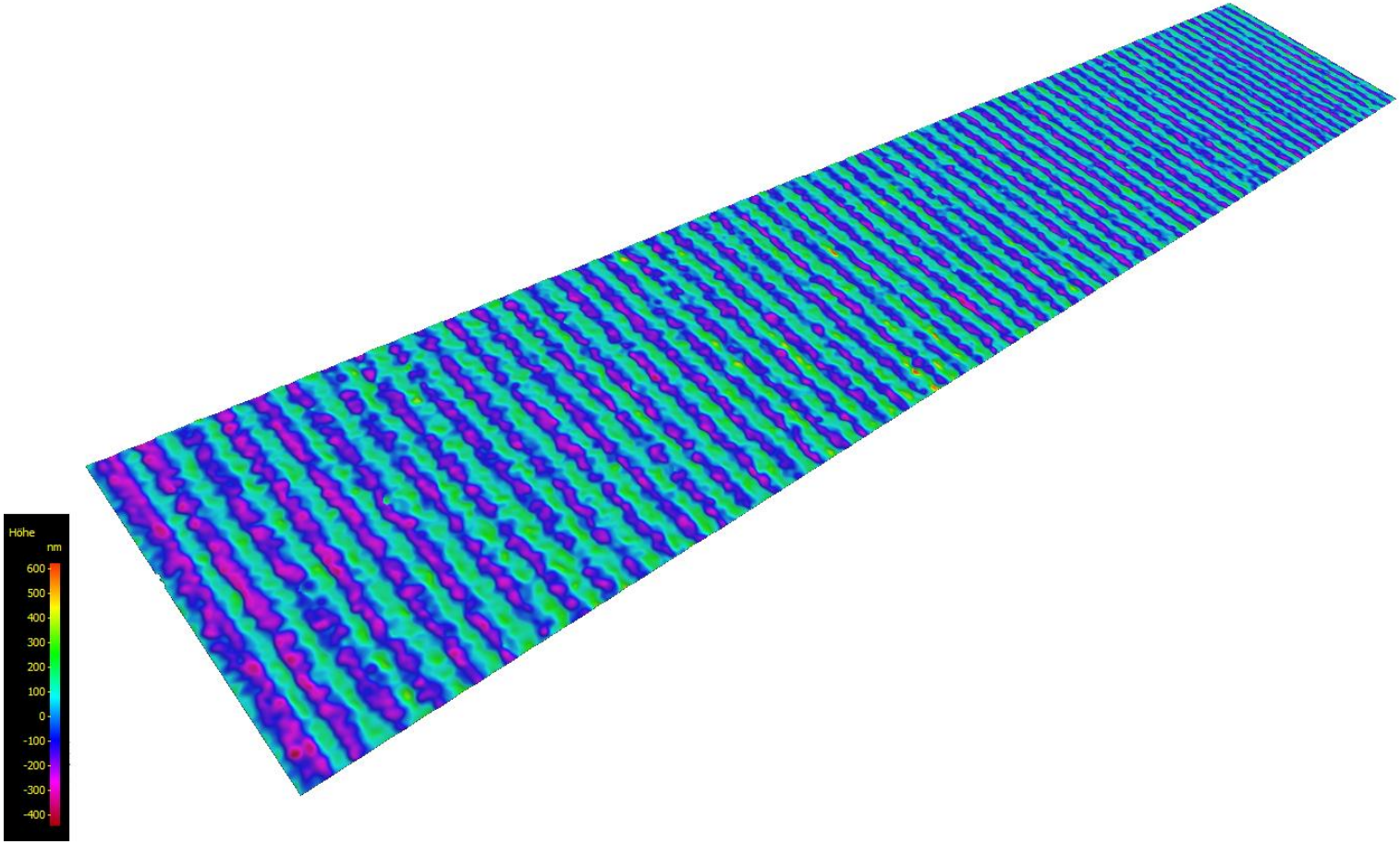
The measurement device must possess a small lateral and vertical resolution.

Example:

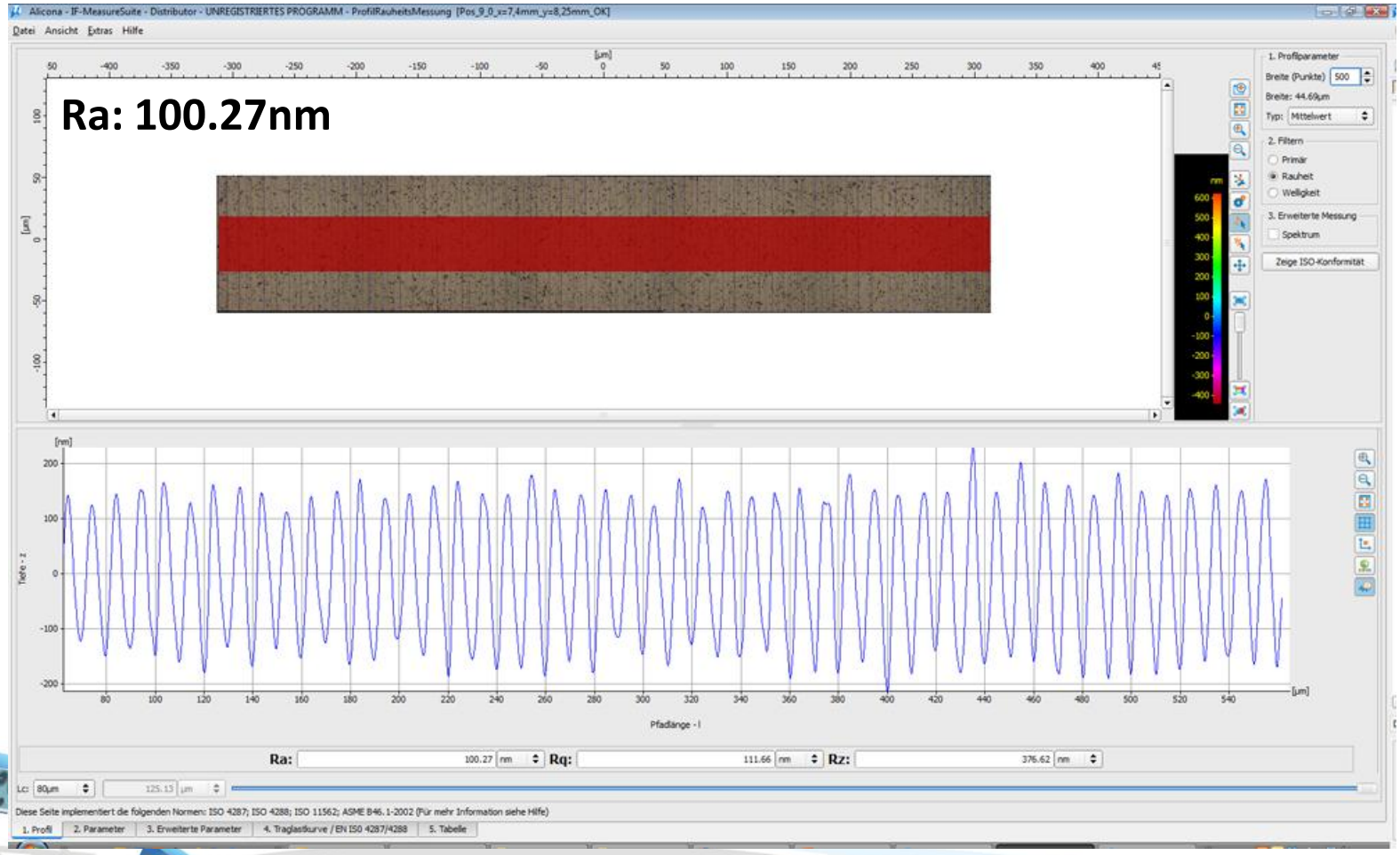
periodical roughness standard IF-RoughnessTool100

Solution: InfiniteFocus has a lateral resolution < 1µm and a vertical resolution of 10nm

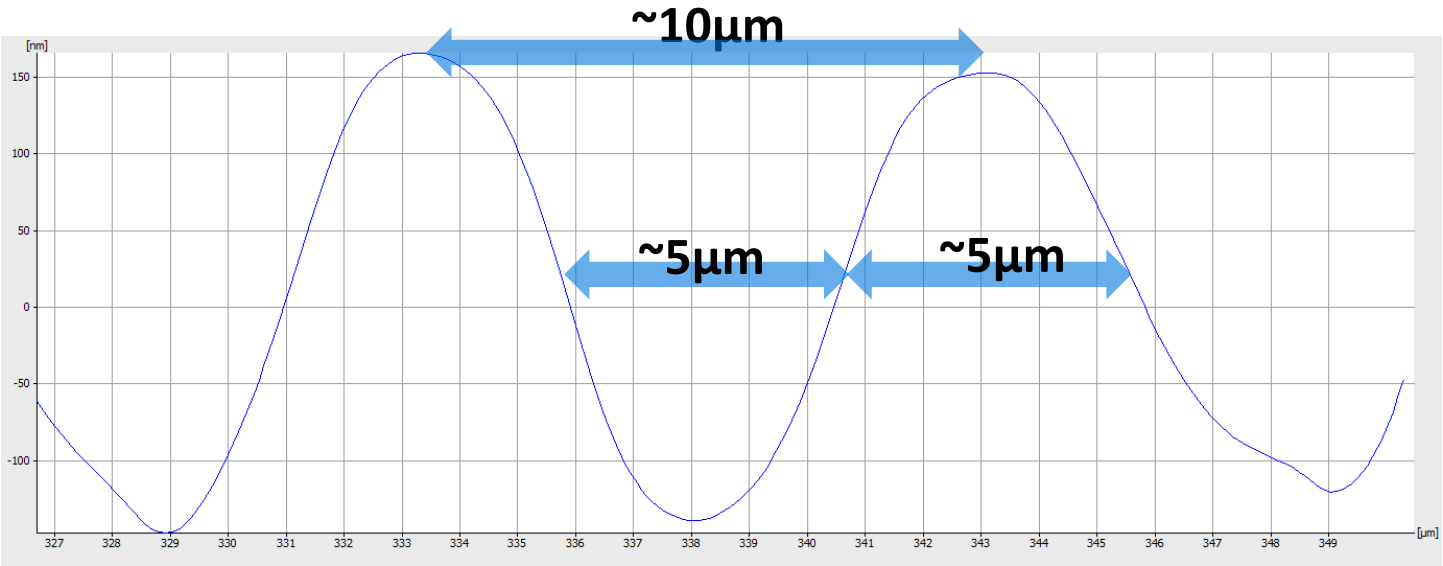
Example: IF-RoughnessTool100



IF-RoughnessTool100



Measurable Lateral Structures



Lateral resolution: 900nm – zoomed view

5µm structures can be measured **efficiently** (without error)

→ also smaller structures (~1µm)

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MEASUREMENT WITH SMALL REAL (RANDOM) STRUCTURES

Random Roughness Standard

Problem

Nearly all real samples have small/random structures.

Example:

- precision components
- milled parts
- roughness standard with random structure

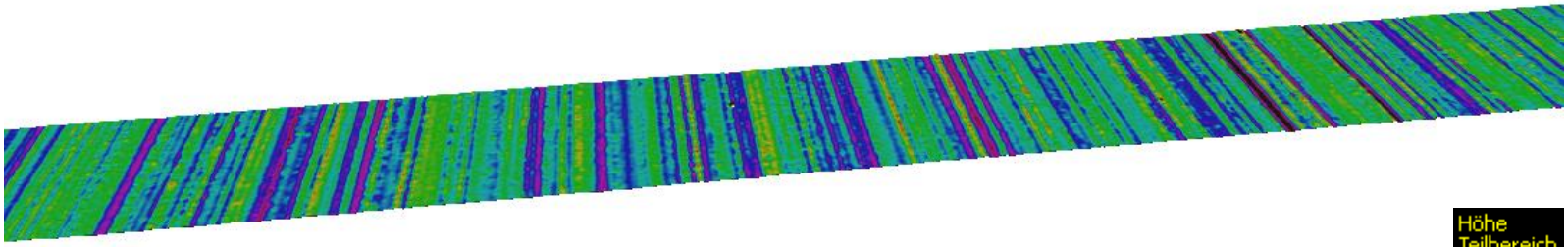
Solution:

InfiniteFocus has a small lateral resolution.

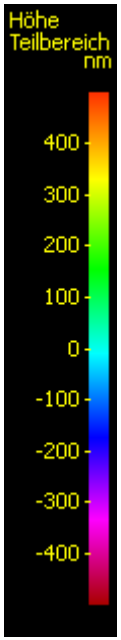
Evidence:

Comparison of a Focus-Variation measurement with a tactile measurement device on a random DKD calibrated roughness standard

3D Measurement of a Roughness Standard with Random Structure



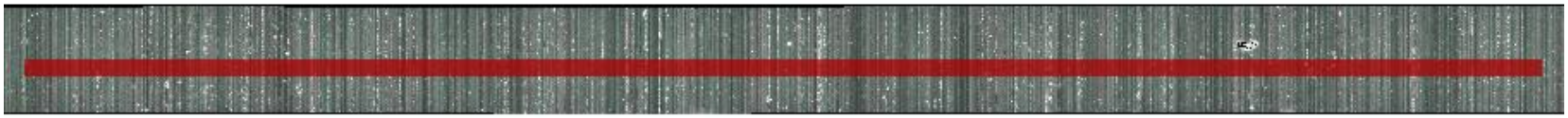
3D Measurement InfiniteFocus



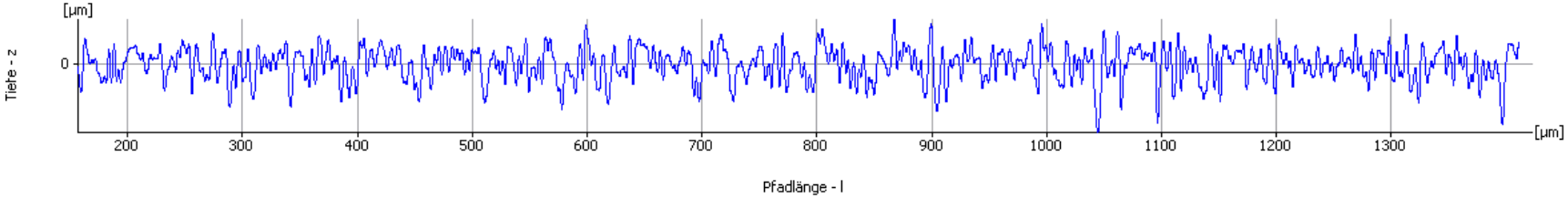
used roughness standard
manufacutrer: Rubert , UK
structure: random
length: 4 x 1.25mm

Profile Comparison: Tactile - InfiniteFocus

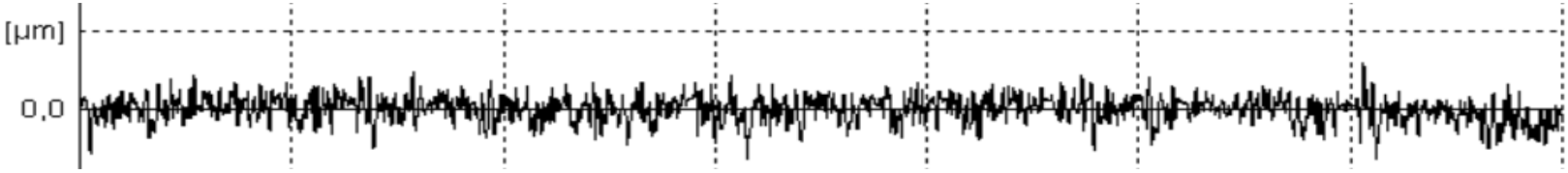
true colour picture with profile path



profile InfiniteFocus



profile tactile measurement device (not at the same position as above)



How good is the correlation of the two profiles?

Accomplishment Profile Comparison

- Superimpose two tactile measurements on different positions
  → allows estimations of homogeneity of the tools
- Superimpose tactile and InfiniteFocus measurements
  → allows estimations of correlation between optical and tactile measurement
- Calculation of the correlation for a quantification

Profile Comparison

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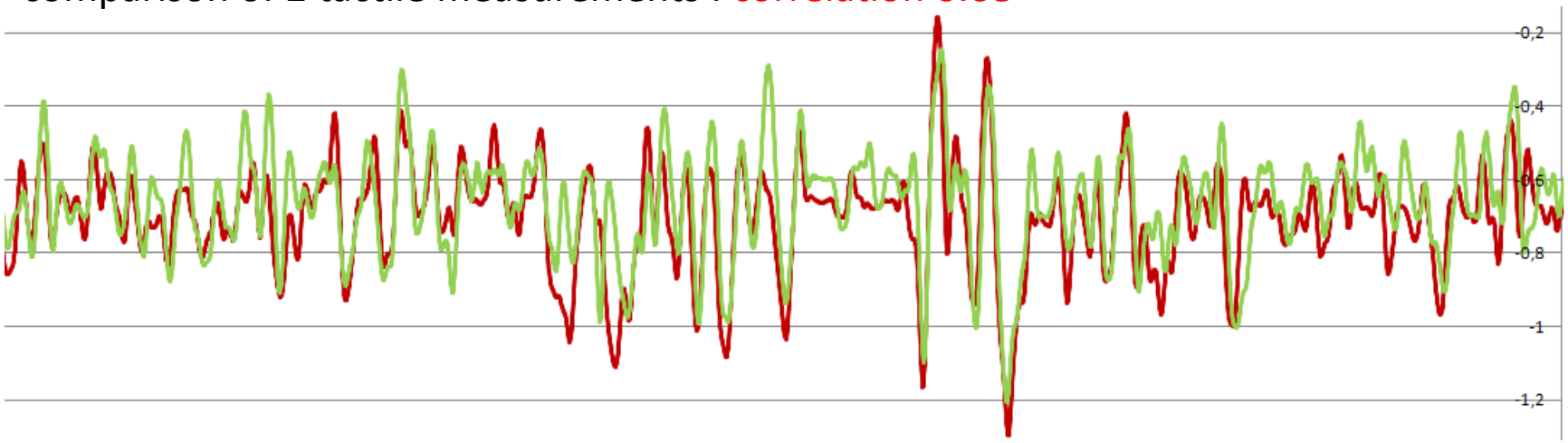
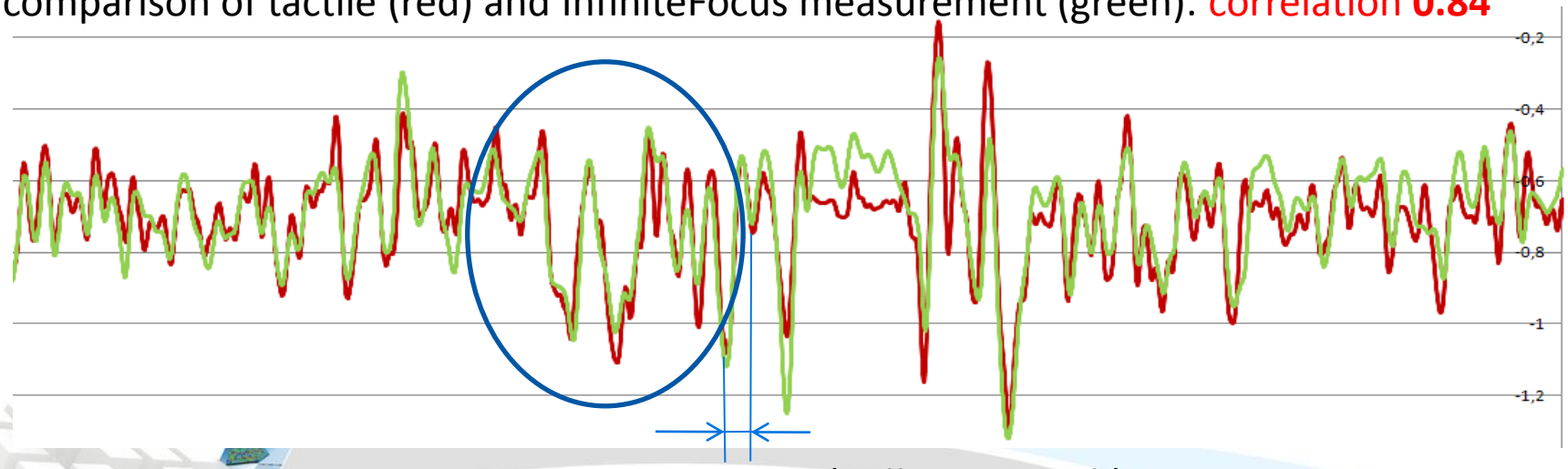
comparison of 2 tactile measurements : correlation **0.68**



comparison of tactile (red) and InfiniteFocus measurement (green): correlation **0.84**



6µm (valley to peak)

The red profile is identical in both diagrams

Interpretation of the Profile Comparison

- Both tactile profiles show some deviations
  --> The tool is not completely homogeneous.
  --> There are artefacts (dust, ..) visible on the tool
- The graphs tactile/optical do coincide better than tactile/tactile
  --> Hence there is a very good correlation between optical and tactile measurement. The influence of the sample is much more evident than the influence of the measurement device.

The correlation of tactile/tactile measurements (0.68) is less than tactile/optical (0.84).

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Comparison of the Ra Values Optical – Tactile Device

	tactile system (9 positions)	InfiniteFocus (10 positions)
average Ra	120	121
min Ra	120	118
max Ra	130	124
repeatability	3	3

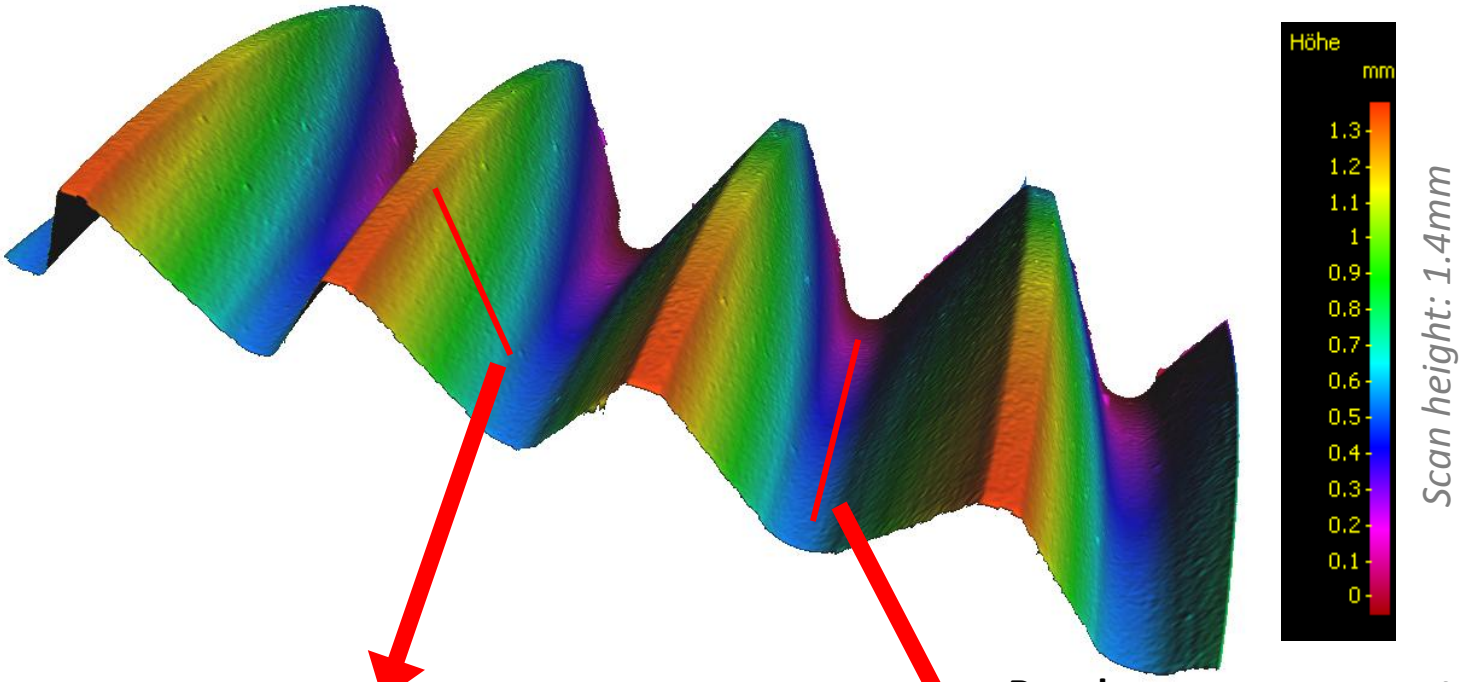
[values in nm]

Measurement length: 1.25mm
Lc: 0.25mm
Tactile stylus radius: 2µm
Lateral resolution InfiniteFocus: 0.9µm
Used objective: 100x

LARGE SCAN RANGES >400µm POSSIBLE

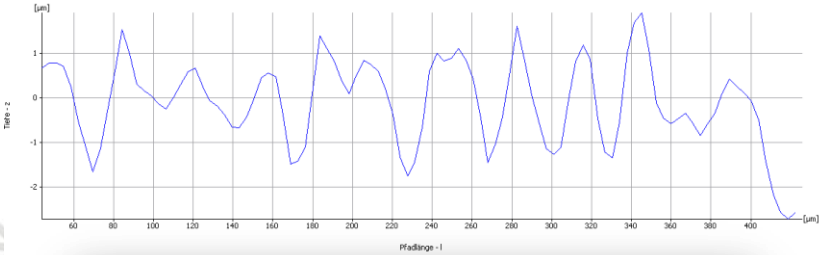
inclined samples

Example: Roughness Measurement of the Thread



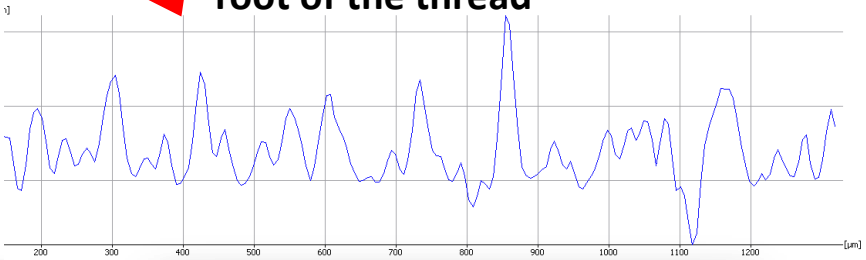
Scan height: 1.4mm

Roughness measurement on the flank



Ra: 766.800946 nm

Roughness measurement on the root of the thread



Ra: 449.445505 nm

Problem

Measurement of roughness over large vertical scan ranges

Example:

- measurement of roughness on inclined surfaces
- measurement of roughness on the thread and in the flute
- measurement of roughness on precision components with declined surfaces

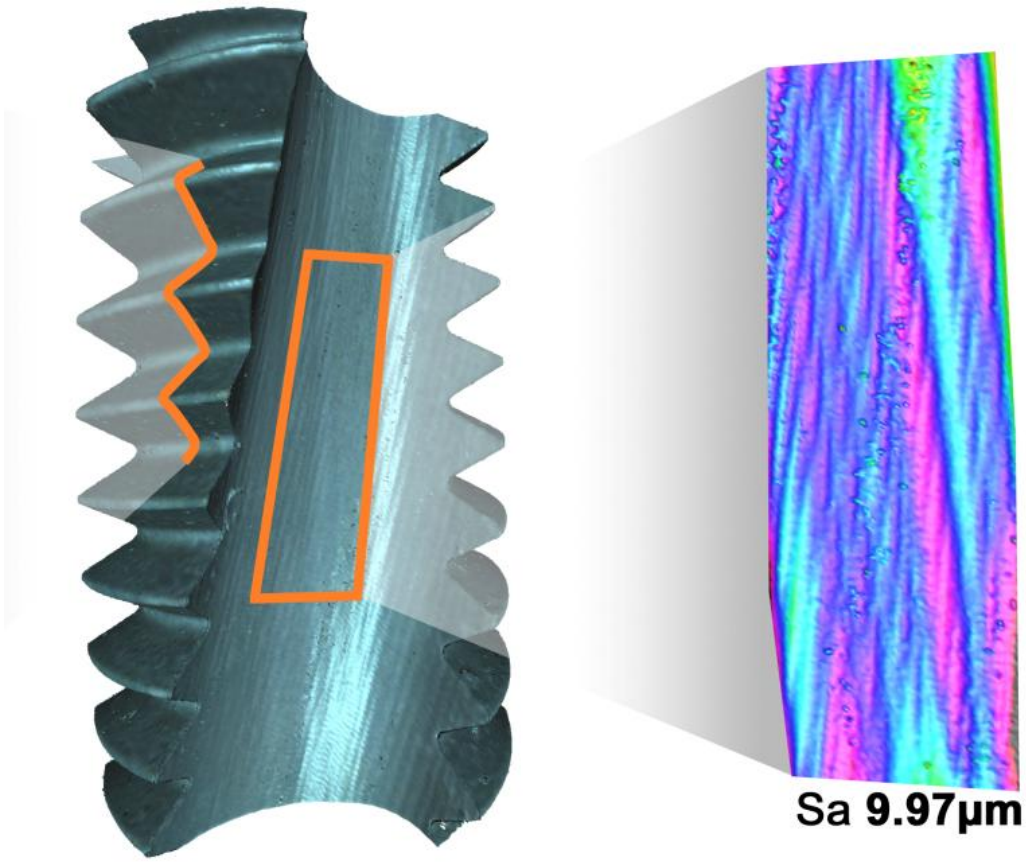
Solution:

- InfiniteFocus enables measurements up to approx. ~85°
- InfiniteFocus has scan ranges up to 22mm

Evidence:

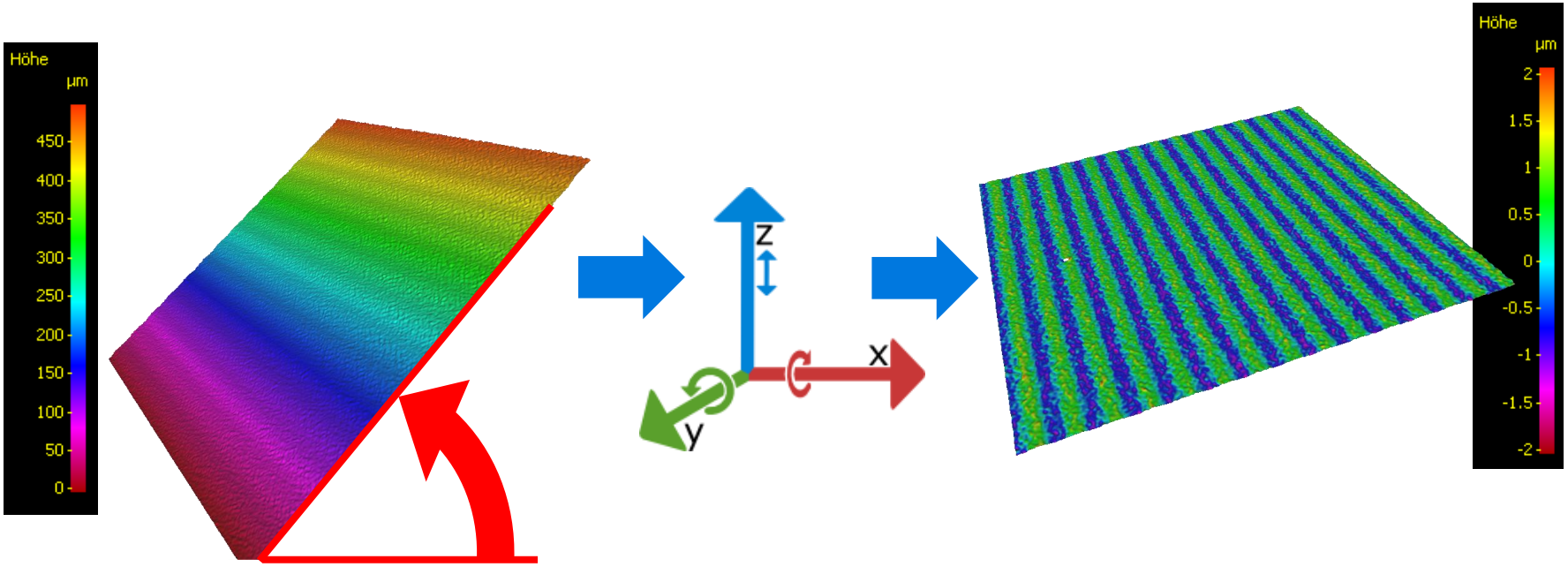
measurement of the IF-RoughnessTool500 at different inclinations

Roughness Measurement on Inclined Surfaces with Scan Ranges > 400µm



Example: roughness measurement in the flute and at the thread

Example: Roughness Measurement on Inclined Surfaces with Scan Ranges > 400µm



IF-RoughnessTool500 measured at an angle of 45°

IF-RoughnessTool500 reference-plane adjusted

Maximum Tilt Angle and Other Instruments

Example confocal:

10x objective: FOV: 1600µm

Scan z = 250µm

→ limited by vertical scan range

Maximum Angle = atan(250/1600)= **8.8°**

(limitation so that the full field of view can be used for Sx calculation)

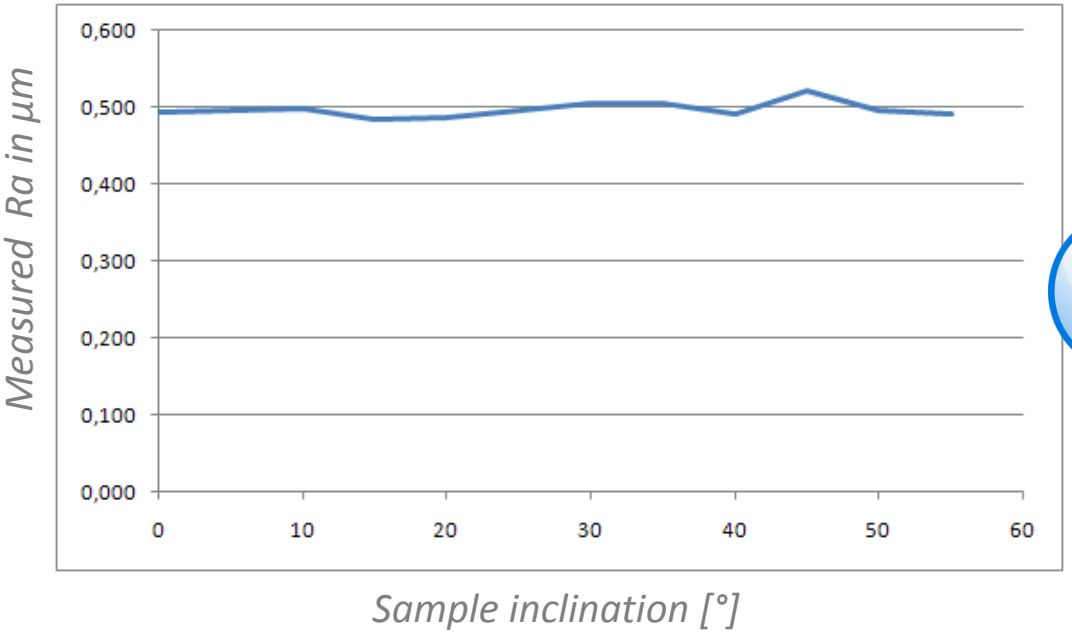
Example WLI:

10x objective, NA = 0.3

→ Limited by numerical aperture

Maximum angle = asin (0.3) = **17°**

IF-RoughnessTool500: Measured Ra Values at Different Sample Inclinations



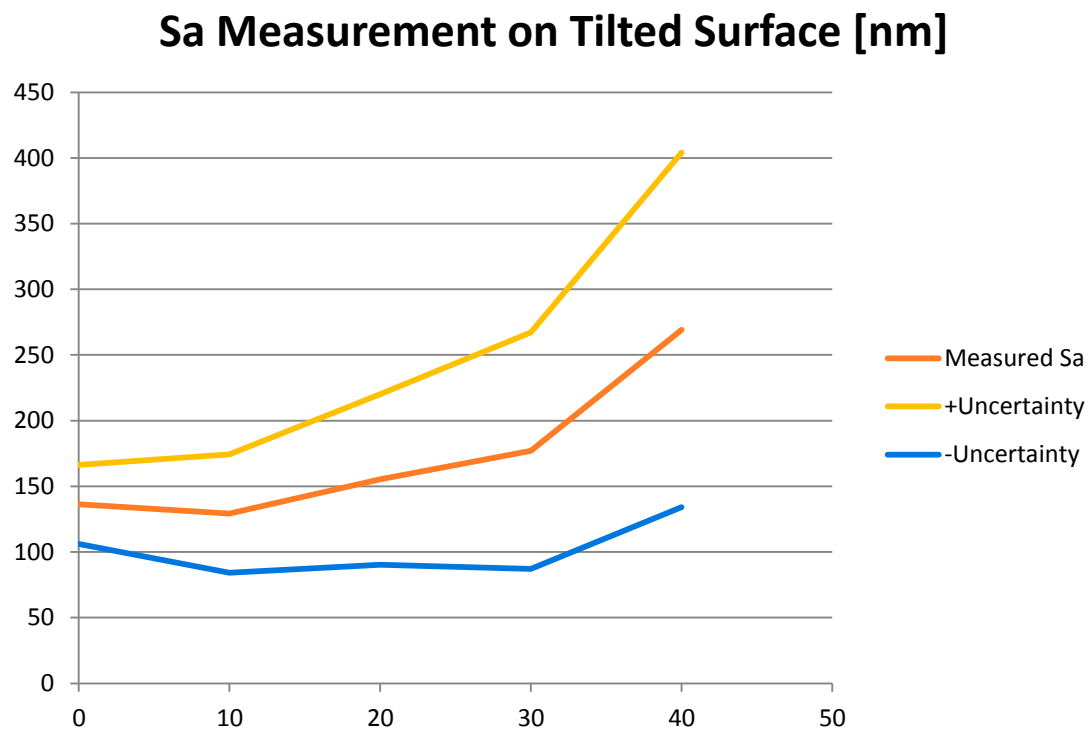
Roughness can be measured on steep flanks

	tactile system (12 positions, all at 0°)	InfiniteFocus (9 positions, all between 0° and 40°)
Average Ra	**495**	**495**
Min	**491**	**485**
Max	**499**	**506**

Roughness Measurement on an Inclined Roughened Gage Block

	100x	100x
Tilt	Sa [nm]	Sq [nm]
0°	136.21	171.01
10°	129.22	164.43
20°	155.25	206.19
30°	177.11	226.43
40°	269.04	339.17

Measured Sa/Sq in µm



Consistent results

LARGE WORKING DISTANCE POSSIBLE

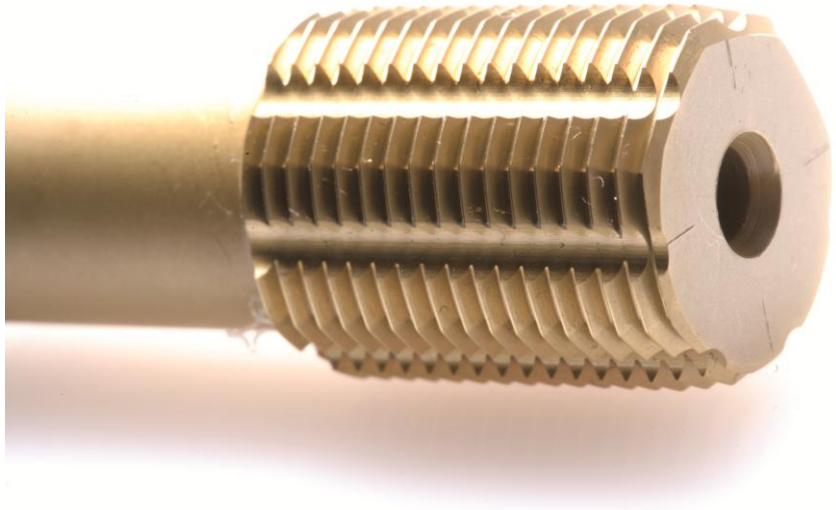
injection nozzles, tap-nut

Problem

Measurement of roughness at position which requires a large working distance

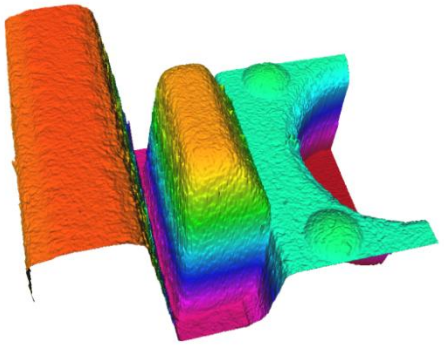
Examples:

- Injection nozzles
- Flute of a tap
- Root of threads from implants
- Diverse precision components



Solution:

InfiniteFocus allows working distances up to 23.5 mm



Large Working Distance

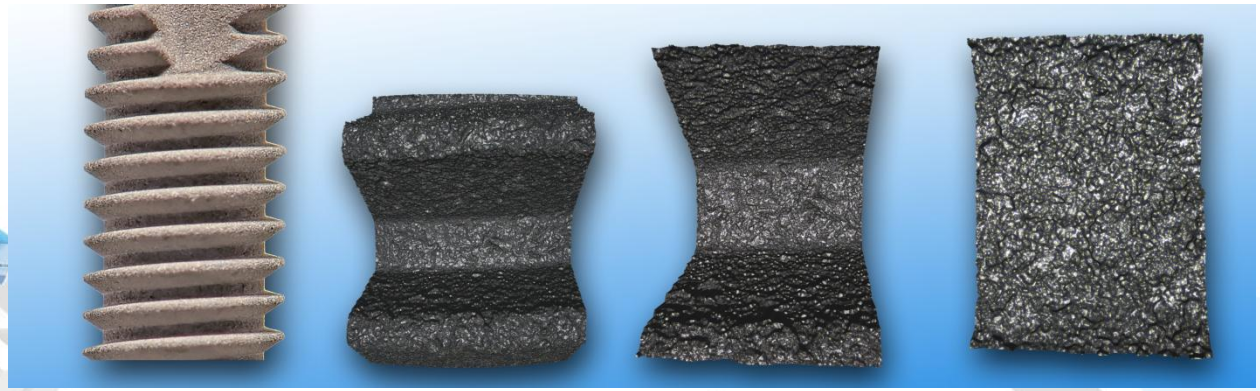
Problem:

Many measurement devices do not support measurement with large working distances.

But this is necessary in many sectors!

Examples:

- injection nozzles
- roughness in the flute of tools
- micro precision components



Working Distances InfiniteFocus

Objectives	2,5x	5x	10x	20x	50x	100x
	8.8mm	*23.5mm*	*17.5mm*	*13.0mm*	*10.1mm*	*3.5mm*

Working distance

4.

TRACEABILITY AND CALIBRATION

Based on Focus-Variation

Traceability of Profile Roughness Measurements

Profile Roughness Measurement:

- Profile standard
- ISO 4287,…
- DAkkS (DKD) Lab
- PTB 5.1

} Complete traceability given

Traceability of Surface Texture Measurements

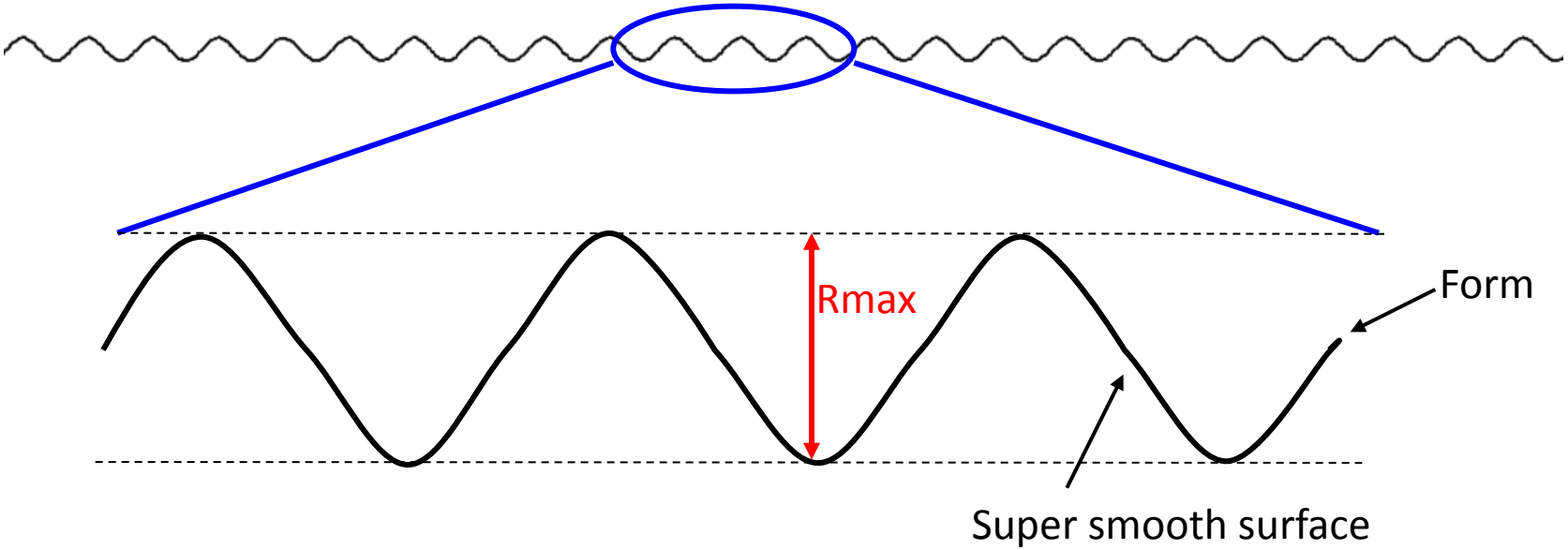
Surface Texture Measurement:

- Surface standard:
  In work (PTB, Japan)
- ISO 25178-x
  Not yet finished
- DAkkS Labs
  Not available
- PTB 5.1 / OpenGPS
  Not yet defined

No complete chain

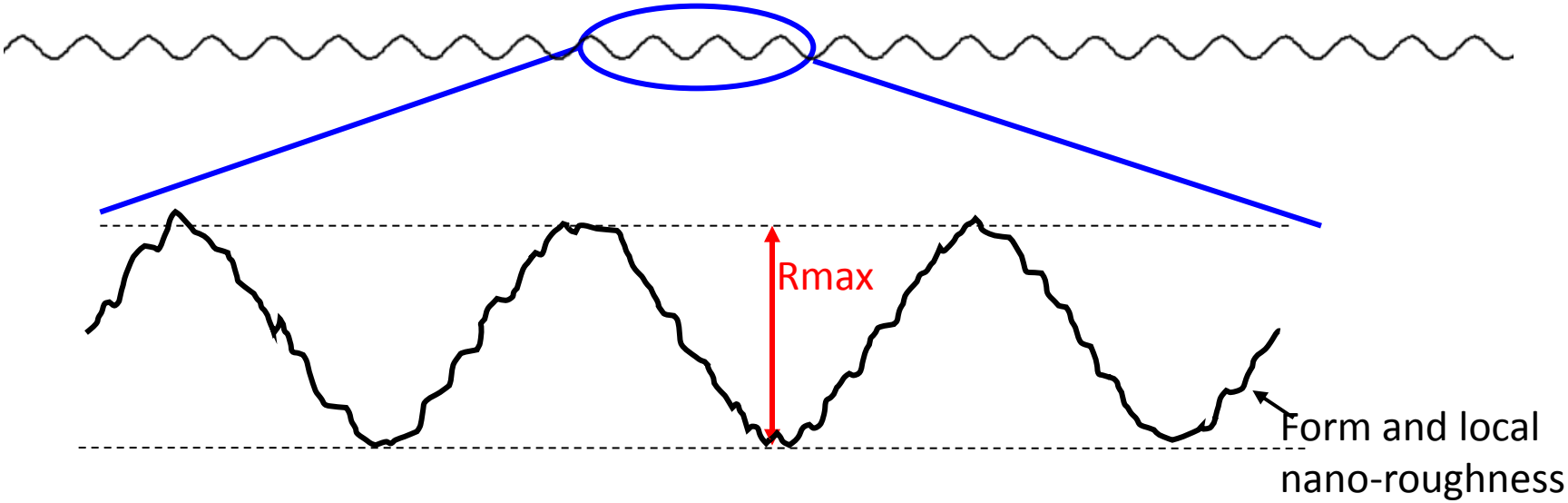
This does not mean that areal based roughness measurements may not be used!

Available Roughness Standards are too Smooth & Specular



- no local nano-roughness: shiny surface, hard to measure for optical instruments
- roughness of the standard: produced by sine wave form

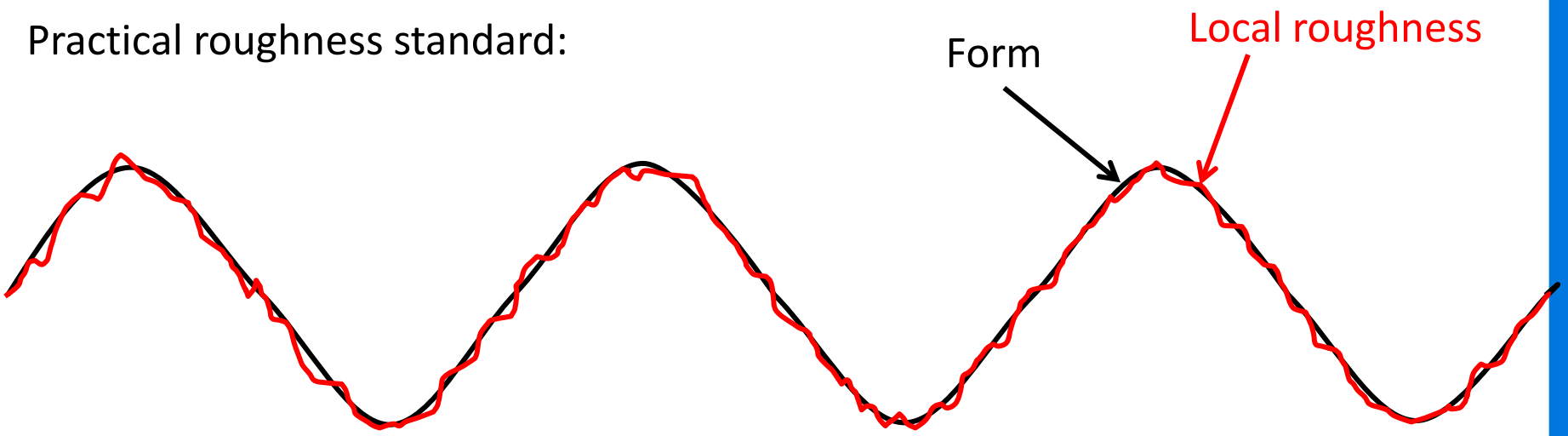
IF-RoughnessTool Optimized for Optical Measurement



- significant local nano-roughness: well measureable by optical and by tactile instruments
- roughness of the standard: mainly produced by sine wave form

Tactile Roughness Standard

Practical roughness standard:



Local roughness of this standard (using a small Lc):

In this case the local roughness represents the form error of the standard

Tactile Roughness Standard

Local roughness of this standard (using a small Lc):

InfiniteFocus can measure the standard well if:
Ra (Sa) of this local roughness is above 10-15nm

IF-RoughnessTool

Problem:

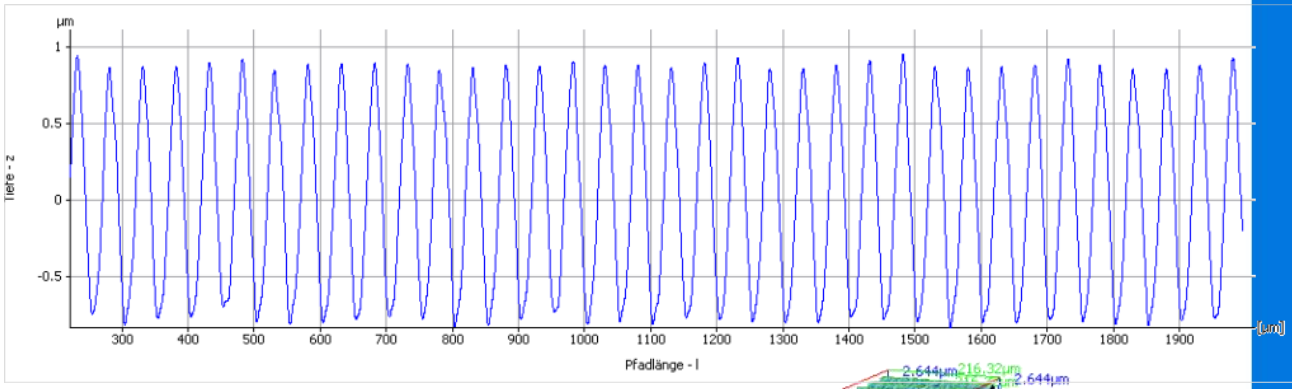
Traceable roughness measurements were not possible because there was no measurable roughness standard available.

Solution:

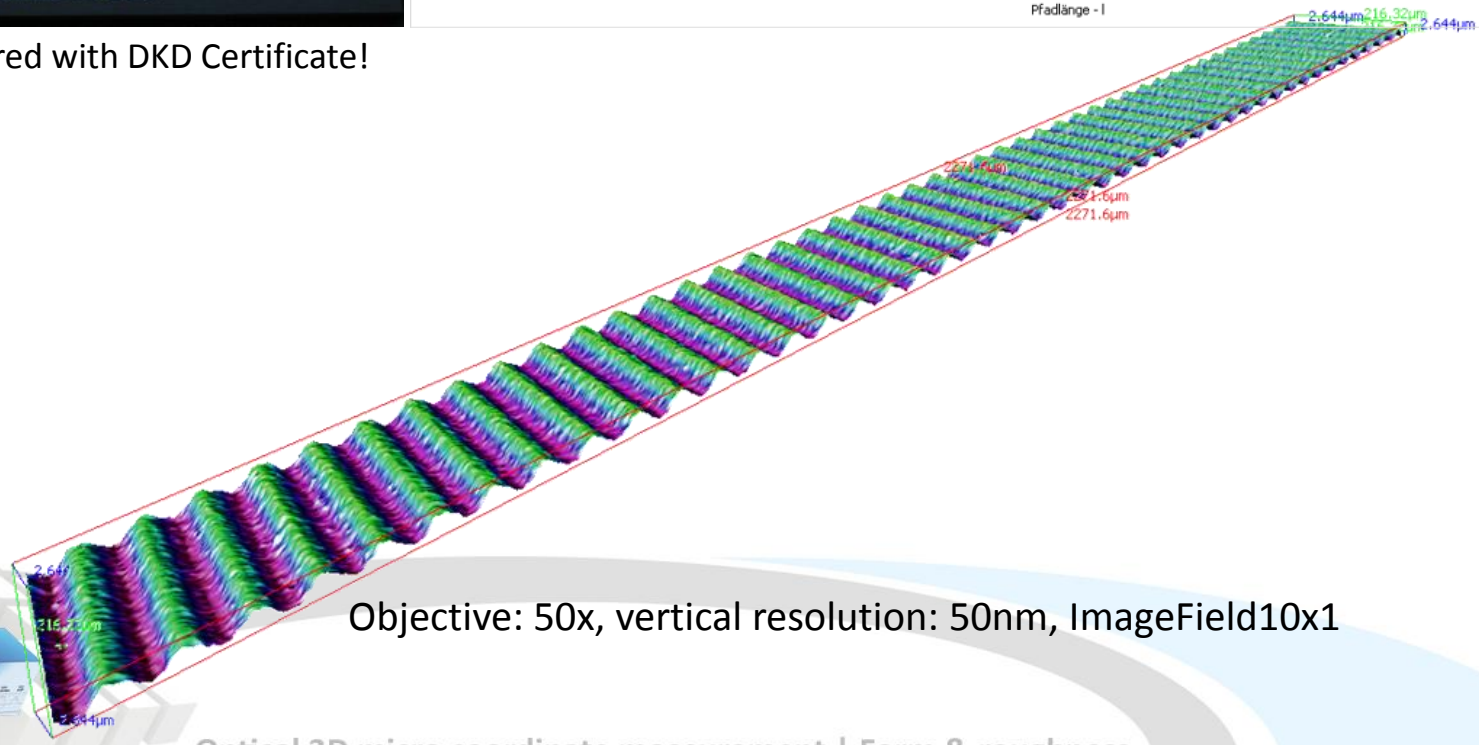
IF-RoughnessTool

Roughness values: Ra: 100nm, 500nm, 1500nm, 3000nm

IF-RoughnessTool Measurement

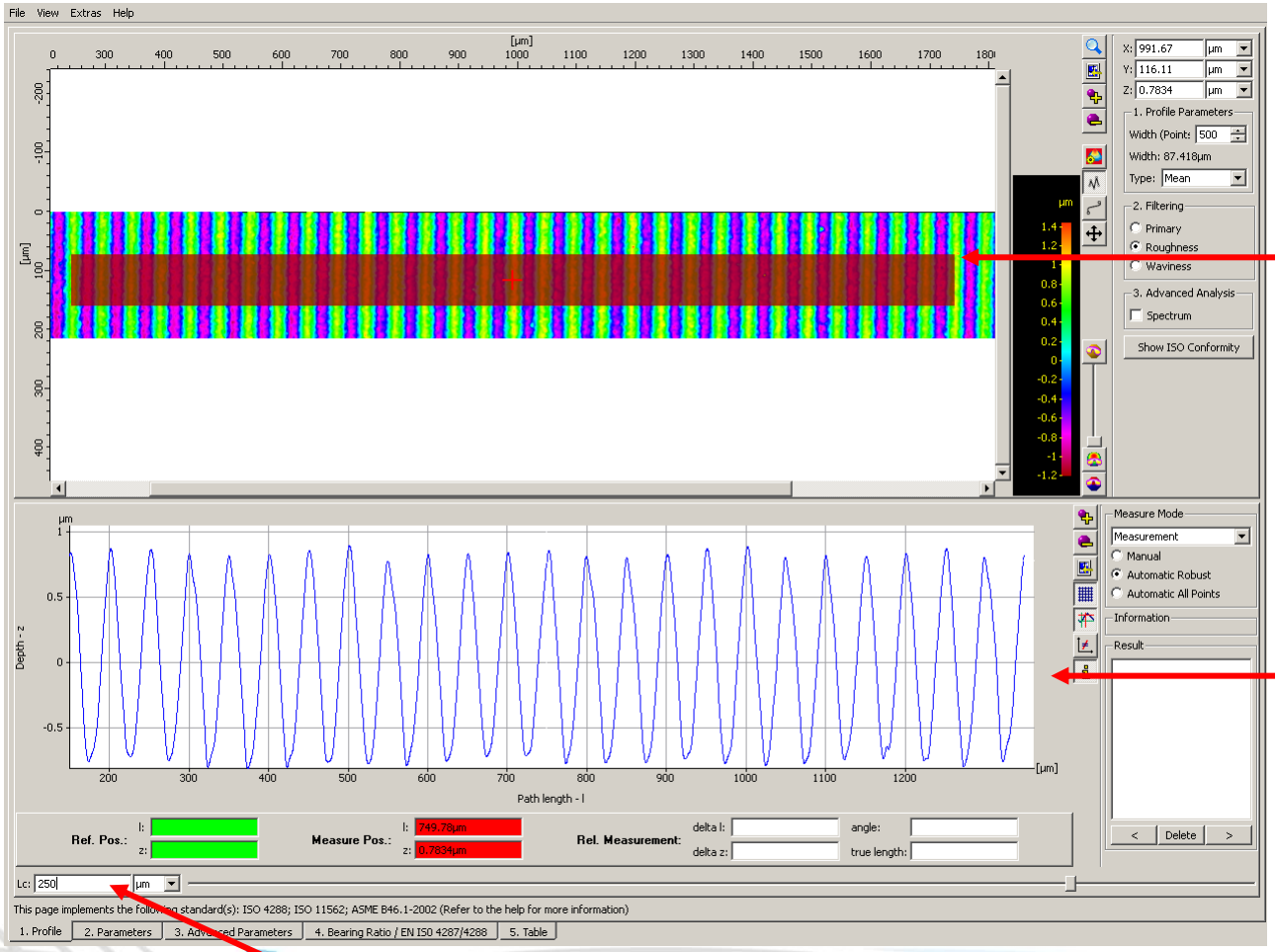


Delivered with DKD Certificate!



Objective: 50x, vertical resolution: 50nm, ImageField10x1

Profile Roughness



Profile Path

Extracted Profile

λc: 250µm

Example: Result IF-RoughnessTool100

	tactile system	InfiniteFocus
average Ra	97nm	105nm
uncertainty	+-5nm	+-20nm
repeatablity	2nm	1nm

- InfiniteFocus is comparable with tactile measurements
- InfiniteFocus has a better repeatability
- InfiniteFocus has a „worse“ uncertainty:

$U_{IFM} = U_{Taktil} + X$

(the uncertainty of the InfiniteFocus is currently based on tactile measurement, including it)

Example: Results IF-RoughnessTool500

	Tactile system	InfiniteFocus
average Ra	503.5nm	501.3nm
uncertainty	+-15nm	+-40nm
repeatability	5nm	1nm

Example: Result IF-RoughnessTool3000

	Tactile system	InfiniteFocus
average Ra	2977nm	3023 nm
uncertainty	+-90nm	+-250nm
repeatability	5nm	8nm

Overview Roughness Measurements with Standards

Nominal Ra	120	100	500	3000
Type	random	sinus	sinus	sinus
Mean deviation (optical-tactile)	5	5	15	80
Repeatability tactile	3	2	2	5
Repeatability optical	3	2	2	8
Uncertainty tactile (U_t)	4	10	15	90
Uncertainty optical (U_o)	20	25	40	250

[values in nm]

The uncertainty optical U_o „includes“ the uncertainty tactile U_t

Overview Roughness Measurements

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Typical values for Ra measurements with real samples at different Ra ranges

Roughness range Ra	50-200nm	200-700nm	700-3000nm
Repeatability	5nm	5nm	15nm
Uncertainty	25nm	50nm	300nm
Max. measurable angle range	30°-50°	20°-50°	10°-50°

Depending on the surface composition of the samples the stated values can deviate.
The measureable angle range depends on the gradient of the surface (e.g.: Rdq parameter)

InfiniteFocus measurement uncertainty is dominated by the uncertainty of the reference measurement.
Improvement of optical measurement devices by:
reduction of the uncertainty of DKD and PTB

Roughness Standards

calibrated roughness standards

- structure is measured with a reference measurement device
  → roughness value for the certificate
- assures reference to national standards
- assures reproducibility with other measurement devices

Institutions for calibration

- DAkkS (prior DKD)
- PTB
- NIST

Standards for Roughness Measurements

Two types of standards:

- » periodical roughness standards
- » random roughness standards

Roughness standard have to be practice oriented

- » similar characteristics as the work piece* to be measured
- » locally rough (hence a certain nano-roughness)
- » similar Ra value as the work piece to be measured
- » similar optical characteristics as the work piece to be

nano-roughness influences significant the measurability

**analogous requirements are valid for dimensional measurements :*
ISO 15530-3: Coordinate measurement machines (CMM): Technique for determining the uncertainty of measurement – Part 3: Use of calibrated workpieces or standards. Section 5.2: Similarity Conditions

Typical Problems of Measurements with Rouhness Standards

- The roughness standard is not applicable for every measurement technology.
  - The measurement is not ideal
  - The roughness measurement is far away from the calibrated value

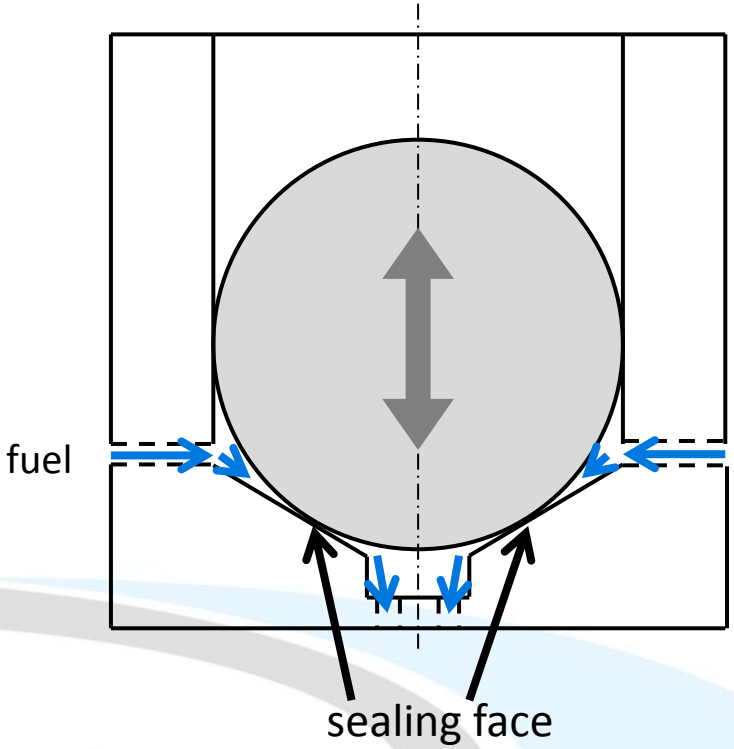
  Example: Usage of very smooth roughness standards for optical roughness measurements.
- **Not the same measurement position** is used for tactile and optical measurement.
- **Not the same measurement setting** are used (filter settings, duration of the measurement).

5.

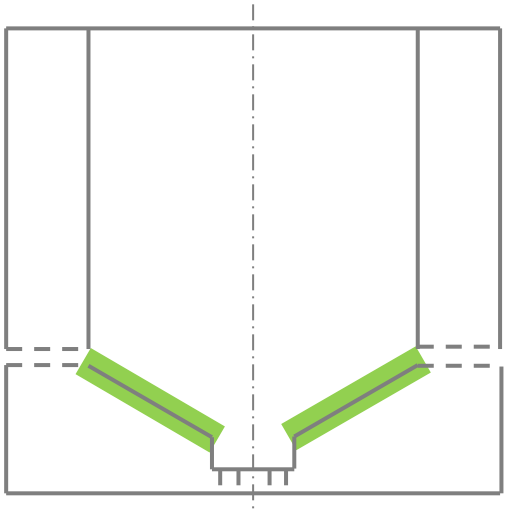
Practical Examples

Example 1: Measurement of Injection Nozzles

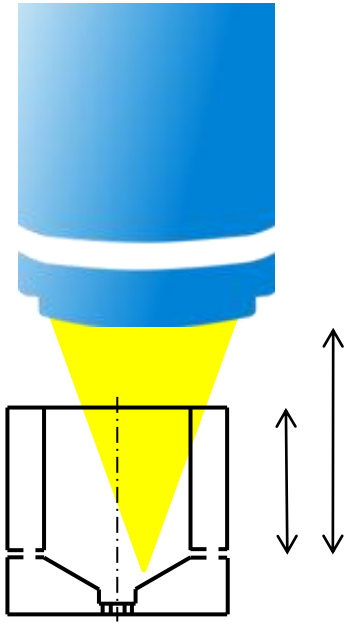
1. High resolution 3D measurement of the entire sealing face
2. Removal of the bevelled form
3. Calculation of the flatness parameter FLTt according to ISO 12781



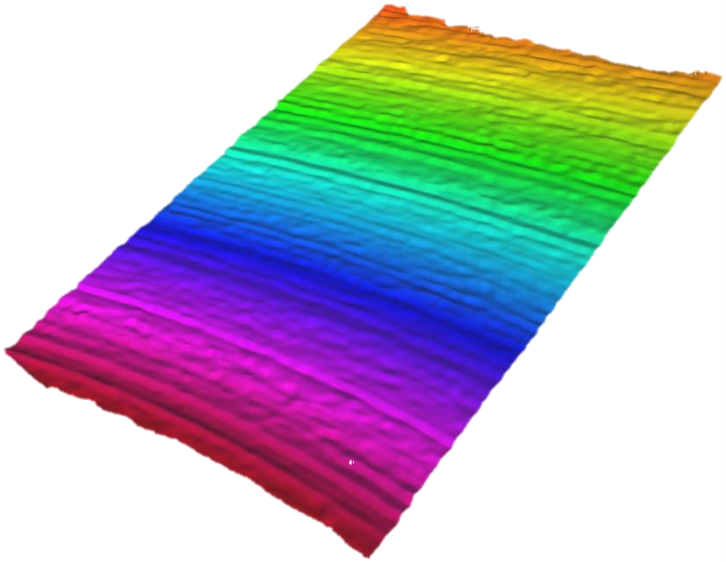
Example 1: Measurement of Injection Nozzles



Sealing surface



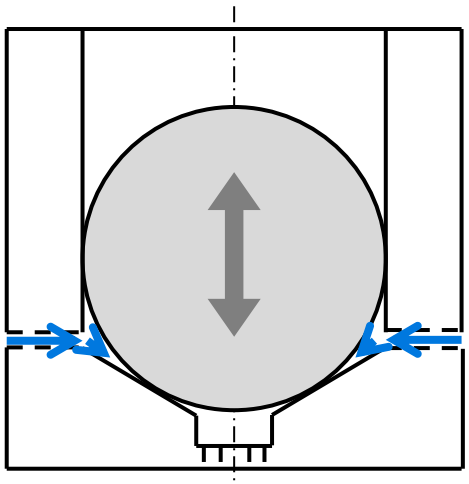
Measurements on the Sealing surface possible



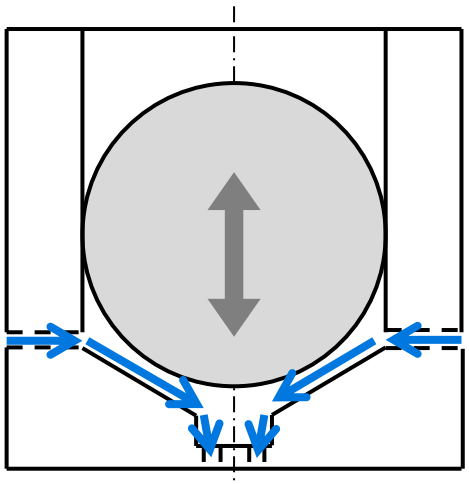
3D measurement of the sealing surface

Measurement Task

valve closed



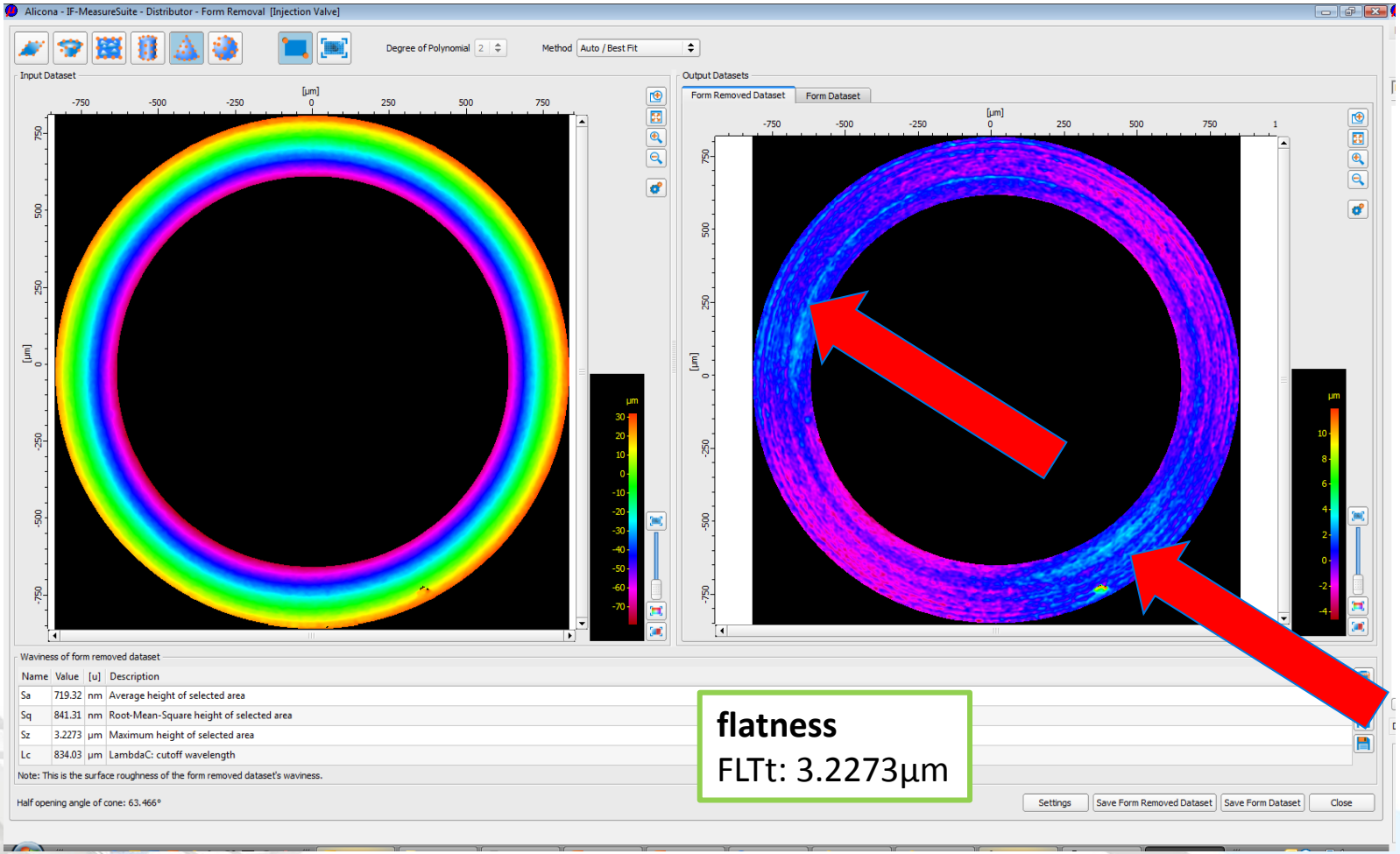
valve open



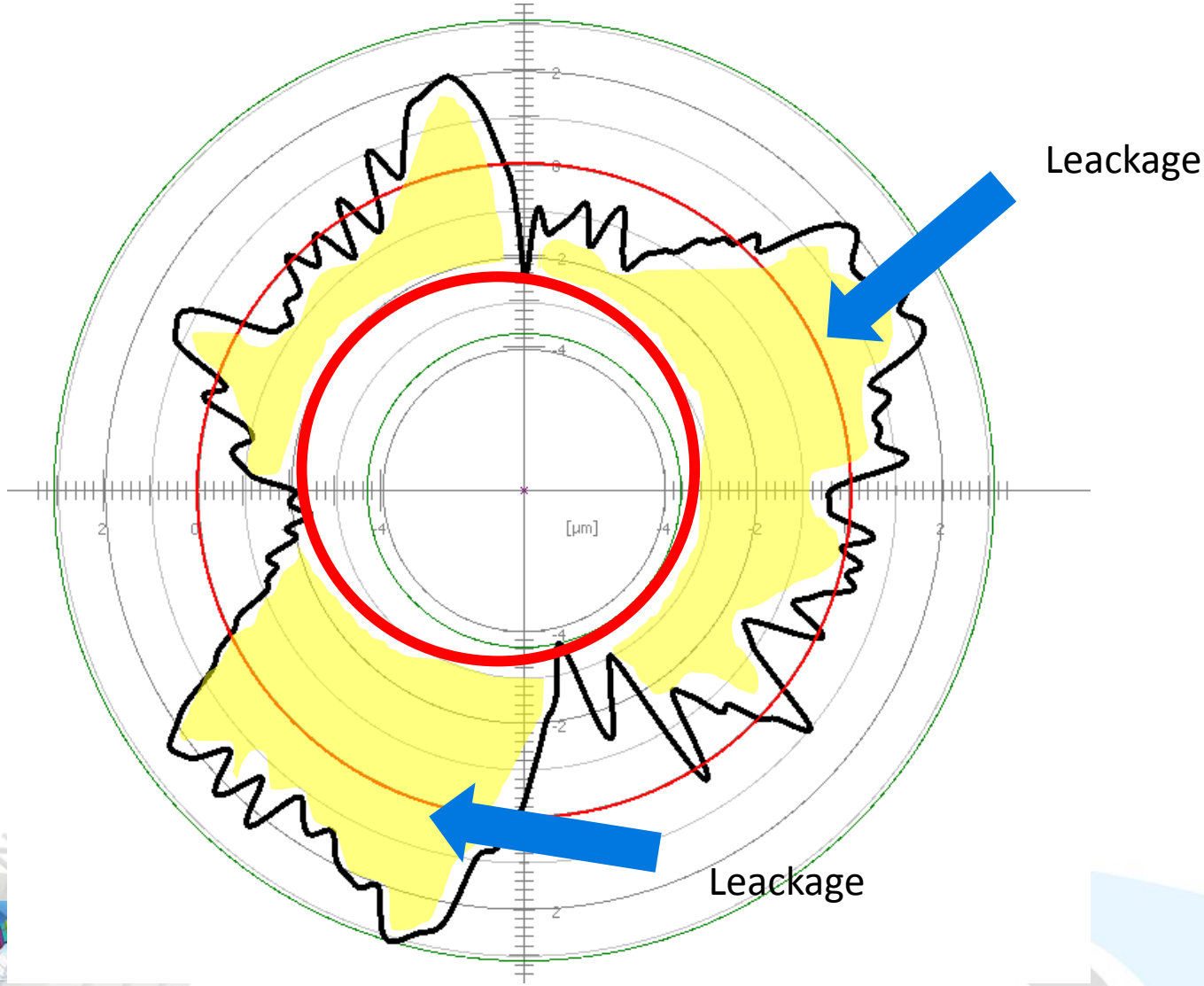
sealed?

Is the fuel supply with closed valve interrupted?
Boundary conditions: multiple injections of lowest quantities, pressures up to 2000bar

Flatness – Visualized After Form Removal



Roundness/ Leak Tightness



Repeatability of Roundness Measurement

Repeatability of roundness measurements
Based on 20 measurements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Standard-deviation
RONa	0,630	0,633	0,653	0,567	0,629	0,603	0,753	0,654	0,611	0,637	0,676	0,677	0,572	0,531	0,683	0,640	0,648	0,584	0,606	0,630	**0,049**
RONq	0,781	0,791	0,806	0,716	0,780	0,755	0,923	0,803	0,753	0,790	0,842	0,853	0,724	0,704	0,847	0,807	0,804	0,735	0,764	0,777	**0,053**
RONt	3,839	3,835	4,317	4,002	4,238	4,231	4,111	4,147	3,820	4,557	4,514	4,508	4,187	4,717	4,251	4,693	3,926	4,055	4,130	4,039	**0,275**
RONp	2,124	2,220	2,388	2,159	2,283	2,287	2,363	2,267	2,151	2,566	2,535	2,555	2,276	2,470	2,413	2,570	2,348	2,221	2,190	2,222	**0,146**
RONv	1,715	1,615	1,929	1,843	1,955	1,944	1,747	1,880	1,669	1,991	1,979	1,953	1,911	2,247	1,838	2,122	1,578	1,834	1,940	1,818	**0,162**

[values in µm]

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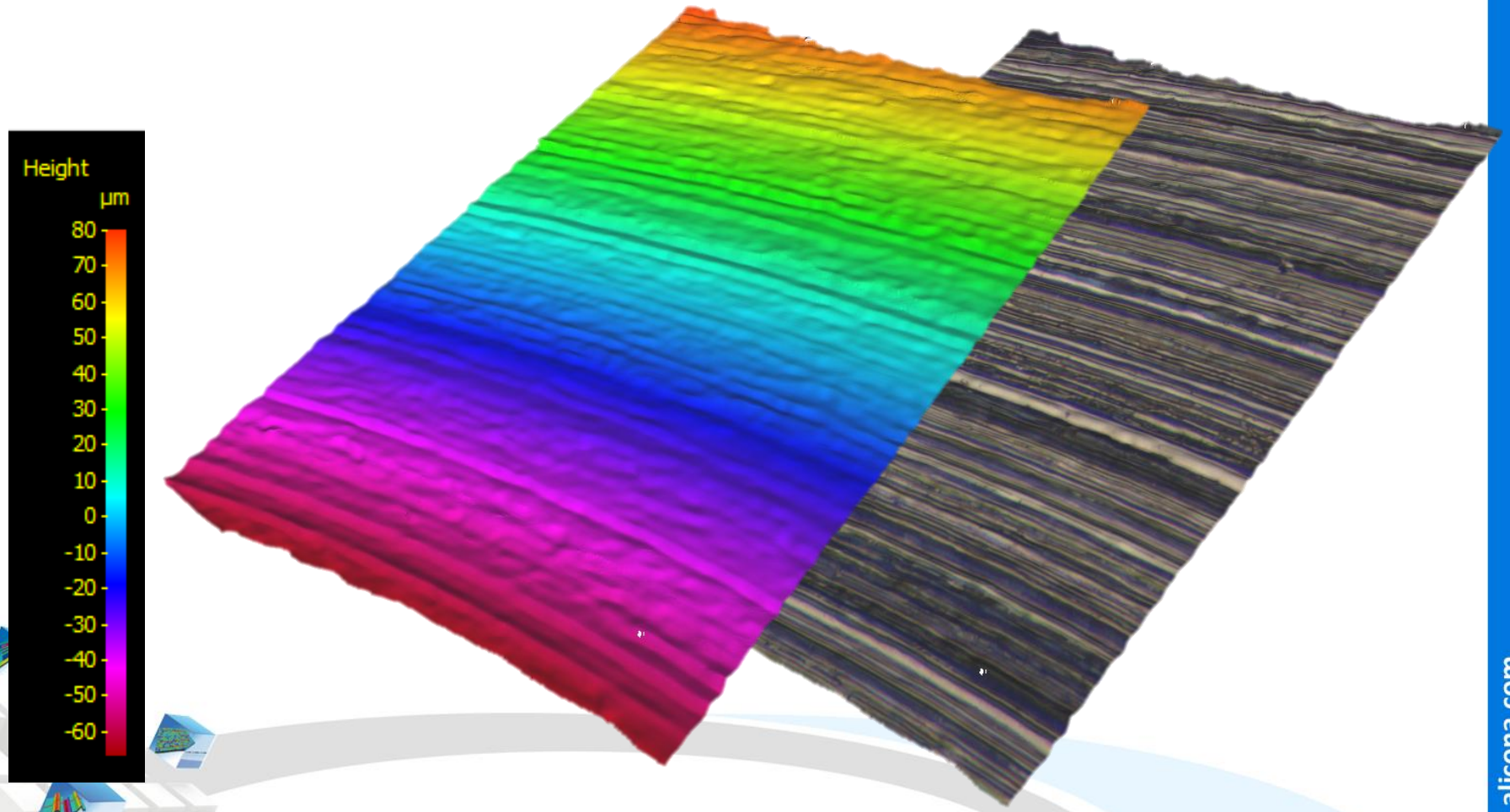
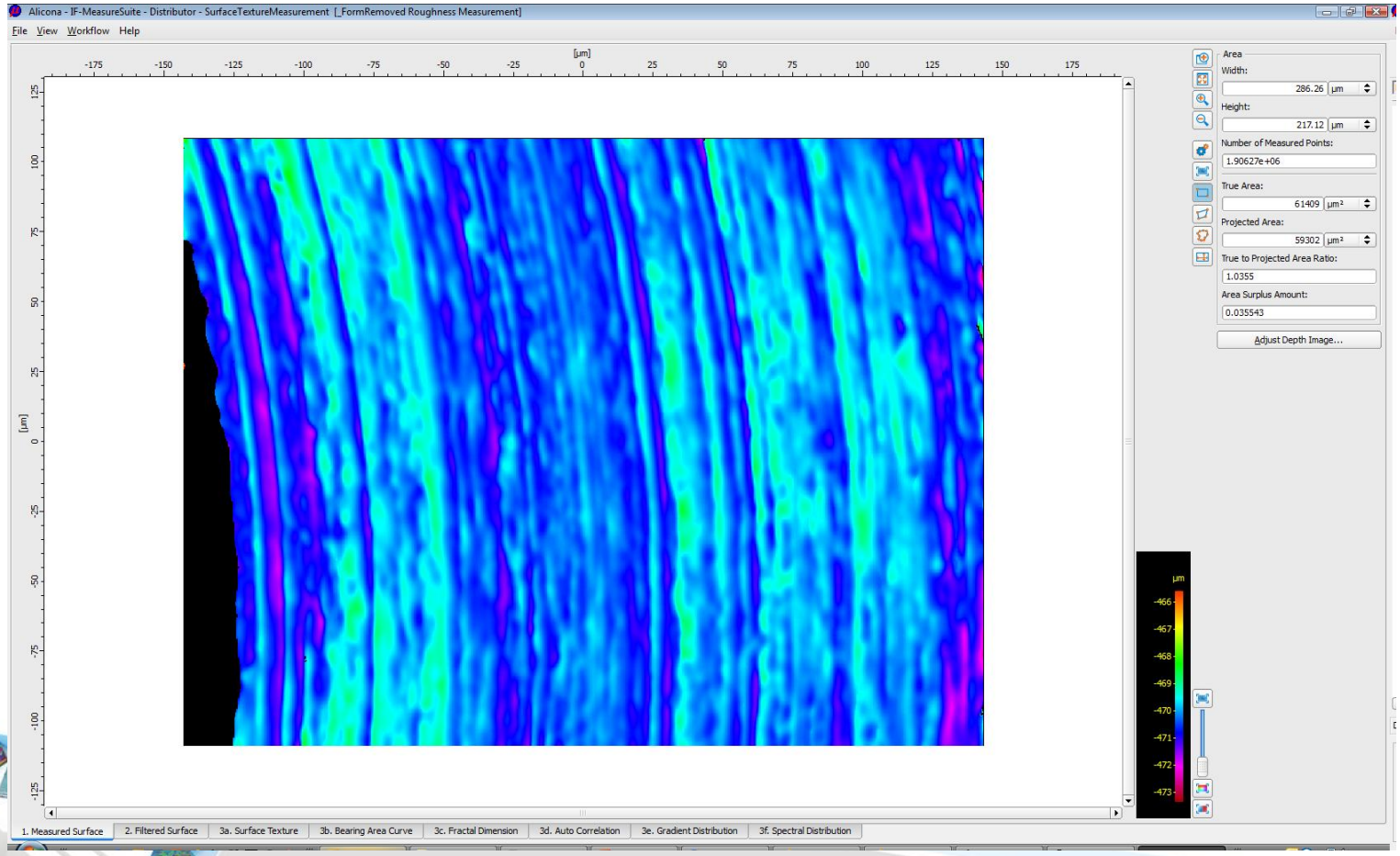
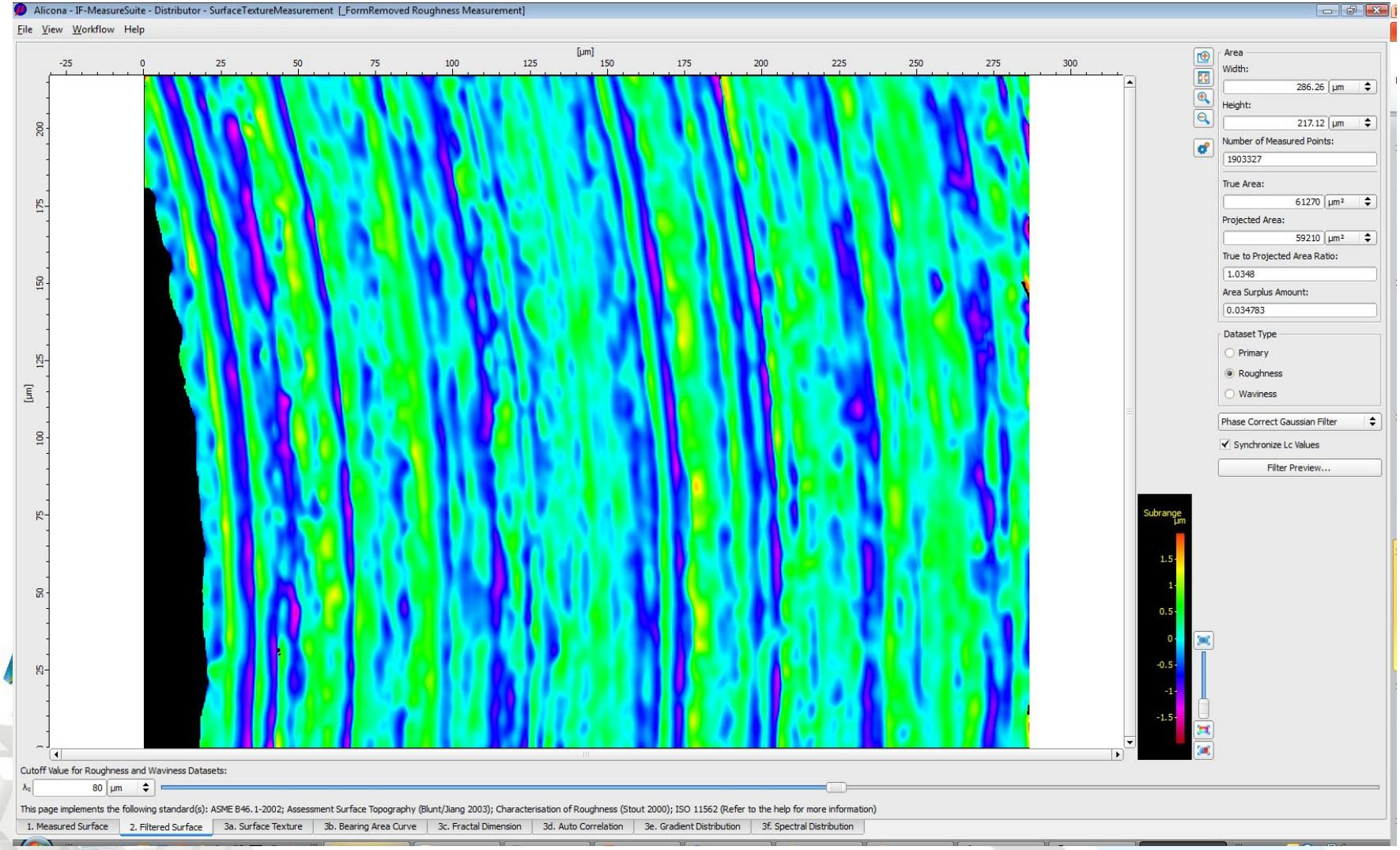
High Resolution 3D Measurement



Form Reduced Datasets



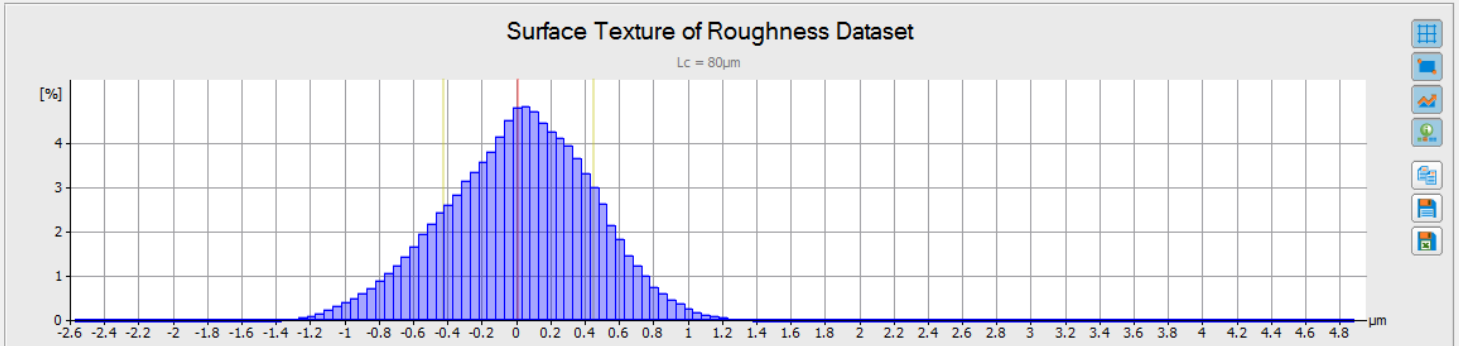
Dataset after Filtering



Roughness Parameters

Alicona - IF-MeasureSuite - Distributor - SurfaceTextureMeasurement [_FormRemoved Roughness Measurement]

File View Workflow Help



Settings

Min. Value:	-2.5709	µm
Max. Value:	4.8791	µm
Class Width:	0.05	µm

Reset

Statistics

Name	Value	[u]	Description
Elements	1906216		Number of data values
Classes	149		Number of histogram classes
Mean Value	0.0139	µm	Mean value of data values
Standard Deviation	0.4345	µm	Mean Value of standard deviation

Selected Class

Name	Value	[u]	Description
Class Index	-		Index of selected class
Percentage	-	%	Percentage of data in selected class
Lower Border	-		Lower class limit
Upper Border	-		Upper class limit

Parameters

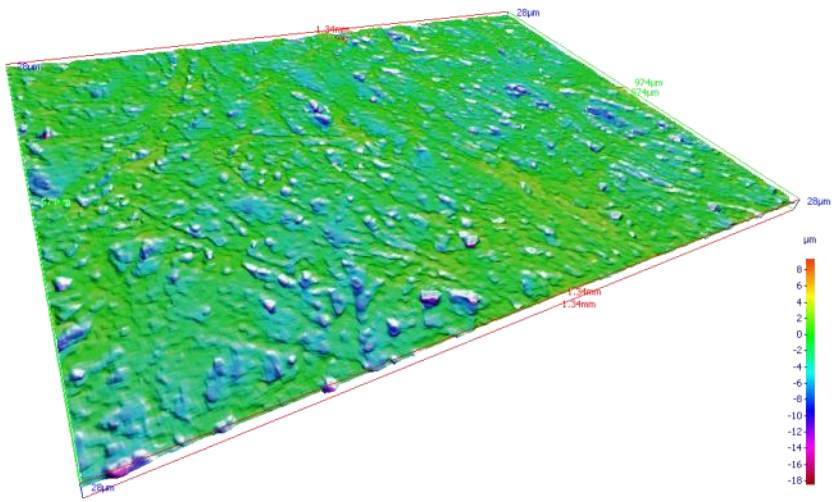
Name	Value	[u]	Description
Sa	347.06	nm	Average height of selected area
Sq	434.73	nm	Root-Mean-Square height of selected area
Sp	4.8514	µm	Maximum peak height of selected area
Sv	2.5709	µm	Maximum valley depth of selected area
Sz	7.4223	µm	Maximum height of selected area
S10z	2.9679	µm	Ten point height of selected area
Ssk	-0.05888		Skewness of selected area
Sku	2.9415		Kurtosis of selected area
Sdq	0.27342		Root mean square gradient
Sdr	3.5126	%	Developed interfacial area ratio
FLTt	7.4223	µm	Flatness using least squares reference plane
Lc	80	µm	LambdaC: cutoff wavelength

Repeatability Roughness Measurement

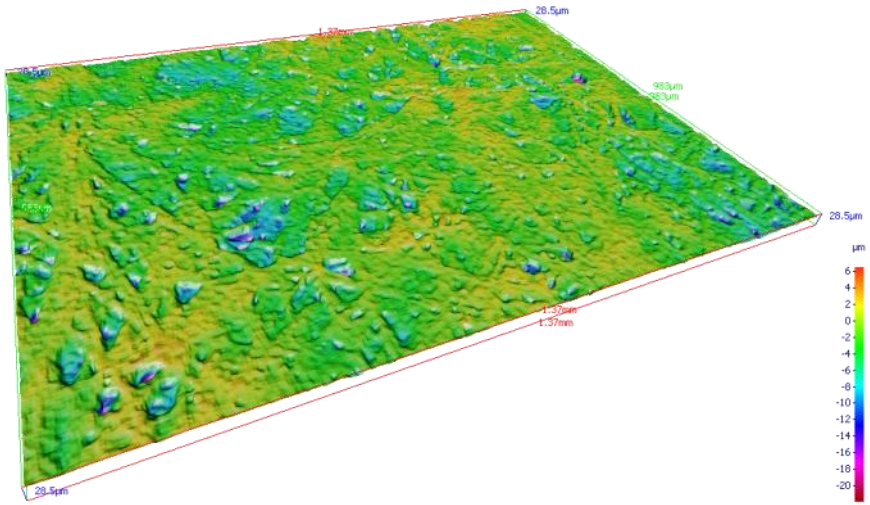
	Measurement 1	Measurement 2	Measurement 3	Measurement 4	Standard deviation
Sa	0.329	0.329	0.329	0.328	**0**
Sq	0.460	0.459	0.458	0.458	**0.001**
Sz	14.33	12.39	14.1	14.2	**0.915**
Sp	11.63	9.389	11.73	11.31	**1.098**
Sv	2.706	3.003	2.369	2.885	**0.276**
Ssk	2.871	2.708	2.694	2.788	**0.081**
Sku	48.69	44.55	45.23	47.76	**1.982**
Sdq	2.67	2.6	2.639	2.608	**0.031**
Sdr	3.092	2.985	3.031	3.038	**0.043**
S10z	11.47	9.654	10.62	11.75	**0.944**

[values in µm]

Example 2: How can printability be quantified?



Good printability

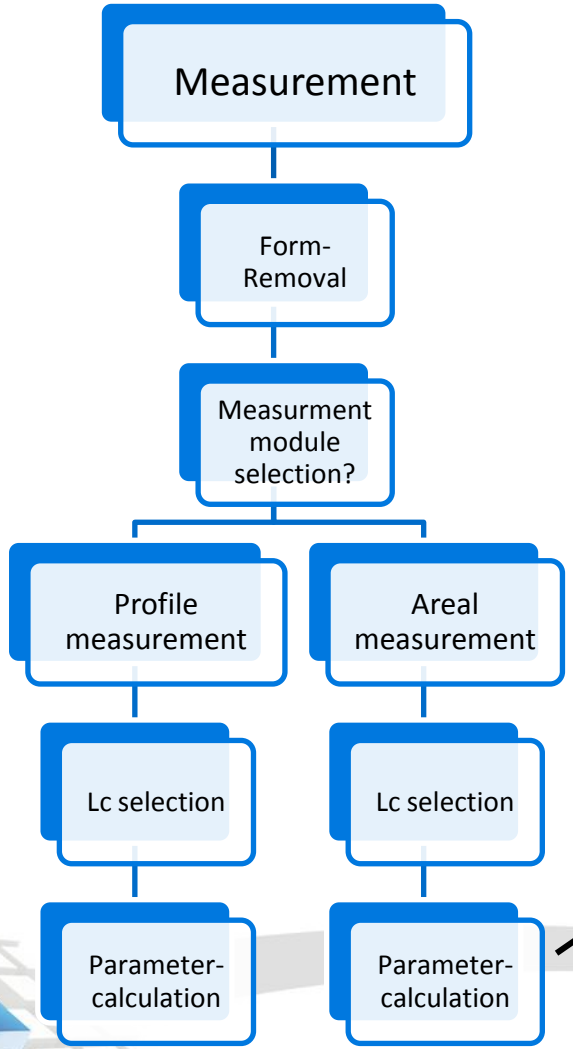


Poor printability

Calculation of roughness parameters

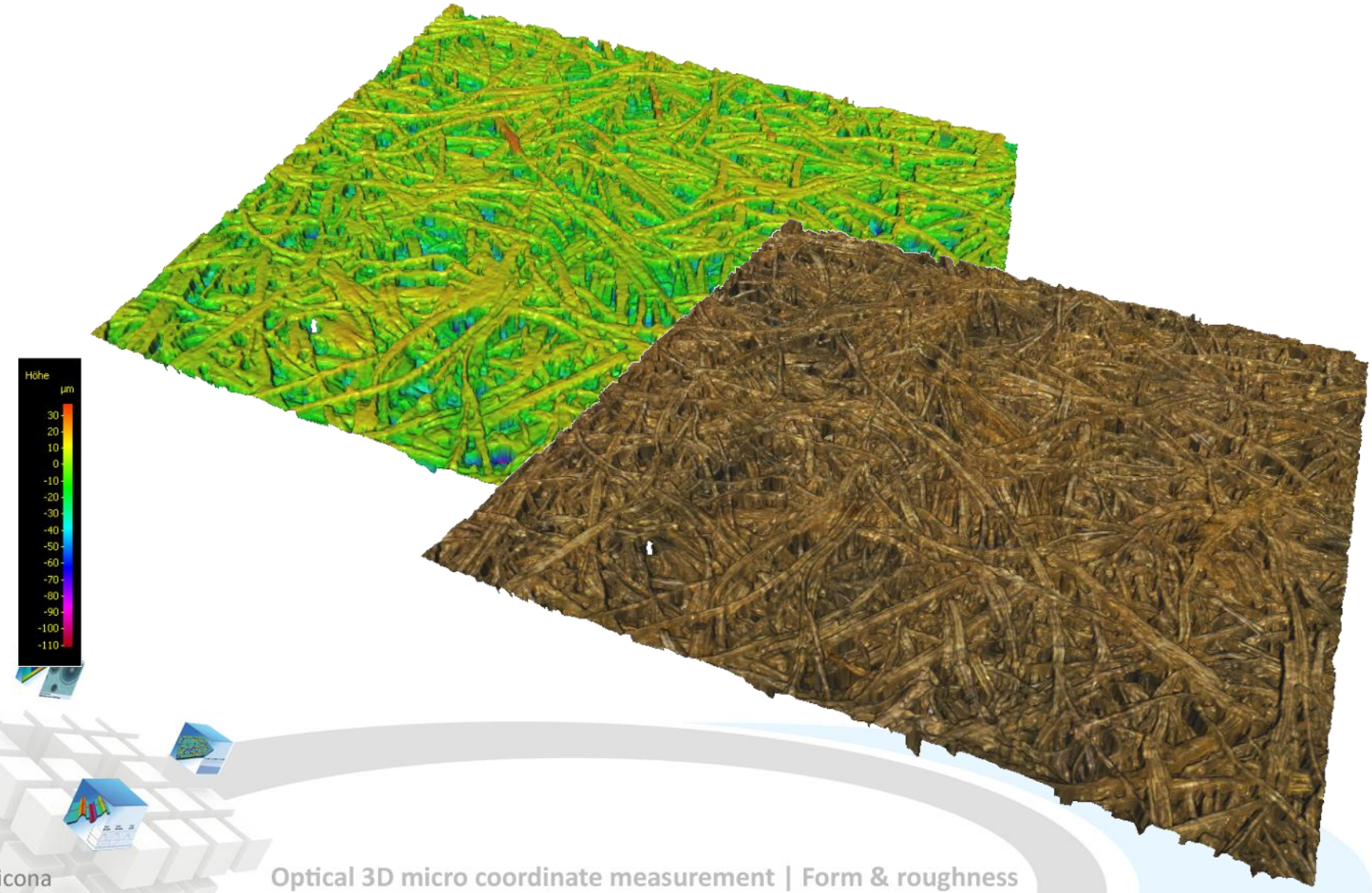
Images from UPM

Calculation of Roughness Parameters

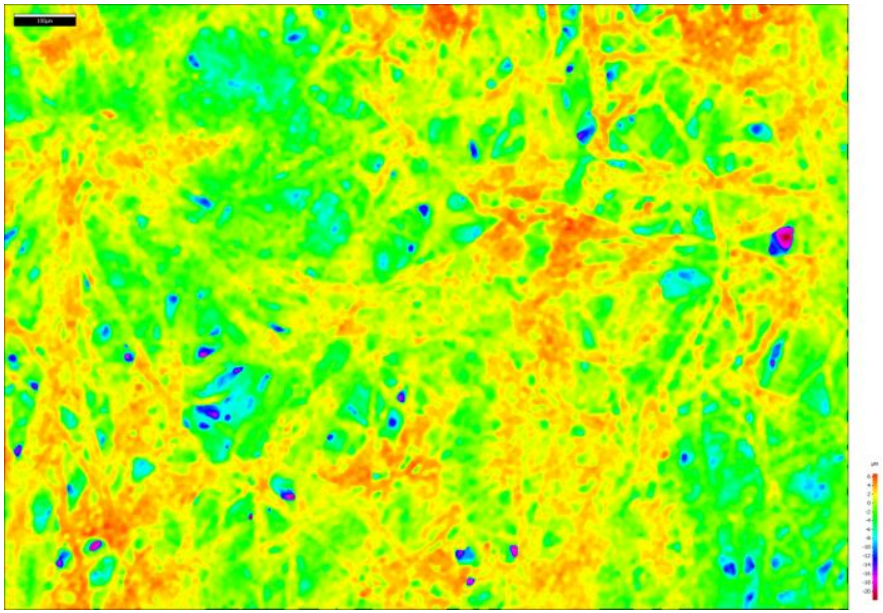


Typical parameters
- Sa
- Spk
- Sk
- Svk
- ftol

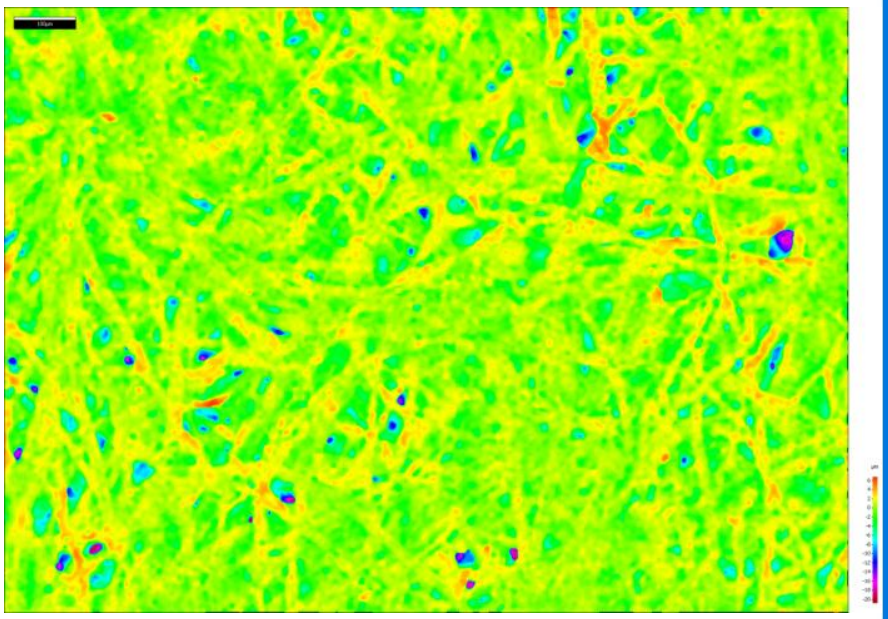
Measurement of the Topography



Roughness Measurement - Removing Waviness



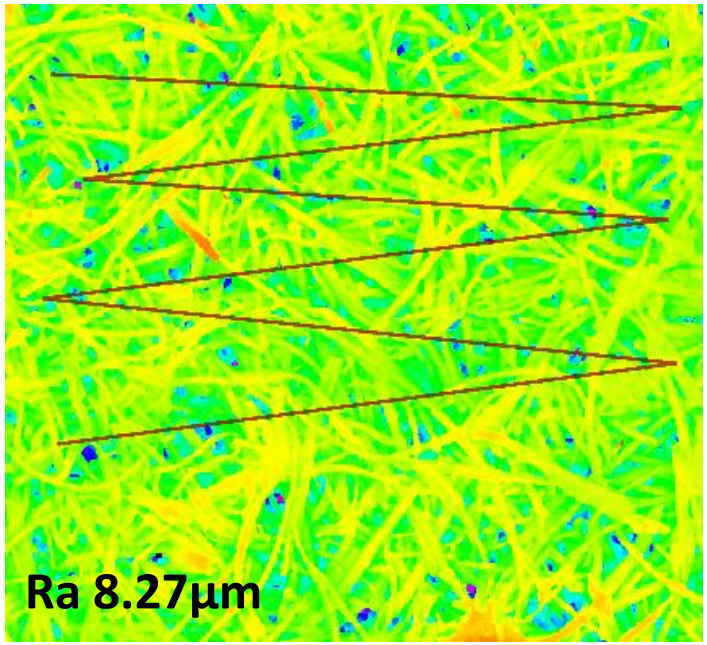
Original measurement

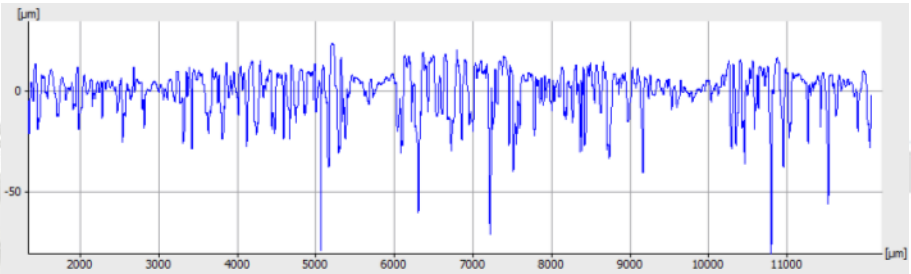


After filtering out waviness

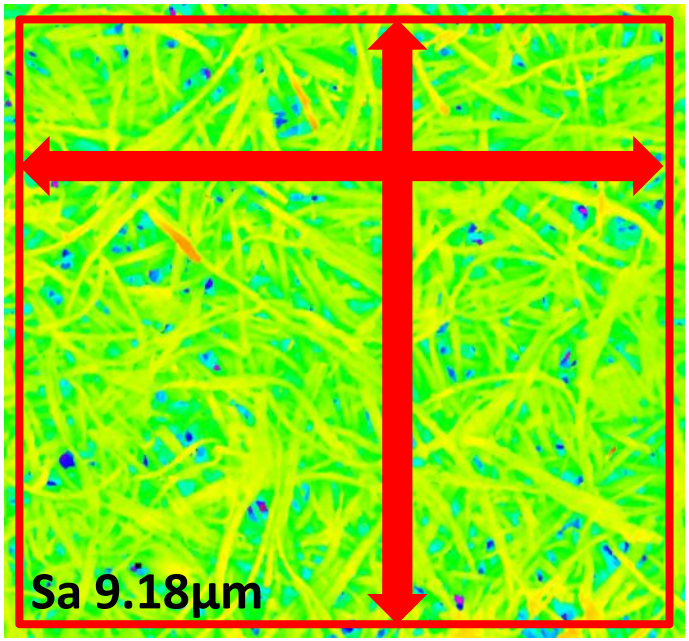
Profile Roughness/Area Roughness

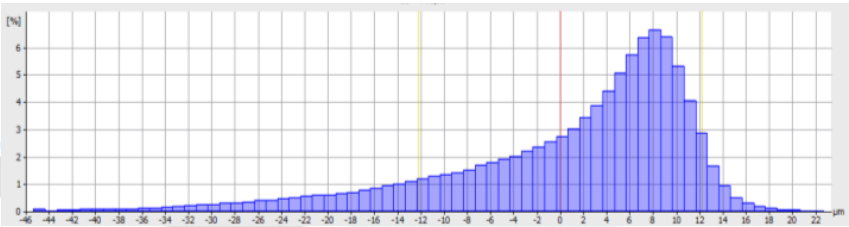
Profile Roughenss





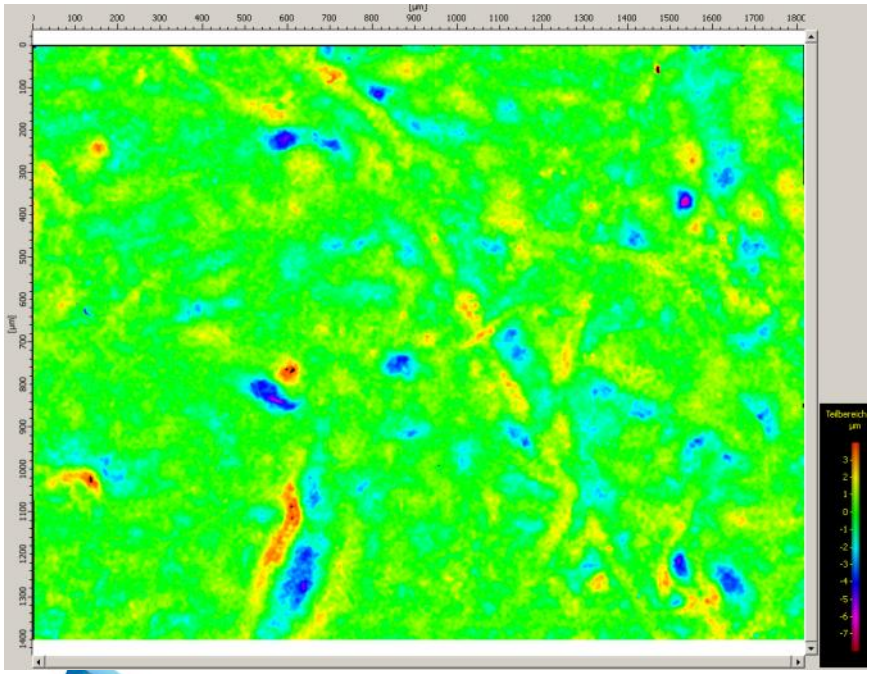
Area Roughness



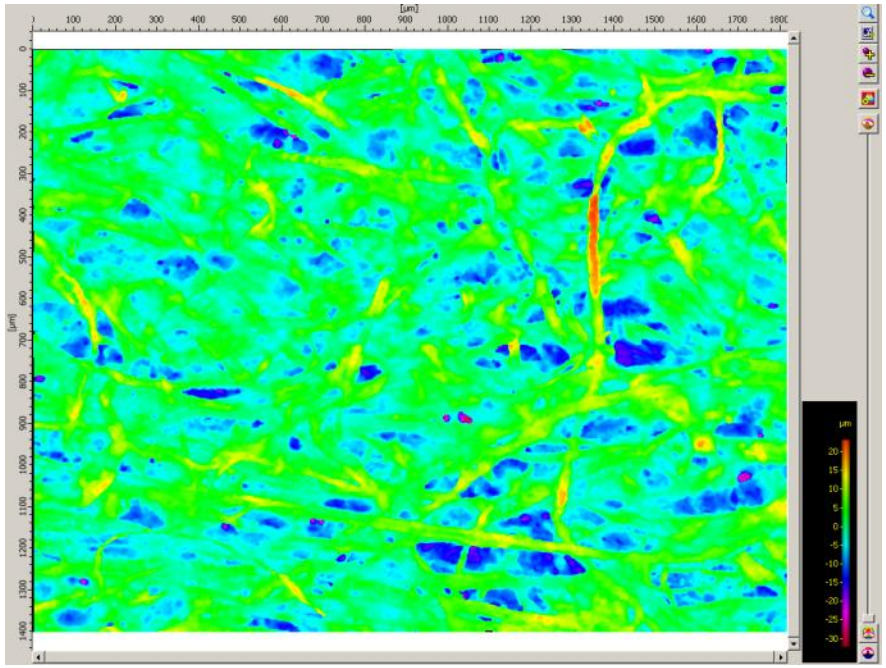


Comparison of Printability

Good printability

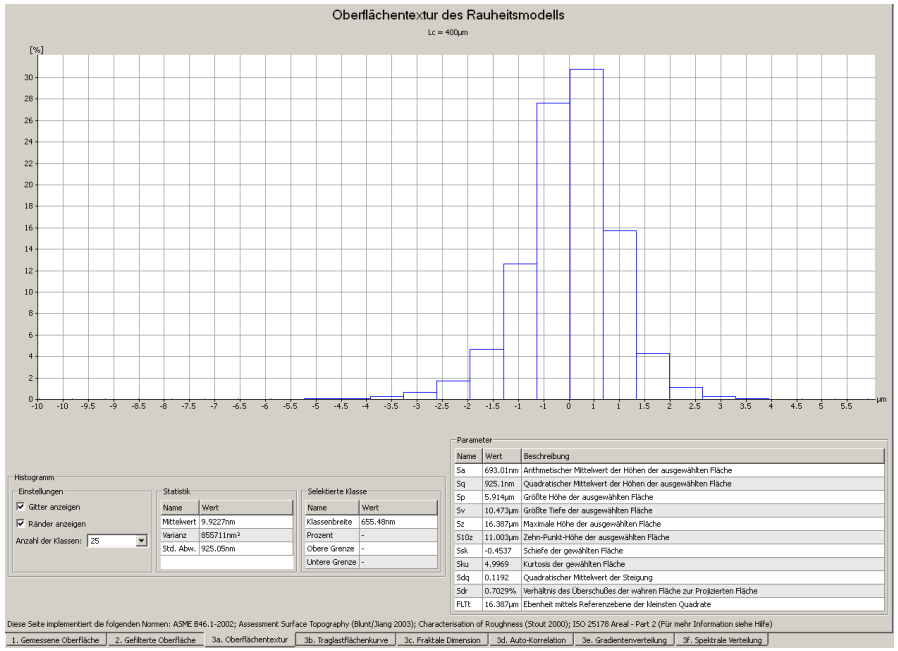


Poor printability

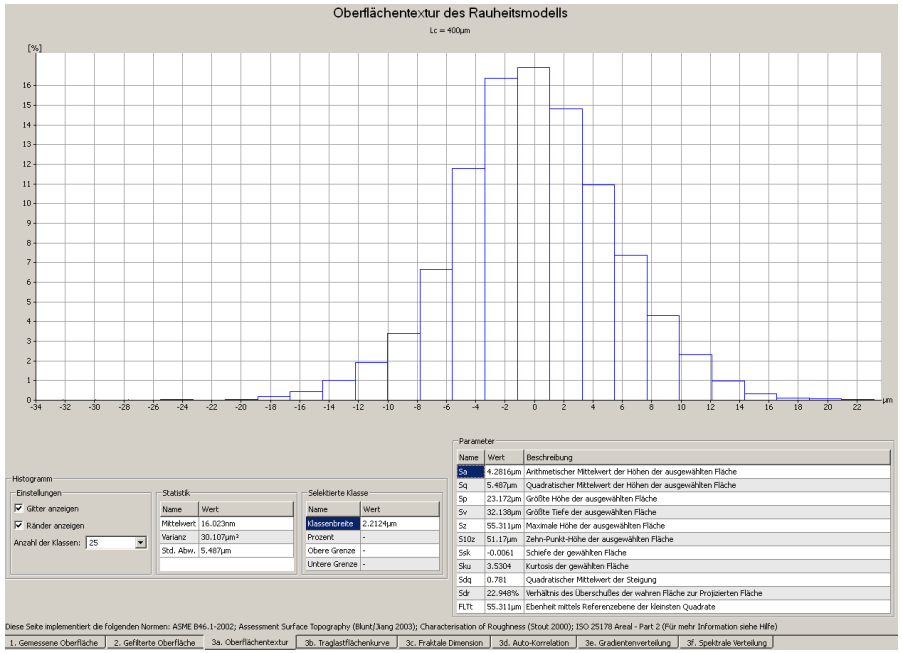


Roughness Measurement: Amplitude Parameter

Good printability



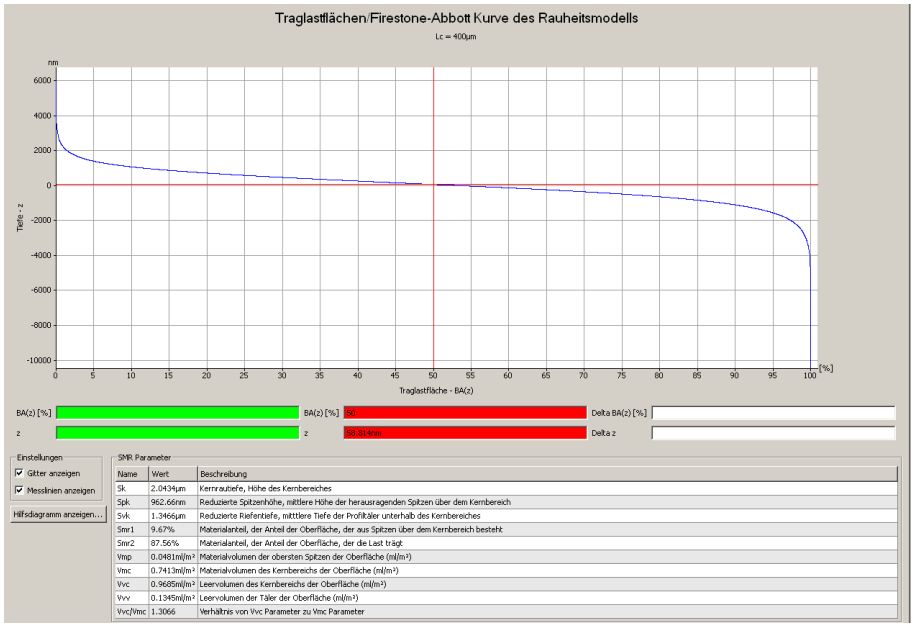
Poor printability



Sa = 0.693µm ⟷ Sa = 4.281µm

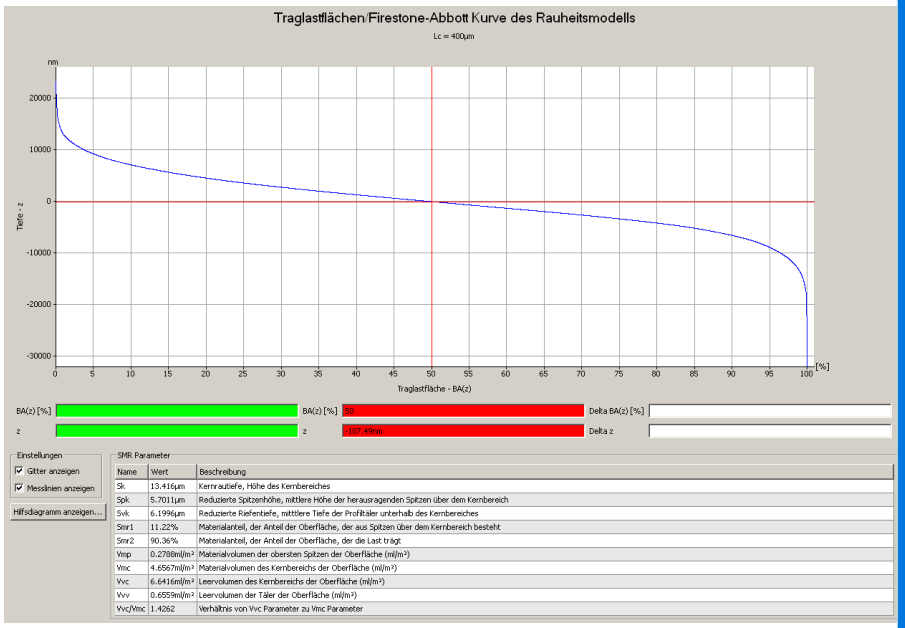
Roughness Measurement: Material Area Curve

Good printability



Name	Wert	Beschreibung
Sk	2.0434µm	Kernrautiefe, Höhe des Kernbereiches
Spk	962.66nm	Reduzierte Spitzenhöhe, mittlere Höhe der herausragenden Spitzen über dem Kernbereich
Svk	1.3466µm	Reduzierte Riefentiefe, mitttlere Tiefe der Profiltäler unterhalb des Kernbereiches
Smr1	9.67%	Materialanteil, der Anteil der Oberfläche, der aus Spitzen über dem Kernbereich besteht
Smr2	87.56%	Materialanteil, der Anteil der Oberfläche, der die Last trägt
Vmp	0.0481ml/m²	Materialvolumen der obersten Spitzen der Oberfläche (ml/m²)
Vmc	0.7413ml/m²	Materialvolumen des Kernbereichs der Oberfläche (ml/m²)
Vvc	0.9685ml/m²	Leervolumen des Kernbereichs der Oberfläche (ml/m²)
Vvv	0.1345ml/m²	Leervolumen der Täler der Oberfläche (ml/m²)
Vvc/Vmc	1.3066	Verhältnis von Vvc Parameter zu Vmc Parameter

Poor printability



Name	Wert	Beschreibung
Sk	13.416µm	Kernrautiefe, Höhe des Kernbereiches
Spk	5.7011µm	Reduzierte Spitzenhöhe, mittlere Höhe der herausragenden Spitzen über dem Kernbereich
Svk	6.1996µm	Reduzierte Riefentiefe, mitttlere Tiefe der Profiltäler unterhalb des Kernbereiches
Smr1	11.22%	Materialanteil, der Anteil der Oberfläche, der aus Spitzen über dem Kernbereich besteht
Smr2	90.36%	Materialanteil, der Anteil der Oberfläche, der die Last trägt
Vmp	0.2788ml/m²	Materialvolumen der obersten Spitzen der Oberfläche (ml/m²)
Vmc	4.6567ml/m²	Materialvolumen des Kernbereichs der Oberfläche (ml/m²)
Vvc	6.6416ml/m²	Leervolumen des Kernbereichs der Oberfläche (ml/m²)
Vvv	0.6559ml/m²	Leervolumen der Täler der Oberfläche (ml/m²)
Vvc/Vmc	1.4262	Verhältnis von Vvc Parameter zu Vmc Parameter

Sk = 2.0434µm ⟷ Sk = 13.416µm

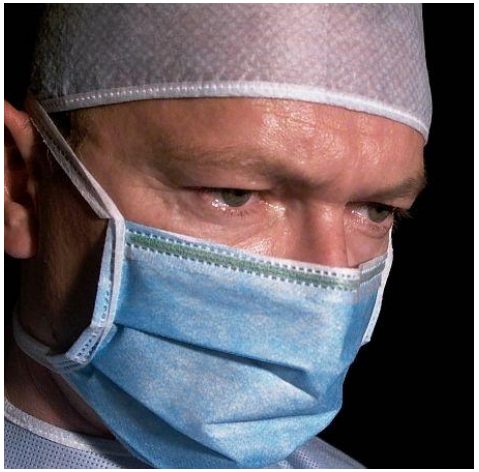
Example 3: Surgeries for a Broken Bone

Broken Bone

1st Surgery

Place the implants

2nd Surgery



Remove the implants

Cooperation project

Project: “BioResorable Implants for Children“

alicona &

Dr. Annelie Weinberg
Laura Bassi Zentrum BRIC

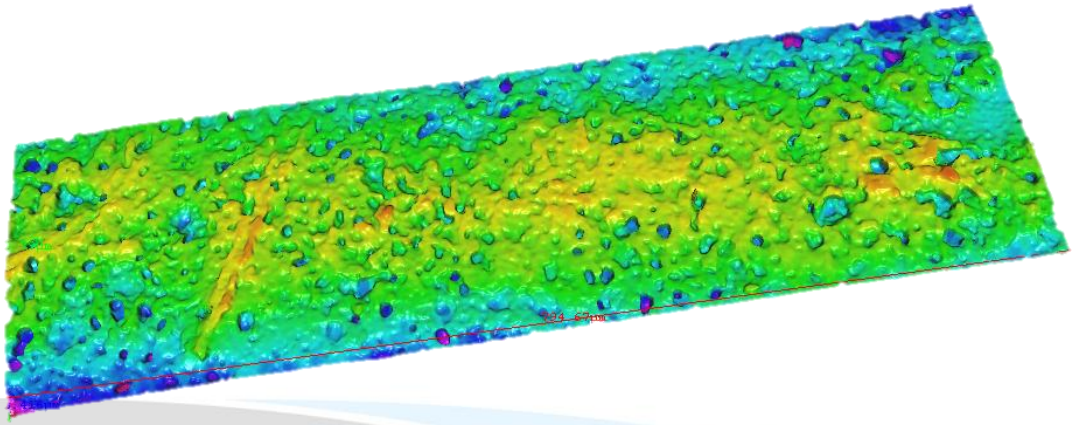
Study of implants made of Mg-Ca-Zn that dissolve in time inside the body and do not need removal surgery; surface of implants has been measured before and after 8 weeks while they were placed inside biological body (rats)

Aim

Find the **correlation between surface and biological behavior**

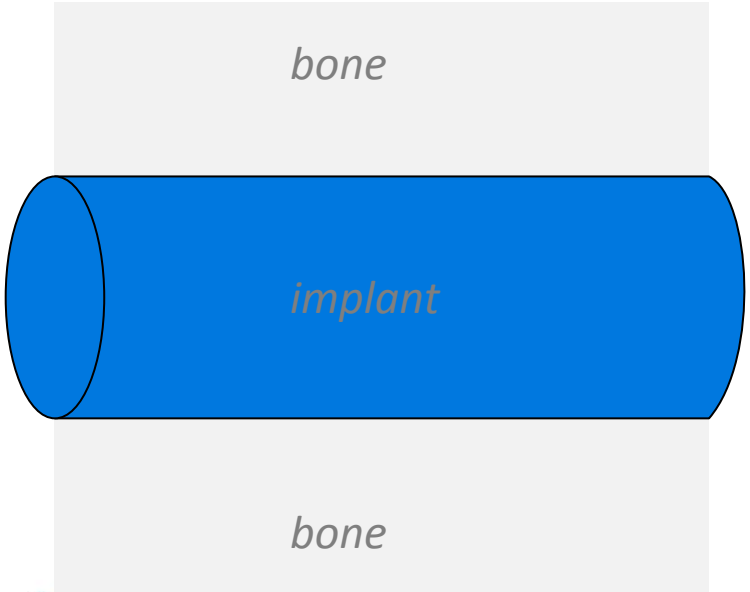
Measurement Challenge

- Rugged surface
- Various materials
- Non destructive measurements
- Repeatable and traceable measurements required

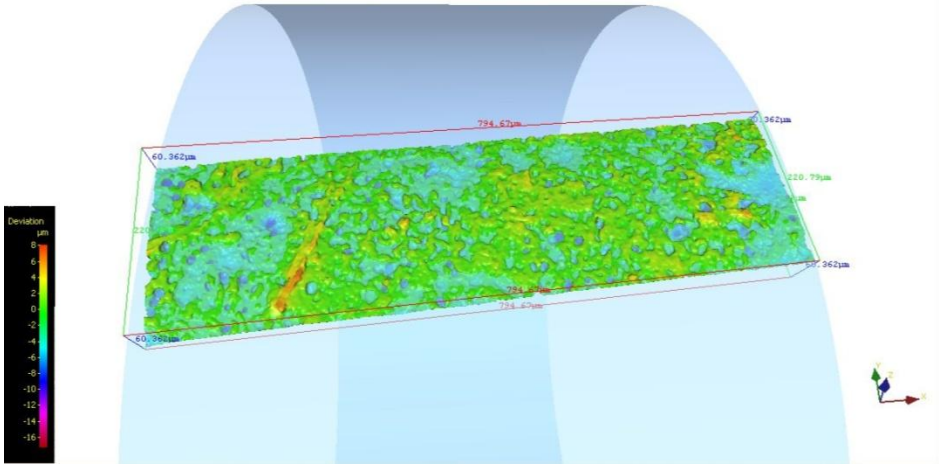


Solution for the Future

Bioresonable implants



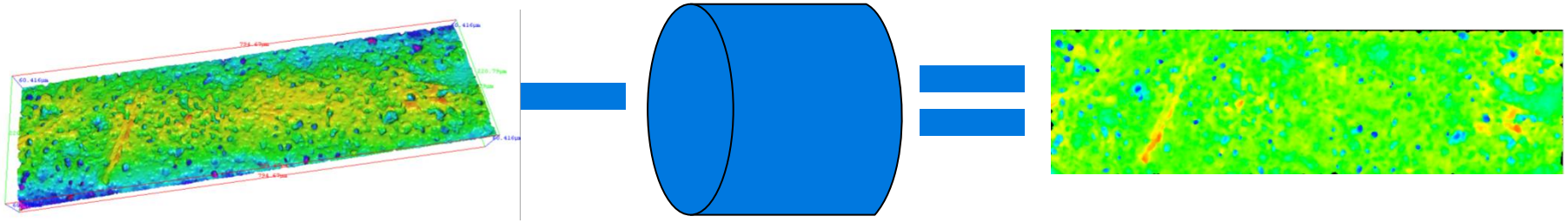
Visualization of the bone implant



3D measurement of an implant

Important for the Roughness Measurement of Implants:

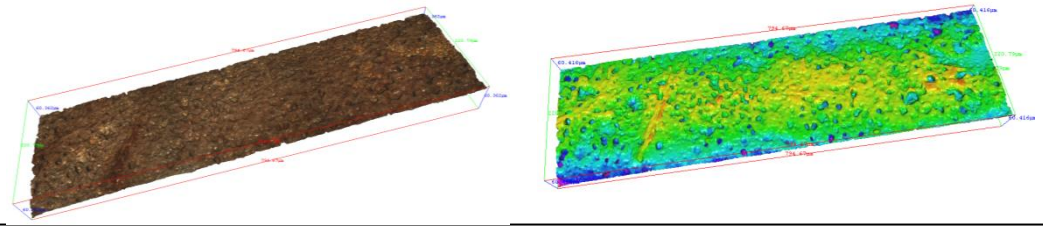
Remove the cylindrical form



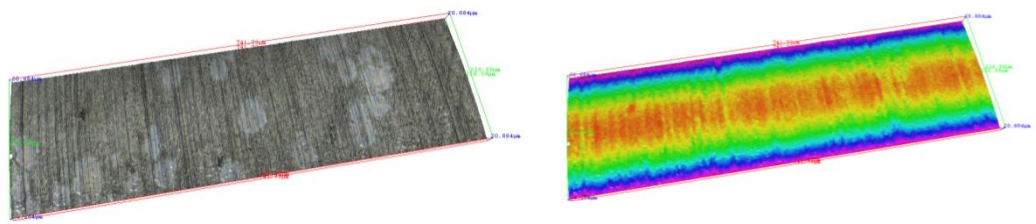
Removing the cylindrical form makes roughness measurements repeatable

Step 1: Measure the Implants

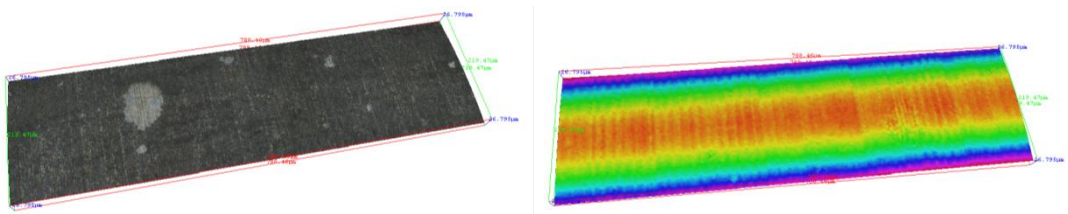
3 different materials were examined



Magox
(LV1 alloy)

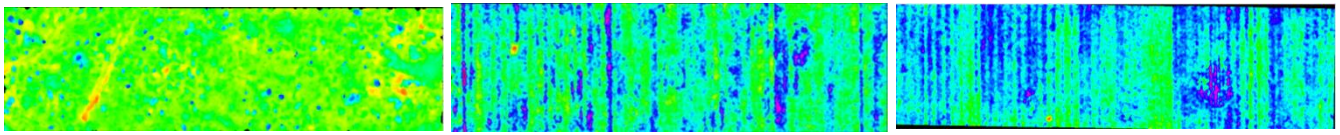


WZ21
(crystalline magnesium alloy Mg, 1% Zn, 0.25% Ca, 0.15%Mn, 2% Yttrium)



LU1
(crystalline magnesium alloy Mg, 5% Zn, 0.25% Ca, 0.15%Mn)

Material Comparison



Parameter	Material 1 Magox	Material 2 WZ21	Material 3 LU1
Sa	1.32 µm	0.19 µm	0.12 µm
Sq	1.85 µm	0.25 µm	0.15 µm
Sz	25.12 µm	2.33 µm	1.87 µm
Lc	200μm	200μm	200μm

Largest roughness values

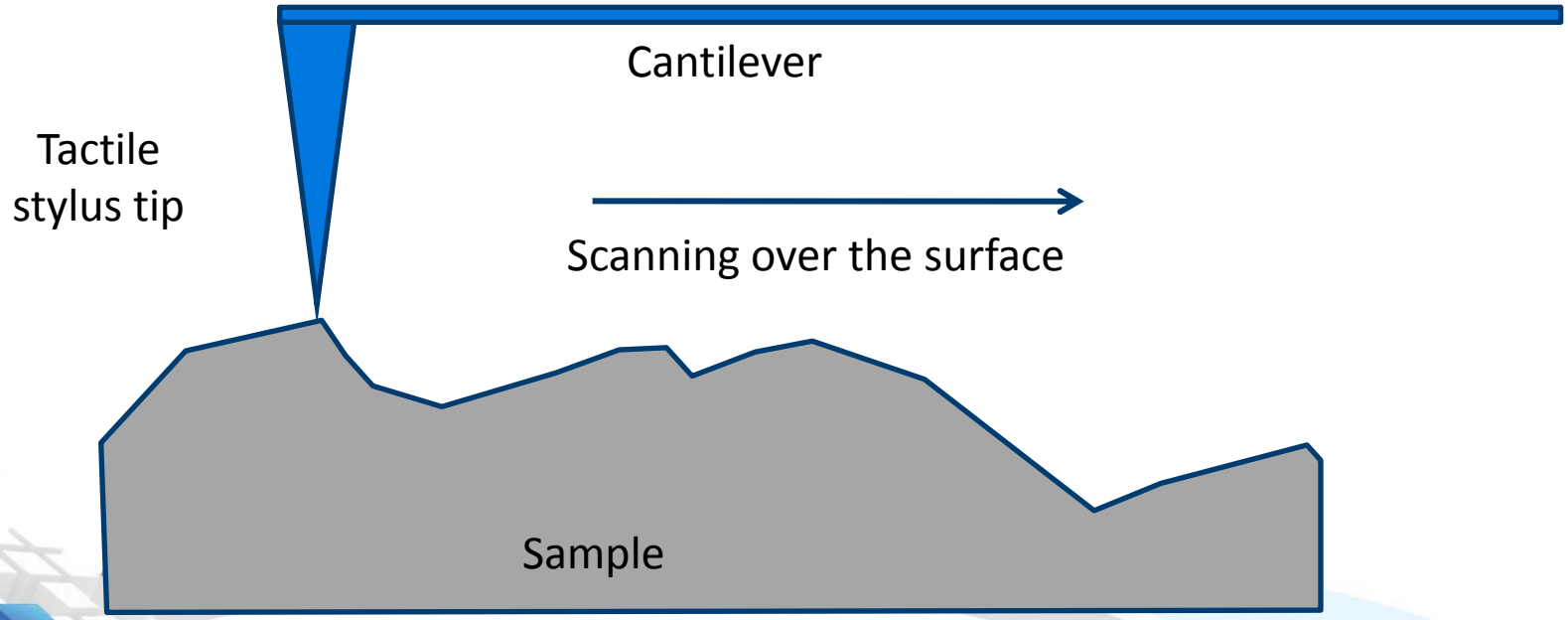
Still contains waviness

6.

Optical versus Tactile

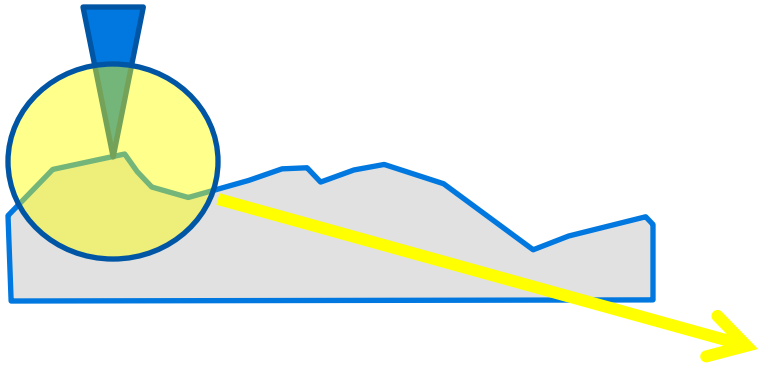
Introduction to Tactile Instruments

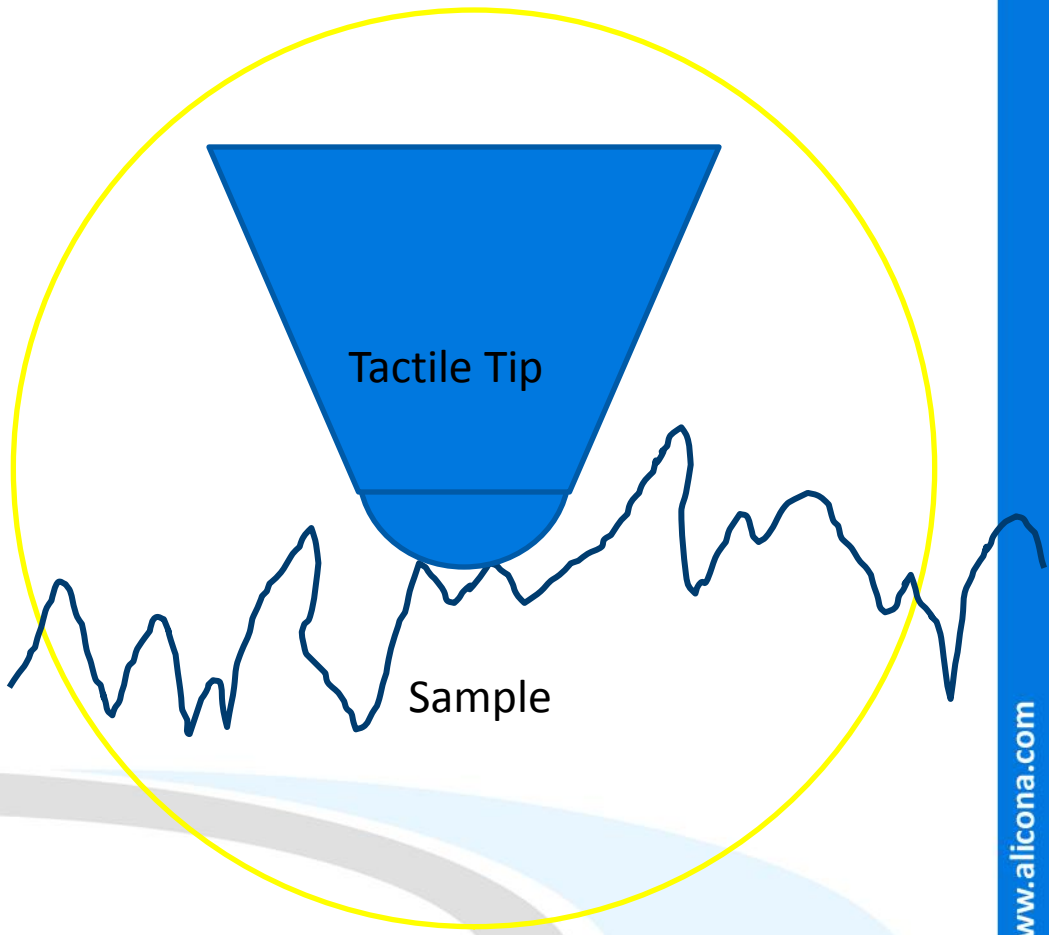
A tactile instrument measures the contact between the tactile tip and the specimen surface. Through moving the tip over the surface a profile or area is measured.



Introduction to Tactile Instruments

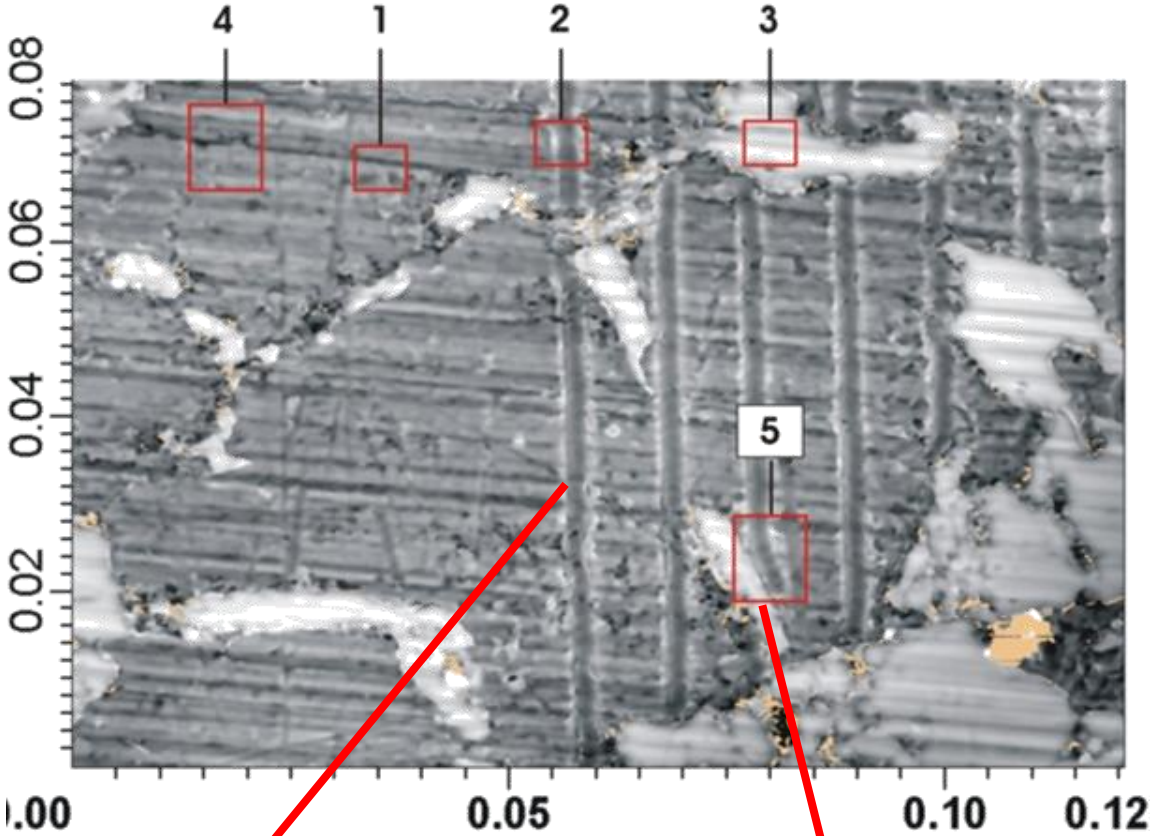
The stylus tip is not sharp but round:



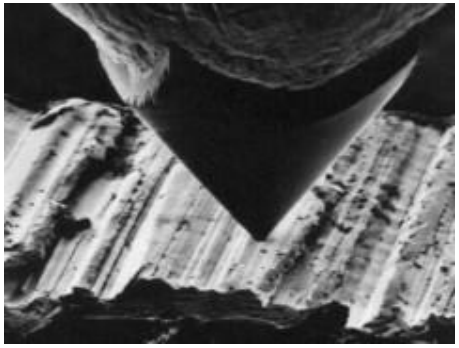


The tip is NOT measuring the surface but the contact points of the tip and the surface

Problems of Tactile Instruments



1 Machining traces
2 Measuring traces
3 Si-crystall (hard)
4 Al-matrix (soft)
5 Deviation of the stylus tip



Images courtesy by Prof. Dr.-Ing. Jörg Seewig, Techn. Univ. Kaiserslautern, Germany

The tip is gene- rating a groove

The tip is deflected

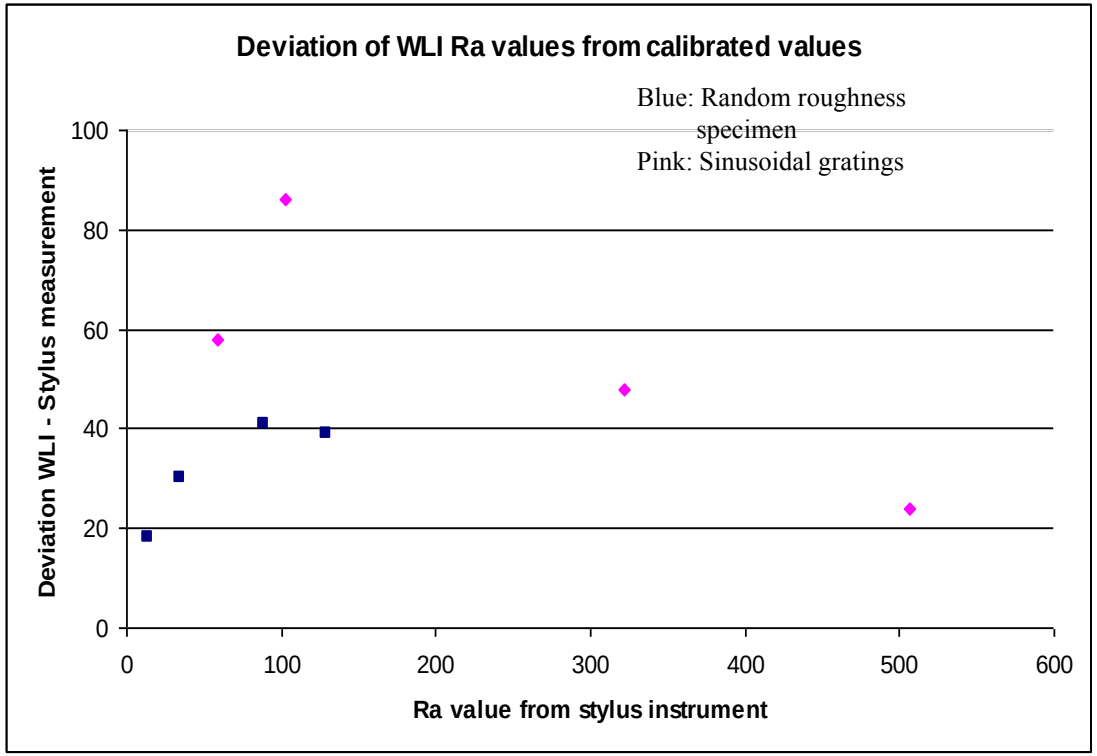
Problems of Tactile Instruments

- Slipping effect
- Bouncing effect
- Material deformation caused by tip
- Less informative (single profile)
- Tip wear
- User does not know where the profile was measured
- Limited vertical scan range
- Often only roughness can be measured
- No steep flanks possible

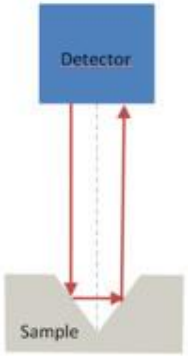
Problems of Optical Instruments

- Most available roughness standards are too smooth and specular for optical systems
- Some optical devices (e.g. white light interferometers) are not optimal for certain roughness measurements

Problems of White-Light-Interferometry



- white-light-interferometry: Deviations of the Ra measurements are very high.
- Up to 100% of the nominal value!
- Especially in the range Ra > 50 and Ra < 300nm



Double reflextions
→ wrong height measurements

Figure taken from
Hyug-Gyo Rhee, Theodore Vorburger, Jonathan W. Lee and Joseph Fu: Discrepancies between roughness measurements obtained with phase-shifting and white-light interferometry. Applied Optics IP, vol. 44, Issue 28, pp.5919-5927, 2005

Theoretical Comparison

Differences at different scales:

- **Big measurement values:** mm range
  very small differences, depending on application

- **Medium measurement values:** µm range
  Depending on surface roughness and material differences can occur

- **Small measurement values:** nm range
  Large differences expected

Problems when Comparing Optical and Tactile Instruments

Problems of Tactile Instruments

- Size and form of stylus tip influences measurement result
- Interaction of stylus tip is complex to understand

Problems of Optical Instruments

- Tactile roughness standards are often too smooth
- Some optical systems (e.g. white light interferometers) are not optimal for certain roughness measurements

Problems of the Comparison Procedure

- It is difficult to find the same measurement position
- International standards are not completely unambiguous
  → different software gives different results on the same profile

Problems of Comparisons

- Correct measurement position
- Structure of roughness standard and part nearly equal!
- Tactile or optical, which is more accurate?
  (especially on random roughness specimens)
- International standards are not completely unambiguous

→ Different software gives slightly different results on the same profile.

Advantages of optical instruments

- Typically at total area is measured
- More data points are measured in less time
- More data points allow filtering surface and surface parameters
- No contact with the sample. This means no wear on the surface.
- True color information

Advantages of InfiniteFocus Compared to Tactile Measurements

Advantages of InfiniteFocus over a profilometer:

- IFM can measure areas instead of profiles
- IFM can measure form and roughness at once
- IFM has got a high vertical scan range
- IFM uses color information to know where you are measuring
- You can measure elastic materials
- You can measure very rough surfaces and surfaces with slopes reliably
- High lateral sampling
- High lateral resolution
- Less maintainence (no stylus tip replacement)
- Very flexible measurement options
- Not only for flat samples

Profile versus Surface

Examples where to use Profile or Area Measurement

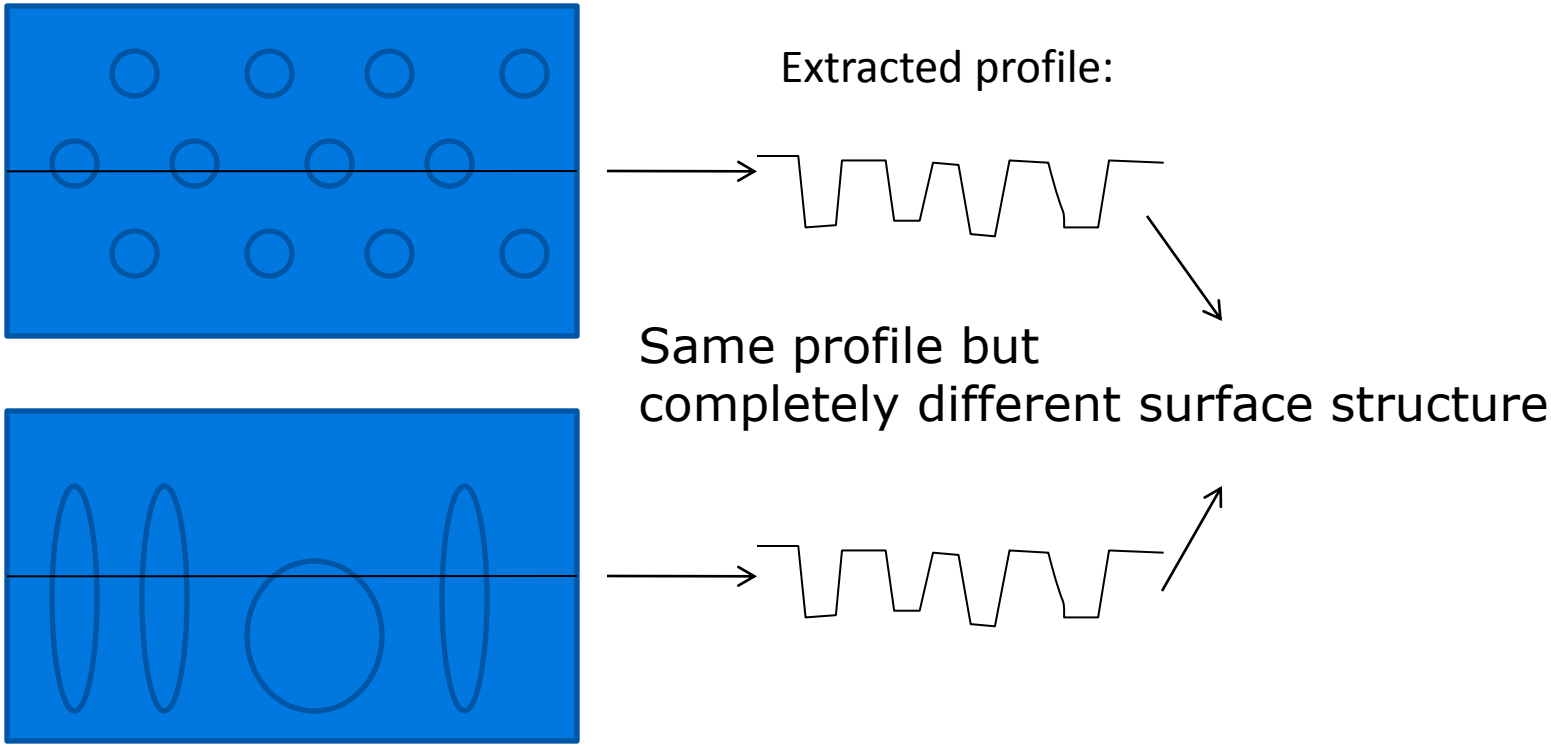
Profile Measurement

- Surfaces with structure in one direction and no structure in the other direction (for example: turned surfaces)
- Roughness measurement that must be comparable with tactile instruments

Area Measurement

- Measuring the flatness of a surface
- Measuring the roughness of structured surfaces with complex forms (eg. paper)
- Surfaces with random surface texture
- Measurement of complex parameters

Area Versus Profile Measurement

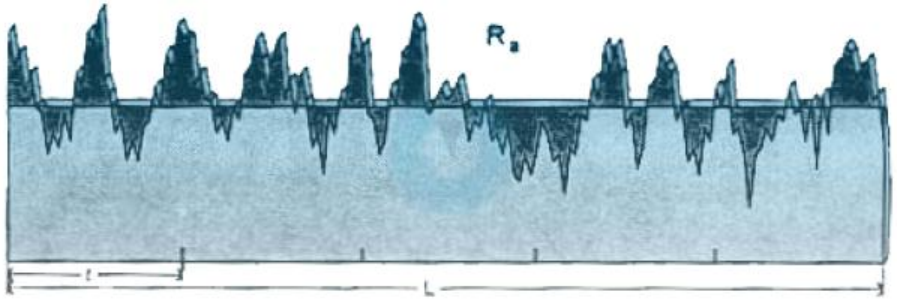


- Profile Measurement gives only limited information
- You have to know your surface and what you are doing
- Area Measurement can help obtaining more reliable results

Area Measurement Advantages

- More repeatable results
- More complex parameters are possible
- More significant parameters (volume parameters,…)
- Less user influence
- Much more parameters are possible (fractal dimension, autocorrelation, local homogeneity, gradient distribution)

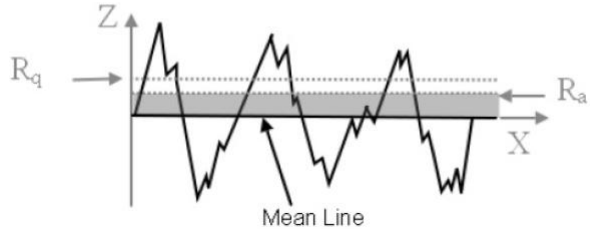
Roughness Parameters



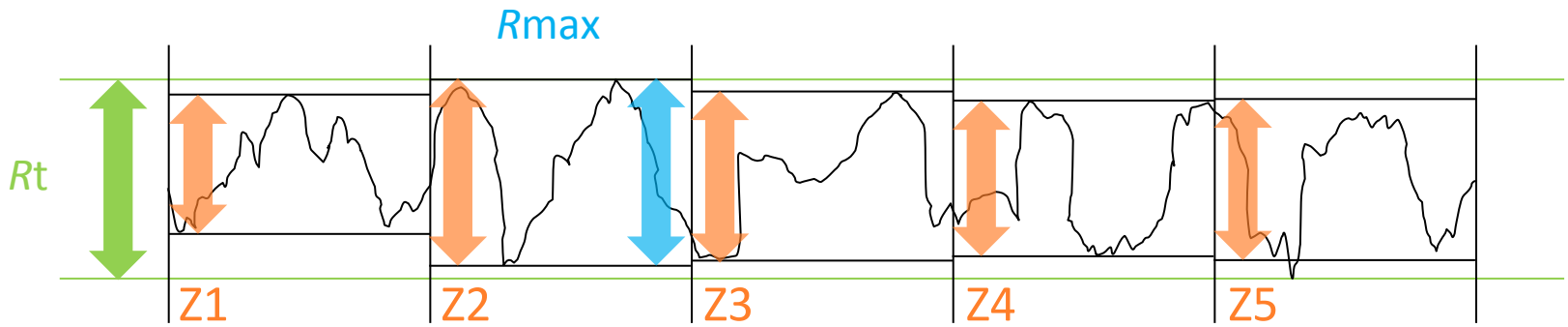
The average roughness, Ra, is an integral of the absolute value of the roughness profile. It Is the shaded area divided by the evaluation length, L. Ra is the most commonly used roughness parameter.

$$R_a = \frac{1}{l}\int_0^l |Z(x)|\,dx \qquad R_q = \sqrt{\frac{1}{l}\int_0^l Z^2(x)\,dx}$$

Z(x) = profile ordinates of roughness profile



Rz – Rmax – Rt



Rz= Mean value of Z1, Z2, Z3, Z4, Z5

» **Rt**
Maximum peak to valley height of the roughness profile

» **Rmax**
Maximum peak to valley height of the roughness profile within a sampling length

» **Rz**
Average peak to valley height of the roughness profile

VDI Roughness Method

VDI Table

In the following, you can determine the roughness for your application according to VDI table.

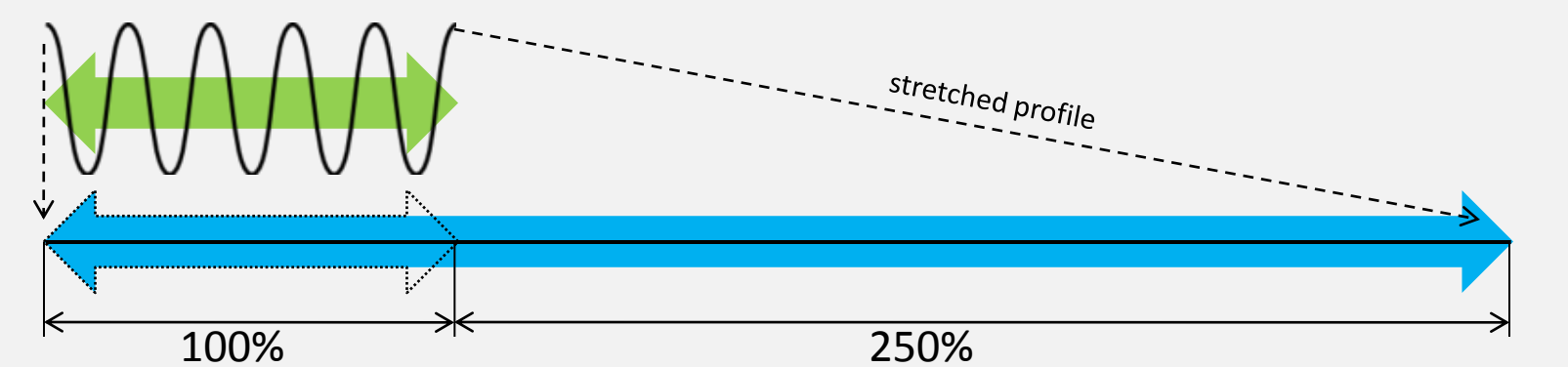
VDI3400 Ra = AA = CLA 0-45	µm	µinch	N3-N10	ISO1302 Rt µm
0	0.1	4	N3	
1	0.11	4.4		
2	0.12	4.8		
3	0.14	5.6		
4	0.16	6.4		
5	0.18	7.2	N4	
6	0.2	8		
7	0.22	8.8		
8	0.25	10		
9	0.28	11.2		
10	0.32	12.8		
11	0.35	14	N5	
12	0.4	16		1.6
13	0.45	18		
14	0.5	20		
15	0.56	22.4		3.2
16	0.63	25.2		
17	0.7	28		
18	0.8	32	N6	5
19	0.9	36		
20	1	40		
21	1.12	44.8		7.5
22	1.26	50.4		
23	1.4	56		
24	1.62	63		12
25	1.8	72	N7	
26	2	80		
27	2.2	88		16
28	2.5	100		
29	2.8	112		
30	3.2	125	N8	20
31	3.5	140		
32	4	160		
33	4.5	180		25
34	5	200		
35	5.6	224		
36	6.3	250	N9	37
37	7	280		
38	8	320		
39	9	360		46
40	10	100		
41	11.2	448		
42	12.6	500	N10	60
43	14	560		
44	16	640		
45	18	760		85

Very old methode, seldom used

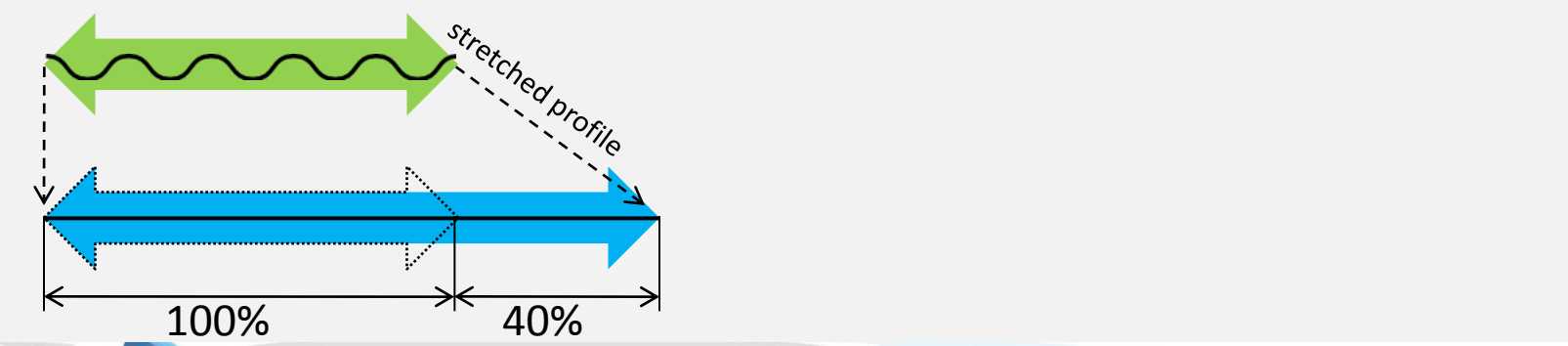
VDI Roughness = 20*lg(10*Ra)

Sdr – Developed interfacial area ratio

Example 1 – **Sdr: 250%**



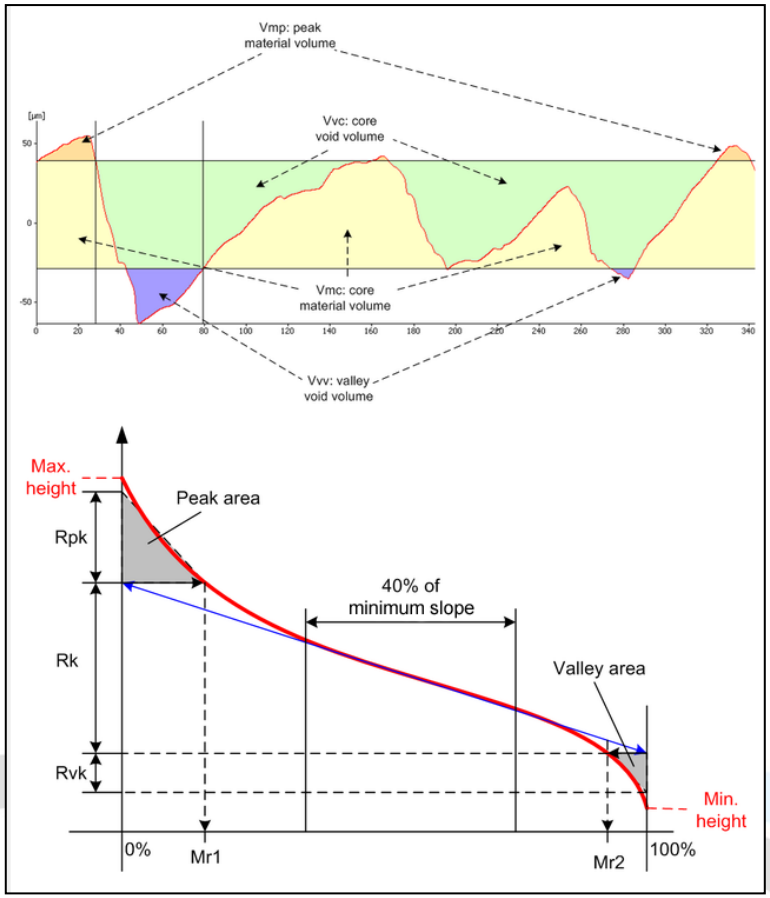
Example 2 – **Sdr: 40%**



projected area true area

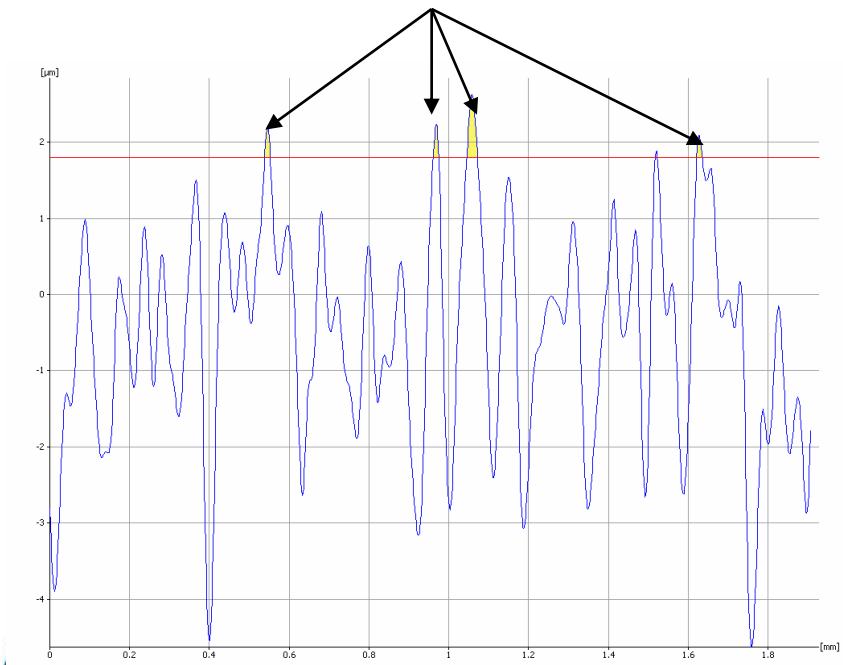
Bearing Area Curve Parameters

- are based on the bearing area ratio curve (Abbot-Firestone)
- includes the Rk family of parameters

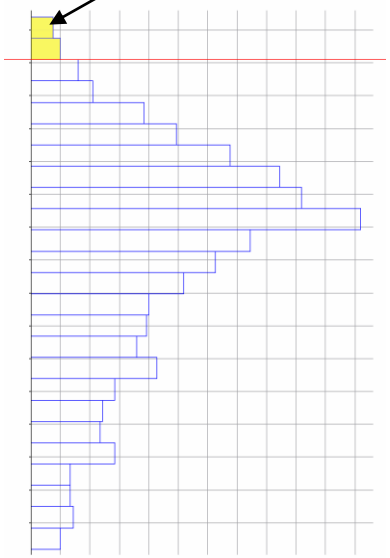


Bearing Area Curve of Rough Surfaces

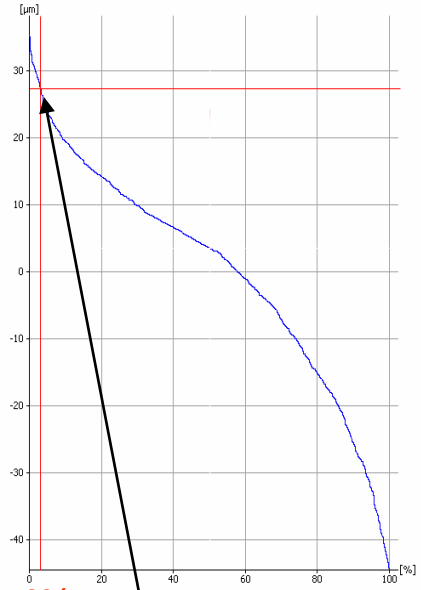
Small bearing area: Example: only 4% of the total surface is above the red line



Profile



Height Histogram

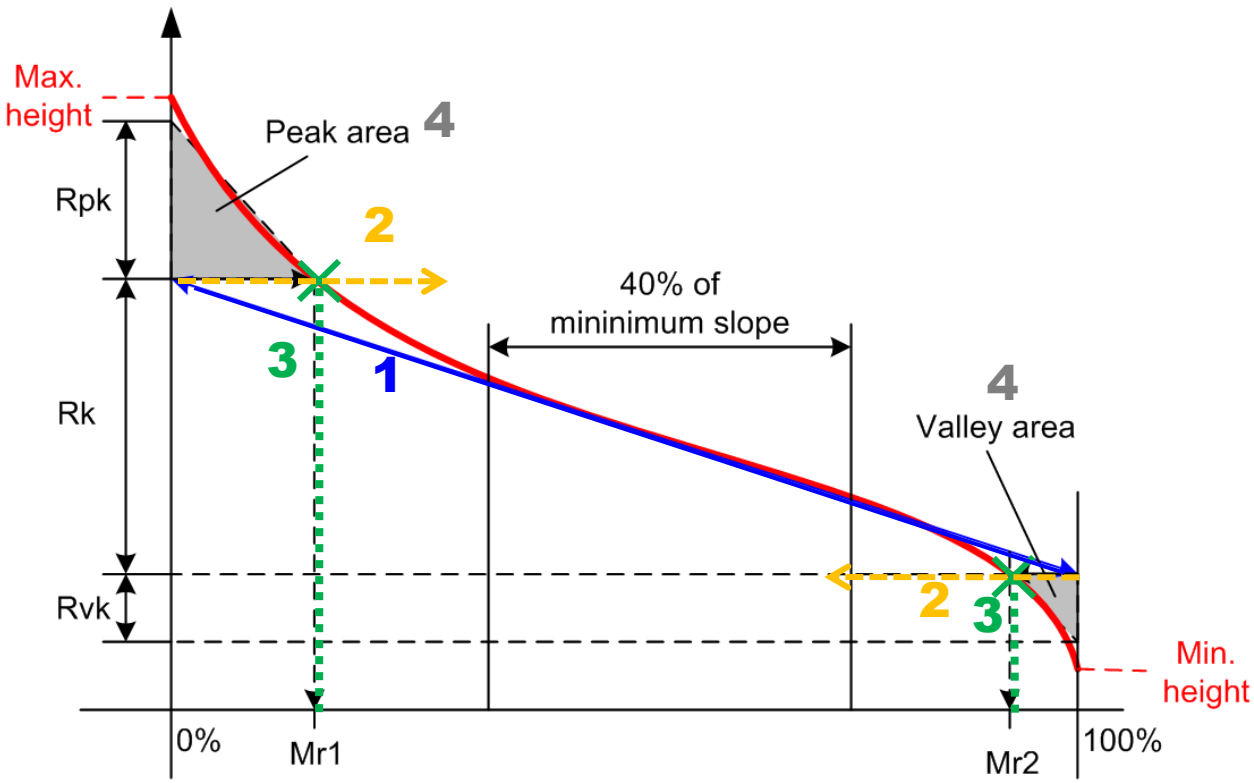


4%

Bearing Area Curve

A small bearing area is indicated by a **steep slope** at the beginning of the bearing area curve

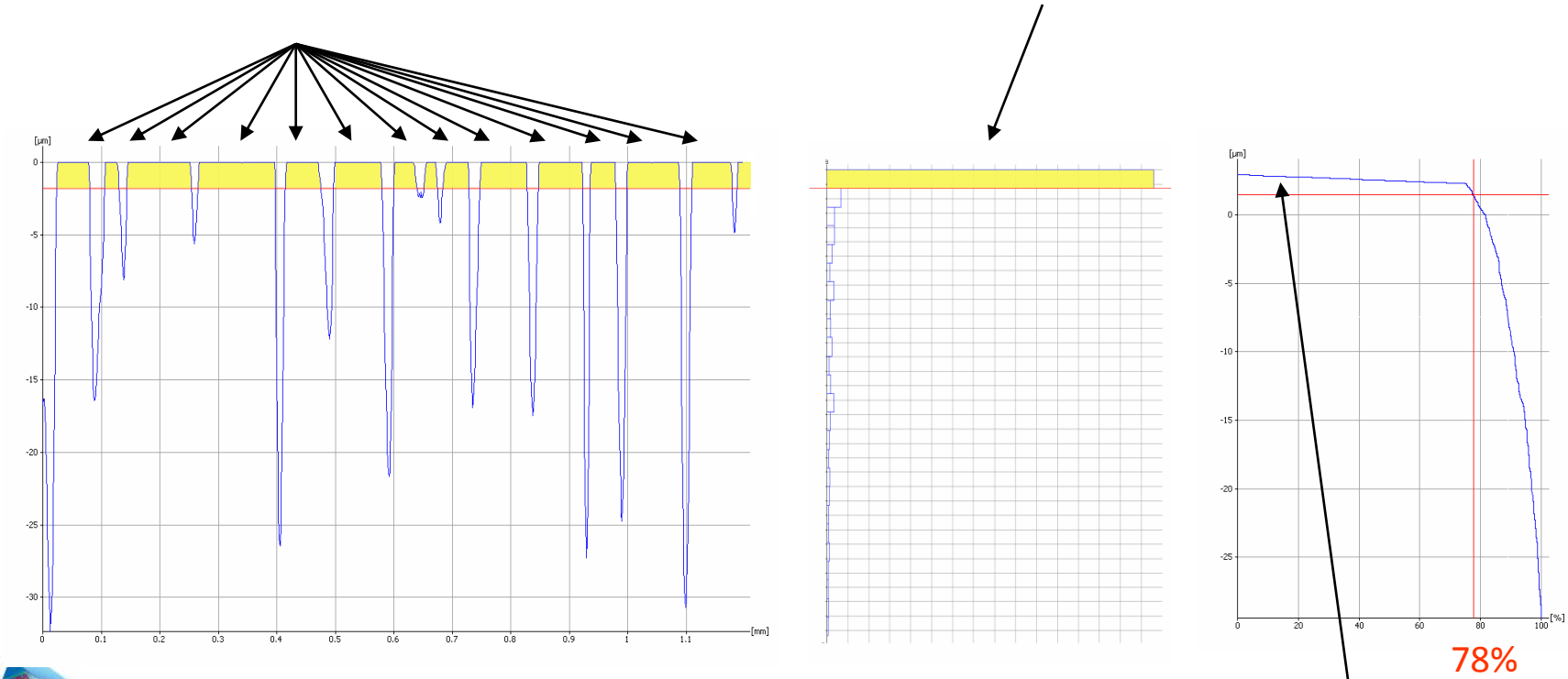
How are the Parameters Rk, Rvk, Rpk calculated?



1. A line (blue) is fitted into the bearing curve (conform to ISO standards)
2. The intersections of this line and the y-axis are determined.
3. Rk, Mr1 and Mr2 are determined from these intersections.
4. The grey areas define the parameters Rpk and Rvk

Bearing Area Curve of Honed Surfaces

Large bearing area: Example: 78% of the total surface is above the red line



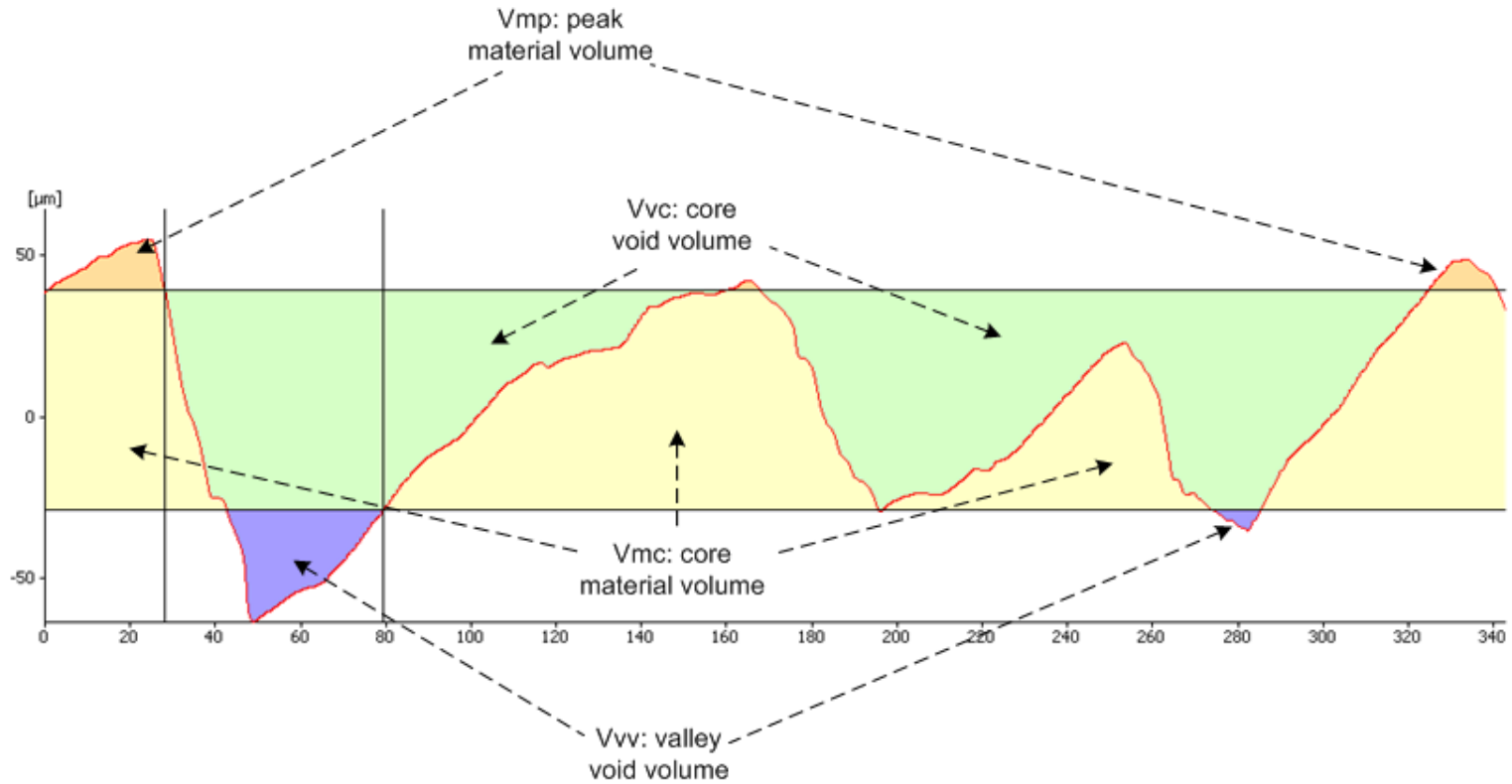
Profile

Height Histogram

Bearing Area Curve

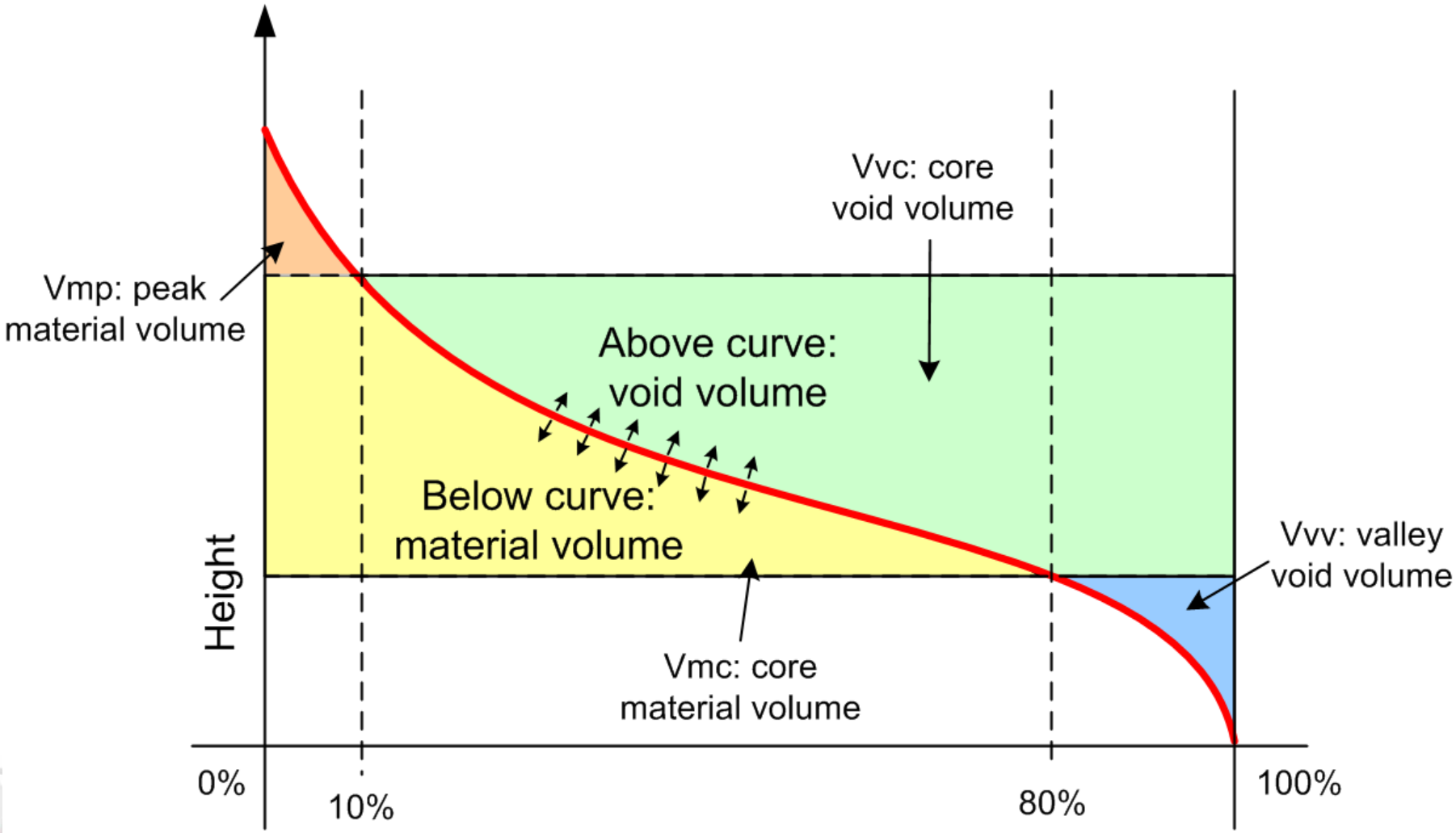
A large bearing area is indicated by a **small slope** at the beginning of the bearing area curve

Functional or Volume Parameters

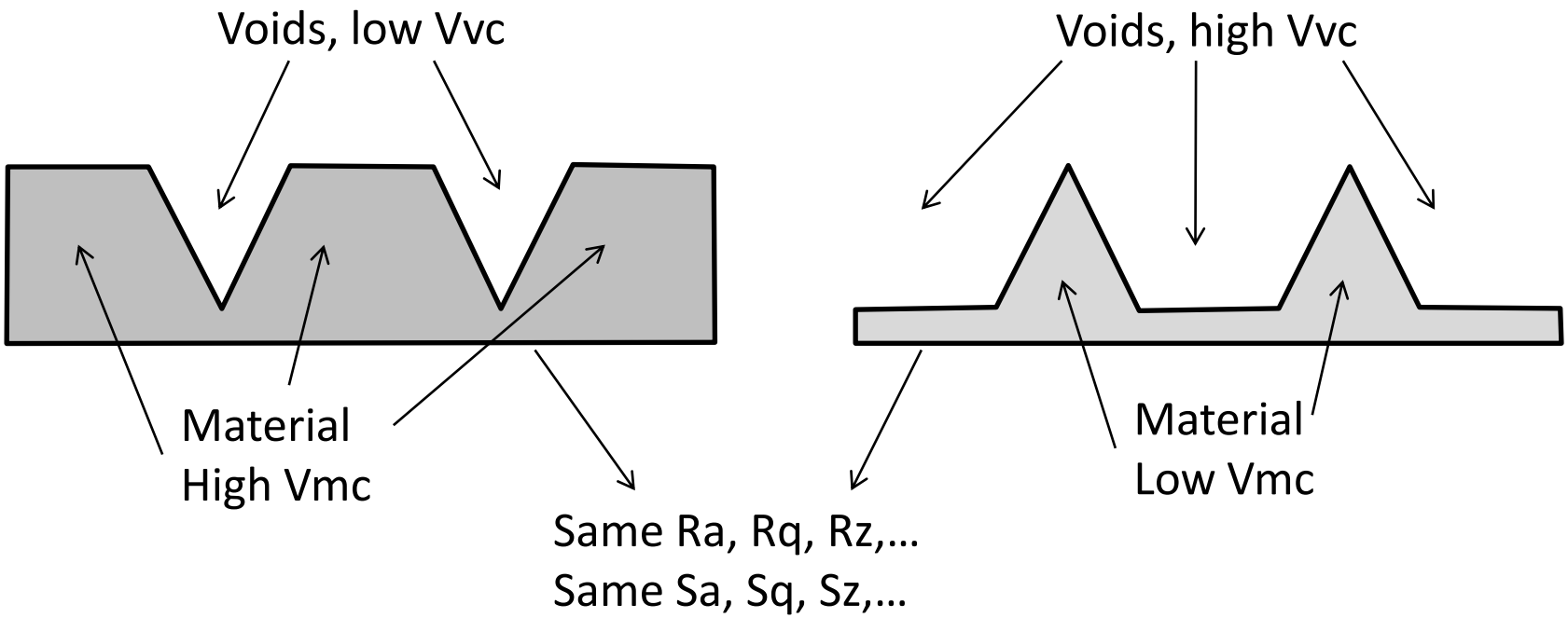


Volume parameters are calculated for whole surfaces. For better visualization only a profile through the surface is shown above.

What are Volume Parameters?



When to use Volume Parameters



→Completely different volume parameters

Volume parameters can distinguish better between surfaces than others. Volume parameters are called functional parameters.

7.

Classification

How can surface parameters be quantified by measurement parameters?

Parameter

&

Classification

What is it?

Classification/Selection is the step of determining the relevant parameters to distinguish good from bad parts.

Why is it important?

1. It helps the user to identify the relevant parameters
2. It helps in classifying unknown parts

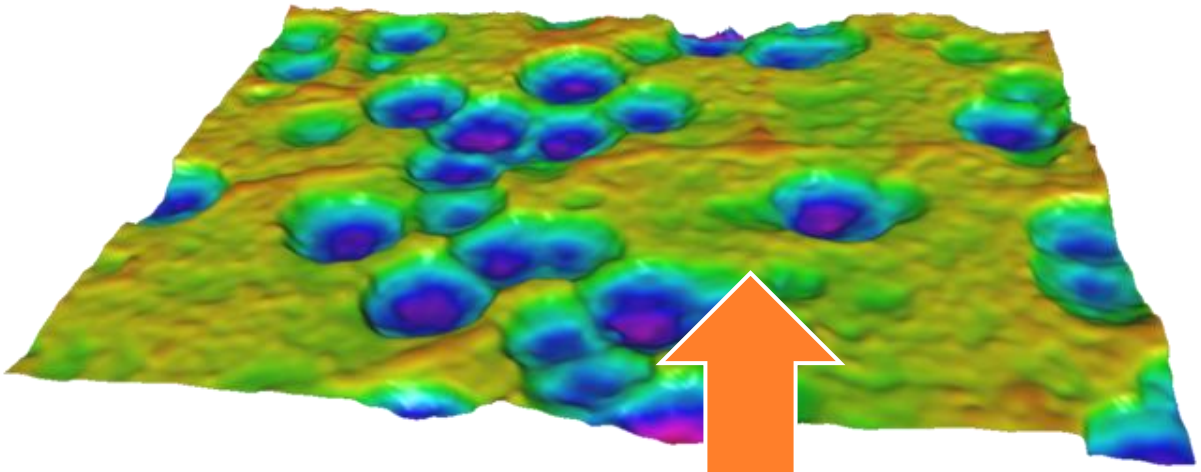
Roughness Parameter Selection

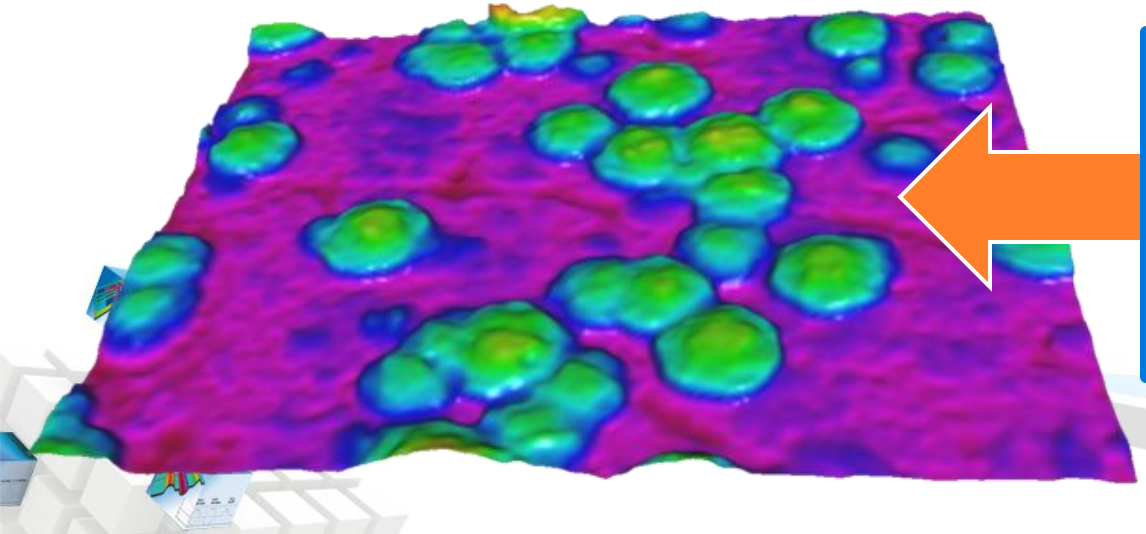
Different parameters to characterize the surface:
Sa, Ra, Sdq, Vvc, Sal…

» Which parameters should be used for which application?

Alicona can give hints which parameters can be useful for which application

Two Different Surfaces – Same Sa, Sq, Sz…



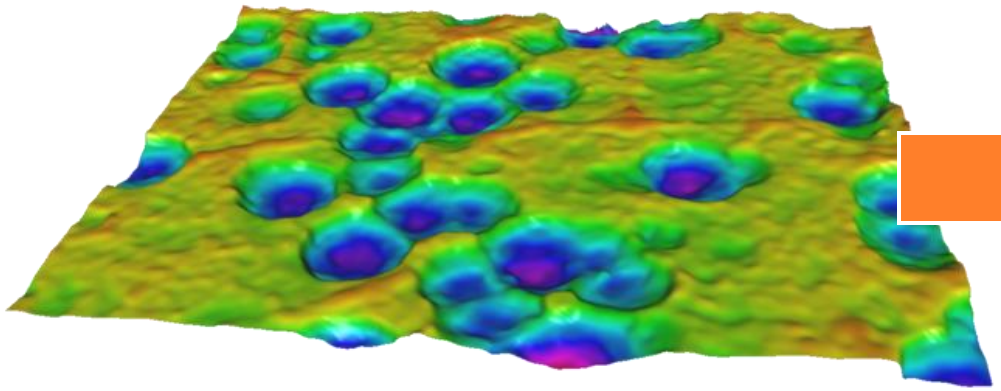


Sa **2.1494µm**

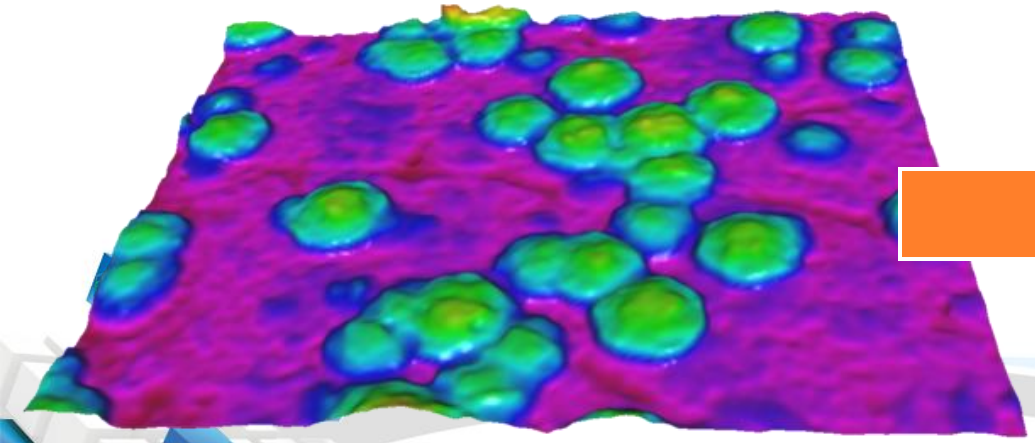
Sq **2.4904µm**

Sz **13.898µm**

…but Different Volume Parameters



Vmp	**0.0369µm**
Vmc	**2.8811µm**
Vvc	**2.1209µm**
Vvv	**0.2898µm**



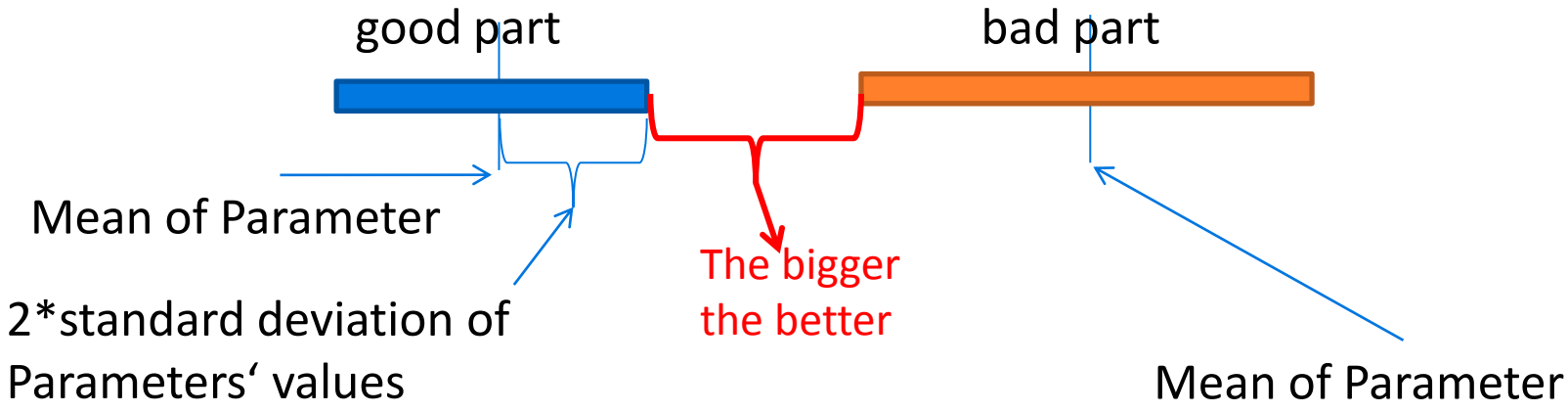
Vmp	**0.1049µm**
Vmc	**2.0427µm**
Vvc	**3.8958µm**
Vvv	**0.0829µm**

Procedure for selecting significant parameters

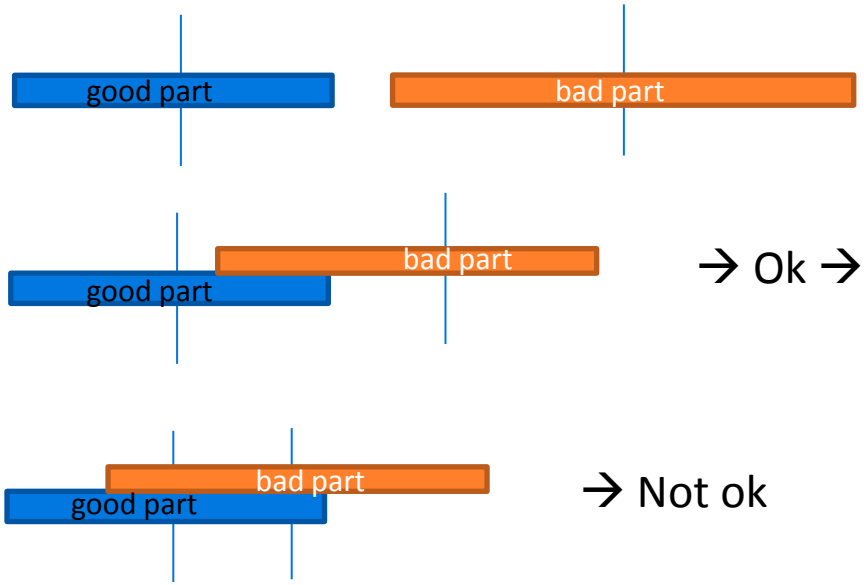
1. Measure good and bad parts on several positions
2. Optionally …
   a. …remove form
   b. …filter out waviness
   c. …filter out unimportant roughness
3. Measure all parameters from good and bad parts
4. Select significant parameters based on mean and standard deviations

Select Significant Parameters

Is the Parameter Significant:



Select Significant Parameters



→ Good

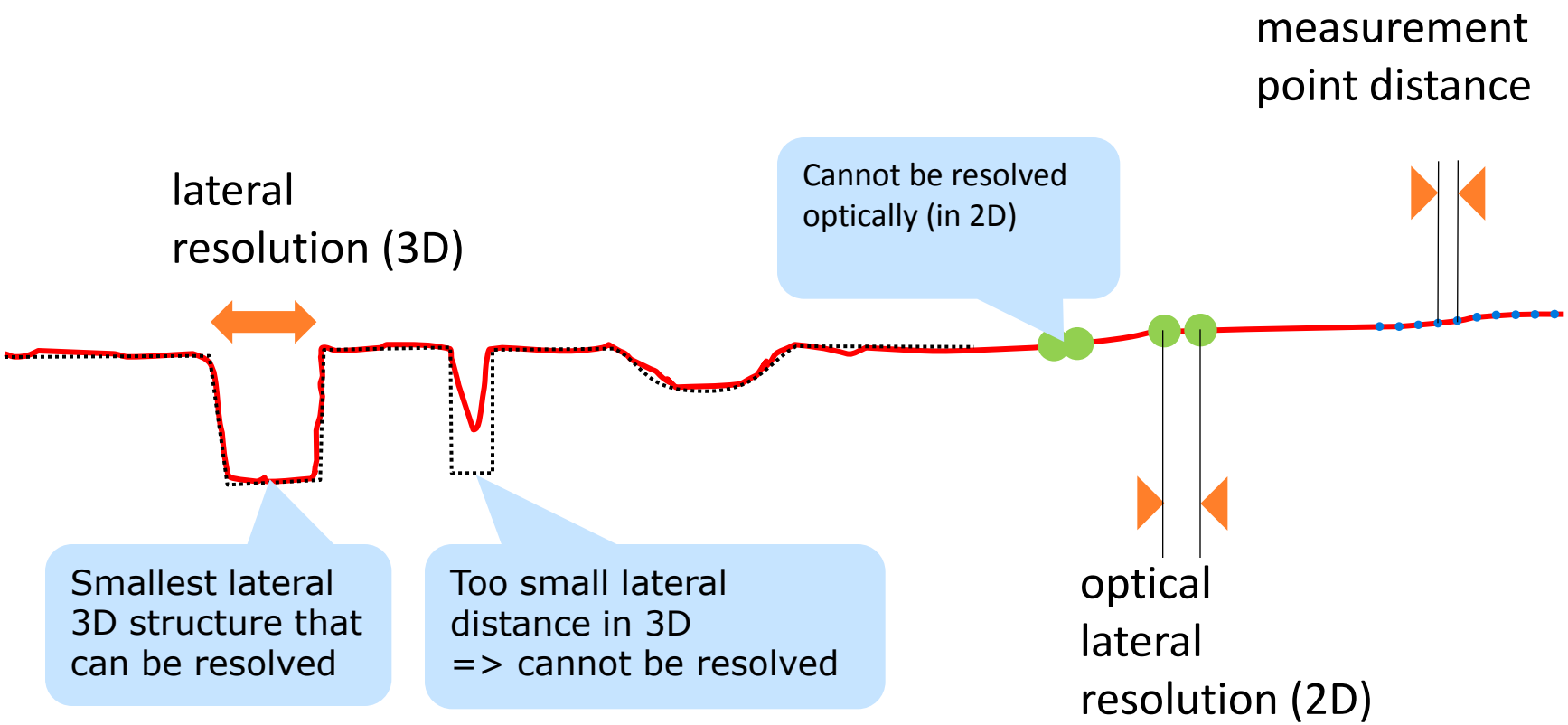
→ Ok → do more searching

→ Not ok

If this does not work it does not mean that there are no significant parameters

- **InfiniteFocus roughness measurements** are **comparable to tactile** roughness measurements
- InfiniteFocus roughness measurements are **traceable to national standards**
- With InfiniteFocus also **roughness on inclined surfaces with large working distance** can be measured

Auxiliary: Overview Lateral



- Measured surface
- Real surface
- Features in optical color image
- Measurement point

Auxiliary: Lateral Resolution and Sampling Distance