Mitutoyo

PRODUCTIVITY QUALITY INC

Surface Finish Analysis

April 2 2014

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Overview

- The Basics
- Equipment
- Measuring Conditions & Correlation
- Parameters Definitions
- Parameters and Function

Measure What?

- The primary metrological features of a surface are:
- Size
- Position
- Form (or Contour)
- Waviness
- Roughness

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Why Measure Surface Roughness?

- It’s on the print
- ISO 9000 and QS 9000 compliance
- Find the bad parts
- **Process Control**

Process Control

- **Turning and Milling, a great indicator of tool life**
- Grinding, when to Redress
- Lapping and Honing
- Extrusion and Injection Molds

The Standards

ASME B46.1-2002	Surface Texture
ASME Y14.36-1996	Drawing Indication
ISO 3287-1995	Instruments
ISO 4288-1997	Methods
ISO 4287-1995	Parameters
ISO 11562-1997	Filtering
ISO 13565-	Plateaued Surfaces
JIS 0660-1998	Terminology
JIS 0651-1996	Instruments
JIS 0610-1997	Waviness
JIS0601-1994	Designation

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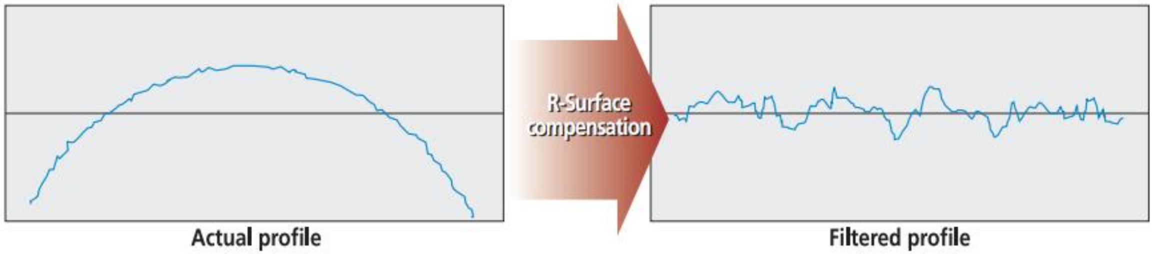
True Surface

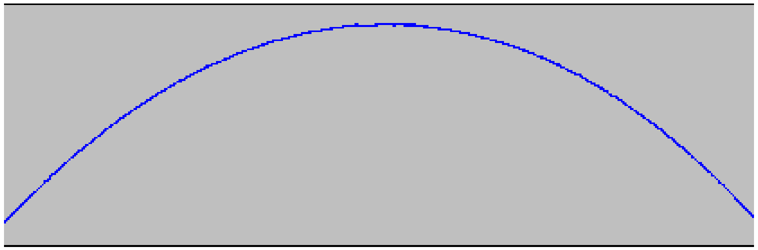
Suppress Overall Contour



Curve Removal

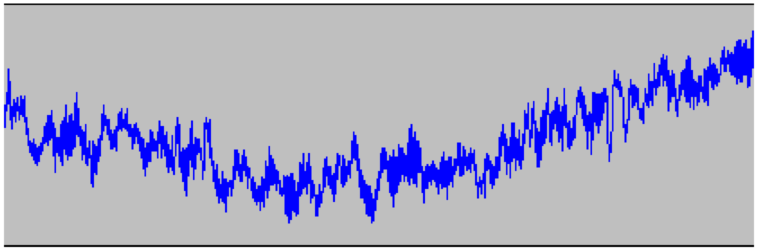
- Original Profile

  Ra 500µin



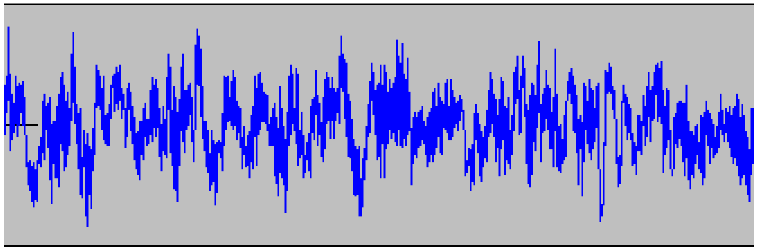
- Curve Removed with λc filter residual error

  Ra 35µin



- Curve Properly Removed

  Ra 15µin



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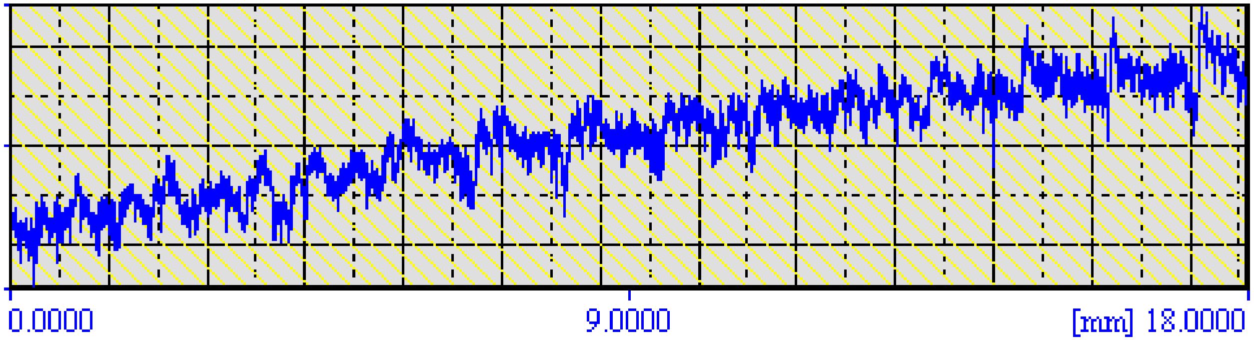
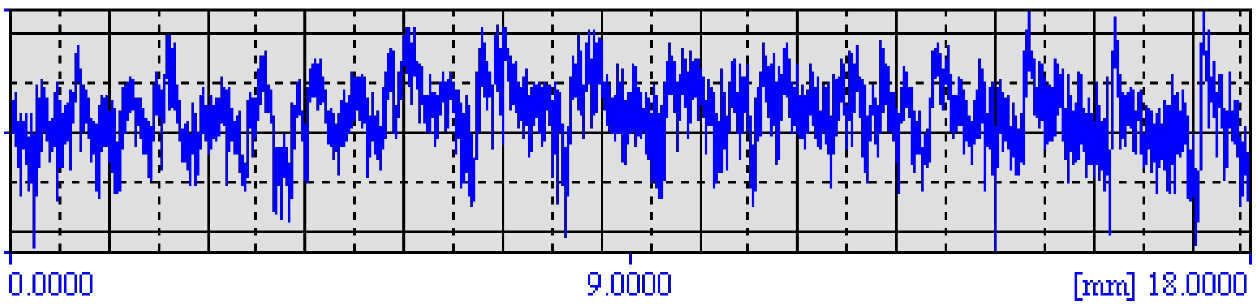
Tilt (Inclination) Compensation

Before



After



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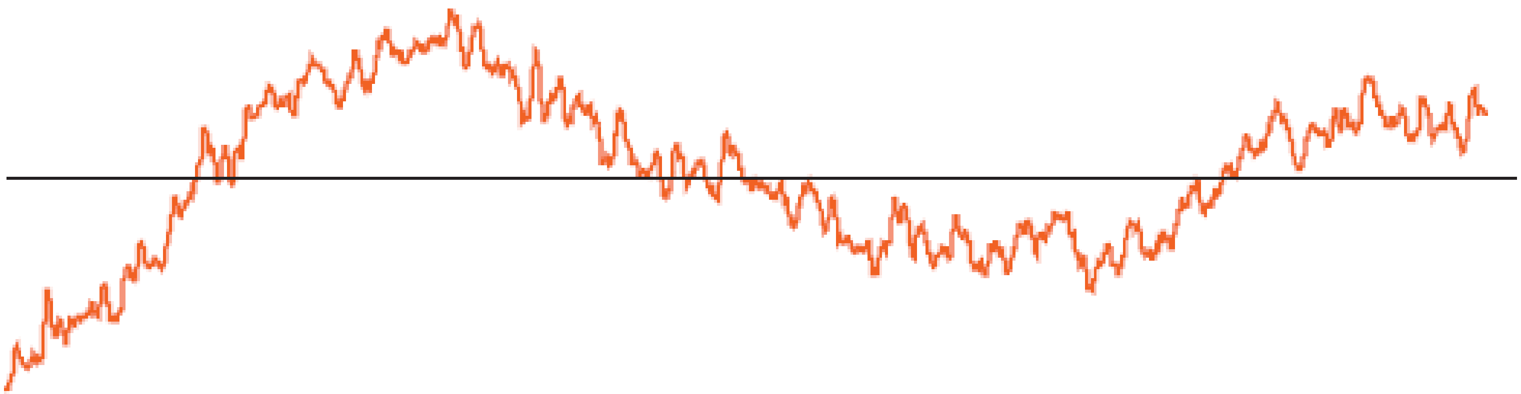
Primary Profile

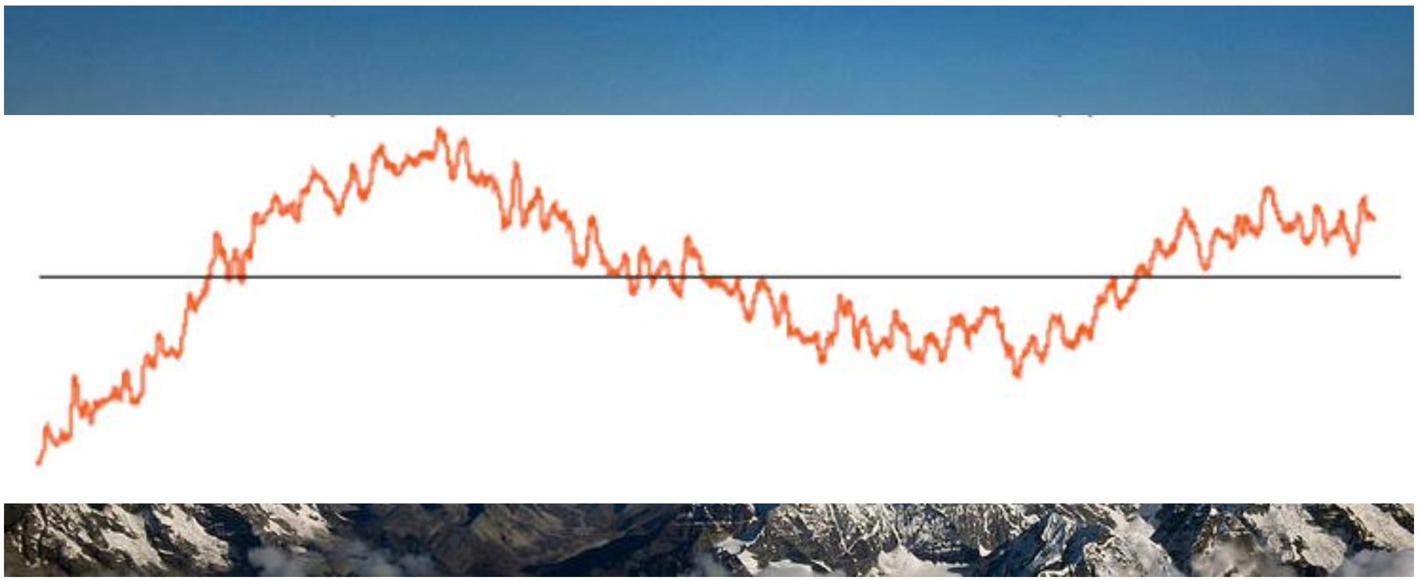
Primary Profile

Profile obtained from a quantized measurement profile to which a low-pass filter of cutoff value λs is applied.



- Any curve or tilt are removed using appropriate compensation
- Lambda s low pass filter applied to eliminate noise

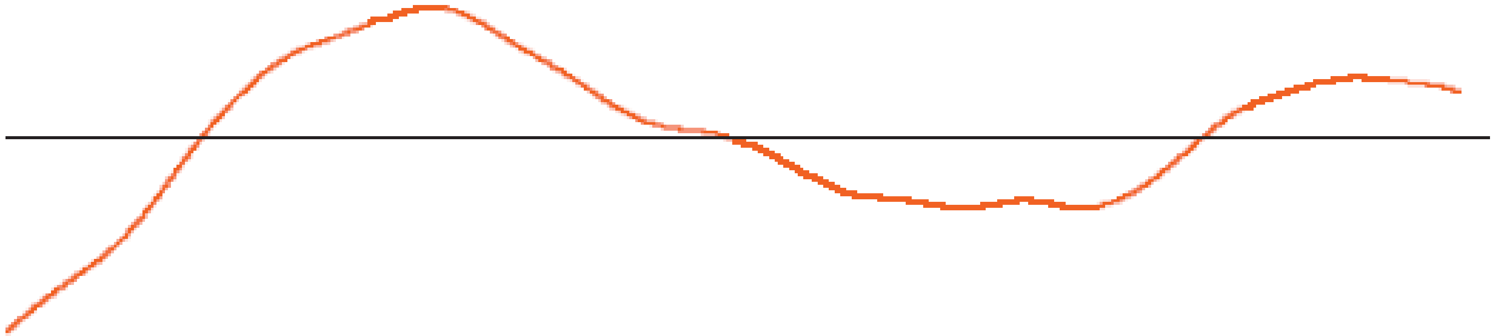
Primary Profile



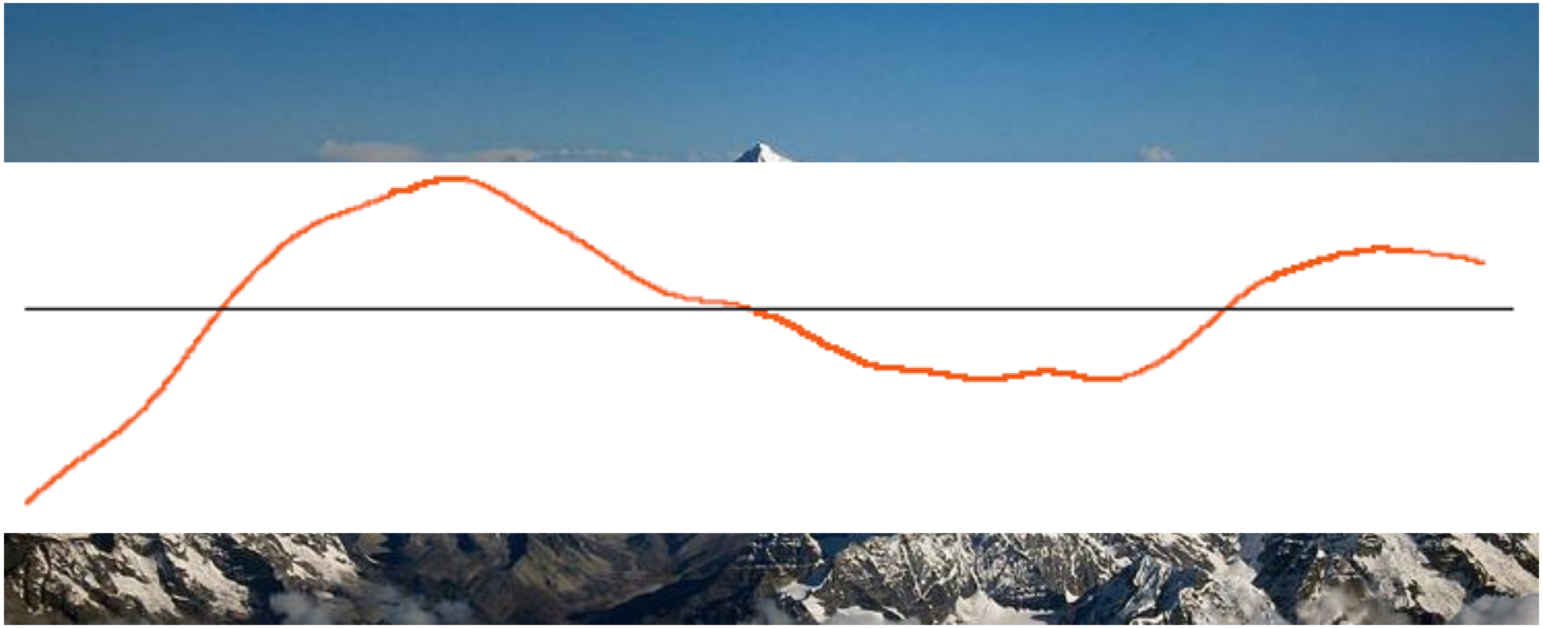
Waviness Profile

Waviness Profile

Contour profile obtained by subsequent application of the profile filter λf and the profile filter λc to the primary profile, suppressing the long wave component using the profile filter λf, and suppressing the short wave component using the profile filter λc.



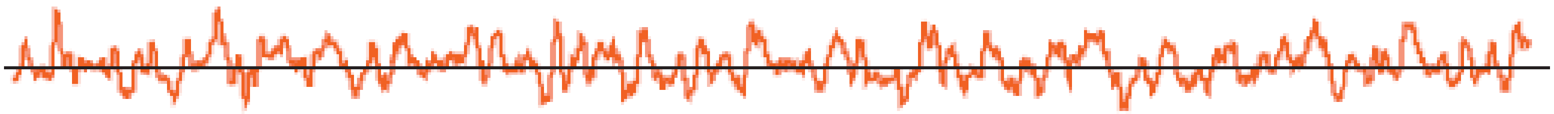
Waviness Profile



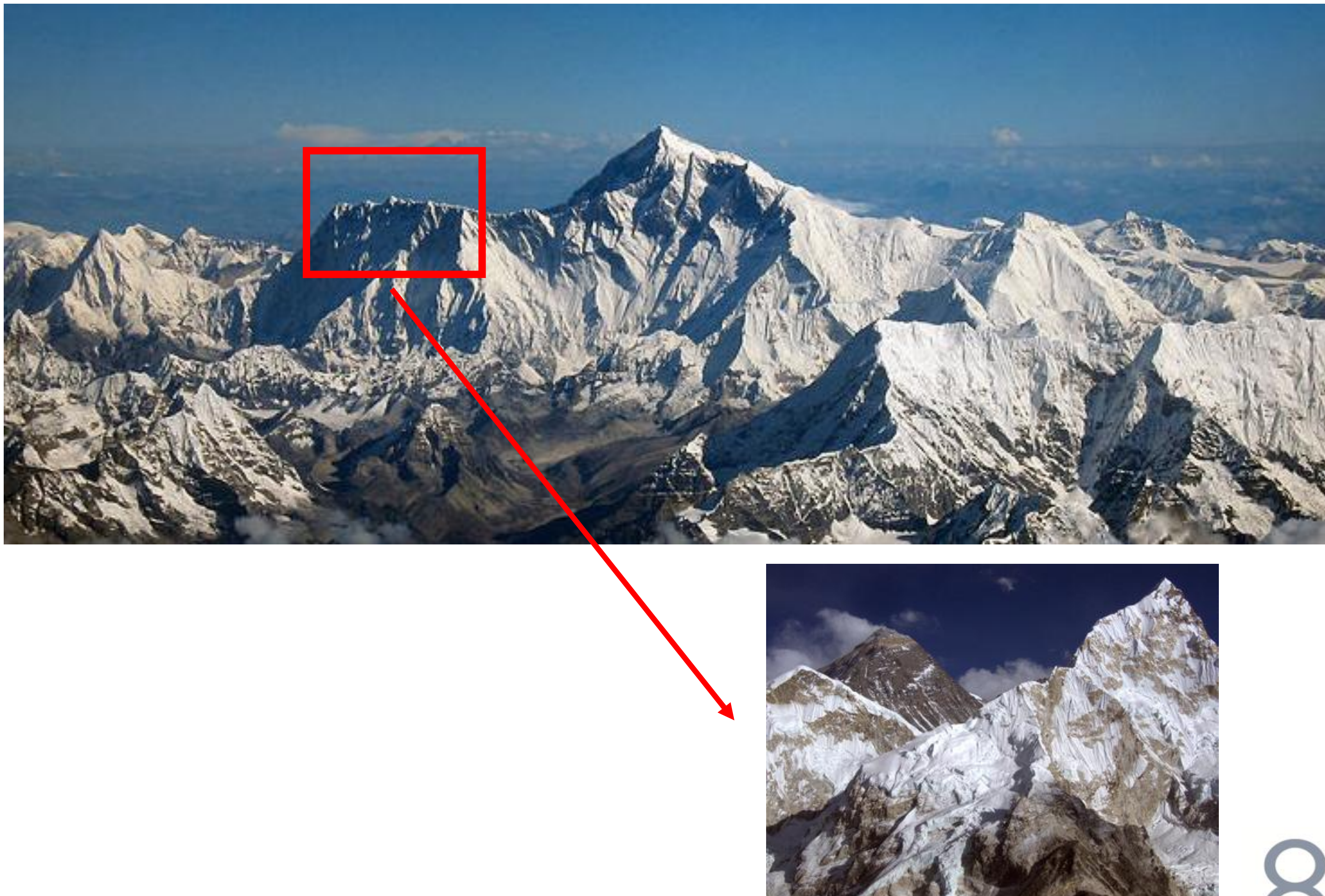
Roughness Profile

Roughness Profile

Contour profile obtained from a primary profile by suppressing the long wave component using the high-pass filter of cutoff value λc.



Roughness Profile



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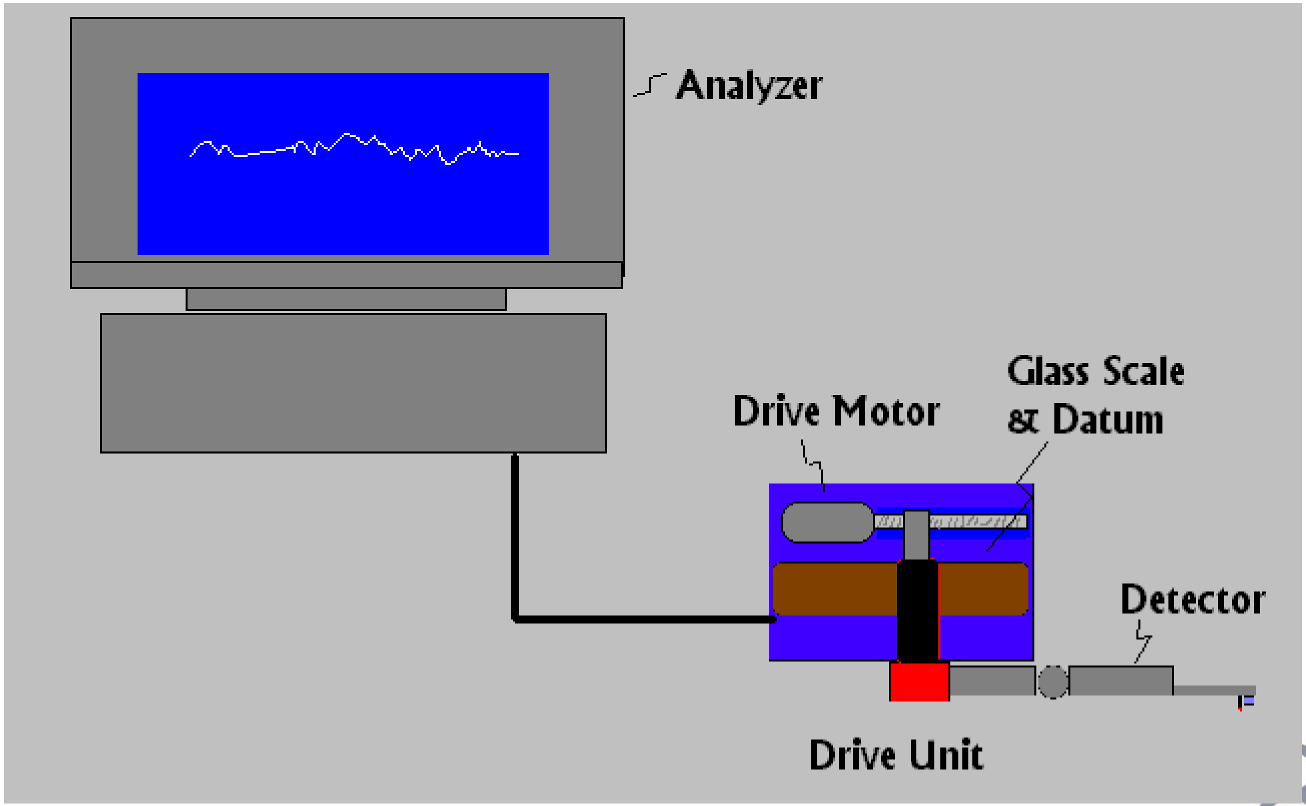
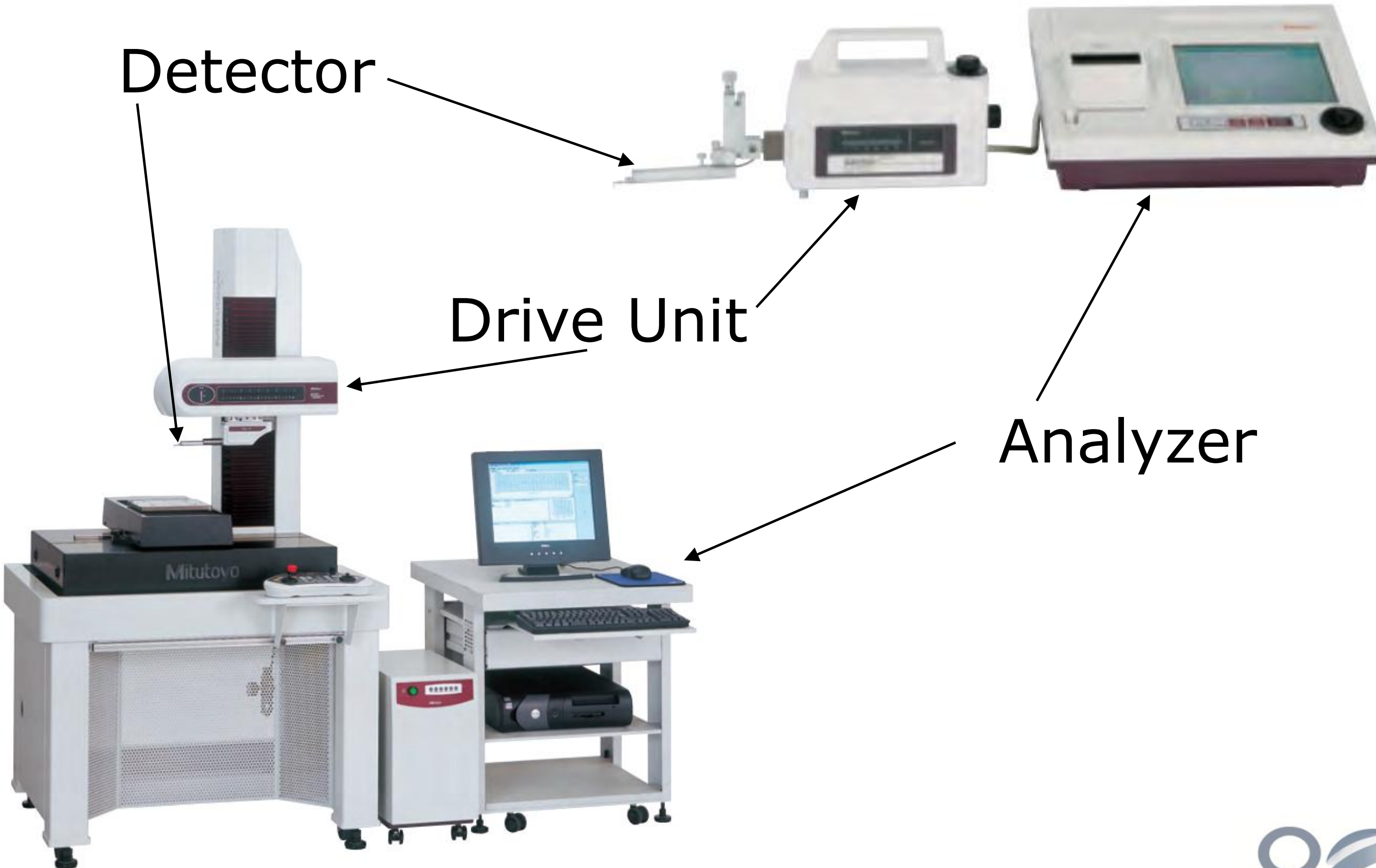
The System

- Motorized Drive Unit with Feedback
- Detector
- Analyzer



Hardware



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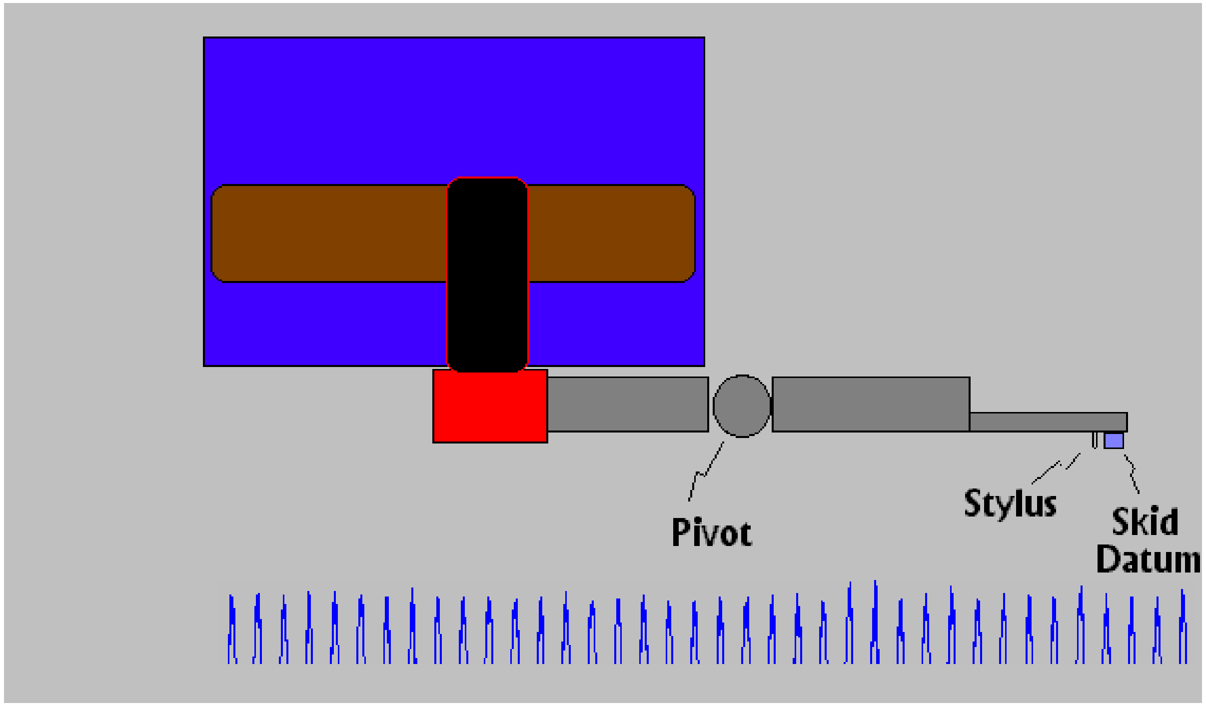
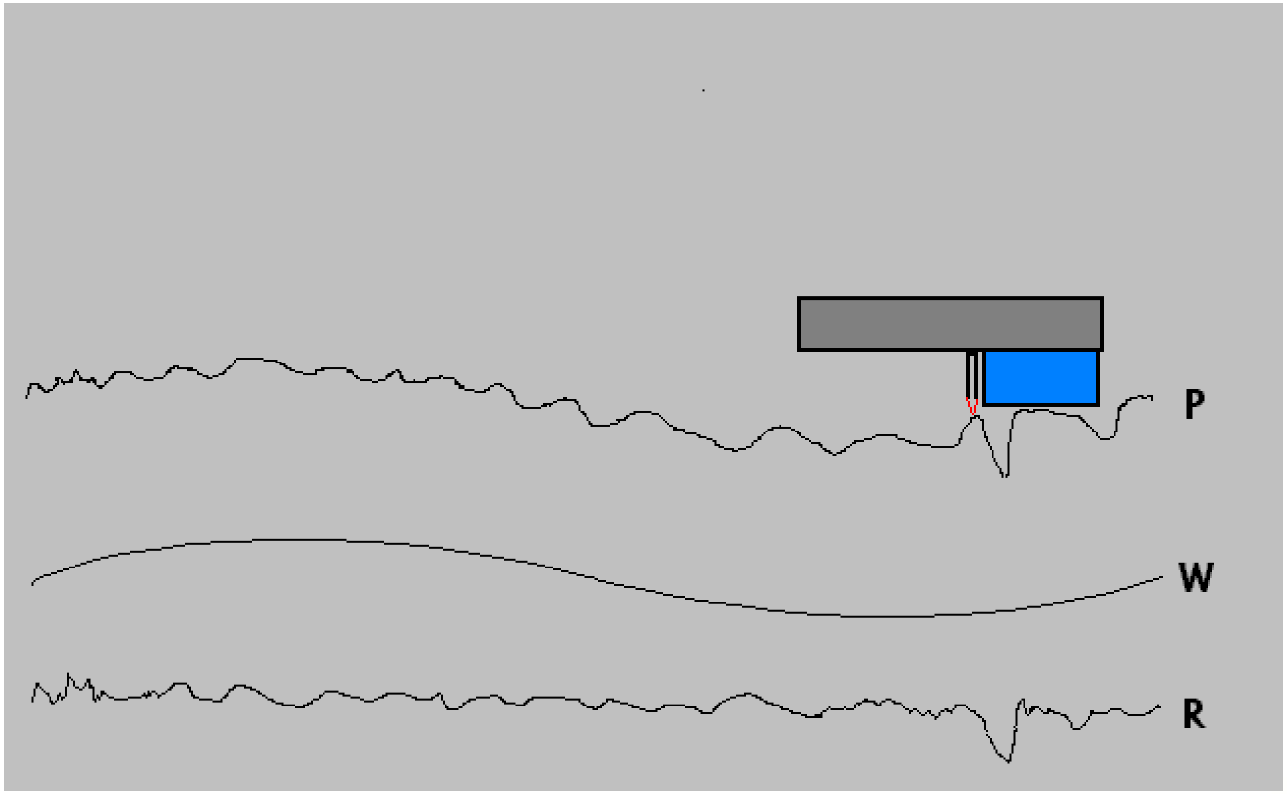
Skid Measurement

- Skid Measuring instruments are used to measure Roughness only
- Less prone to noise
- Most commonly used



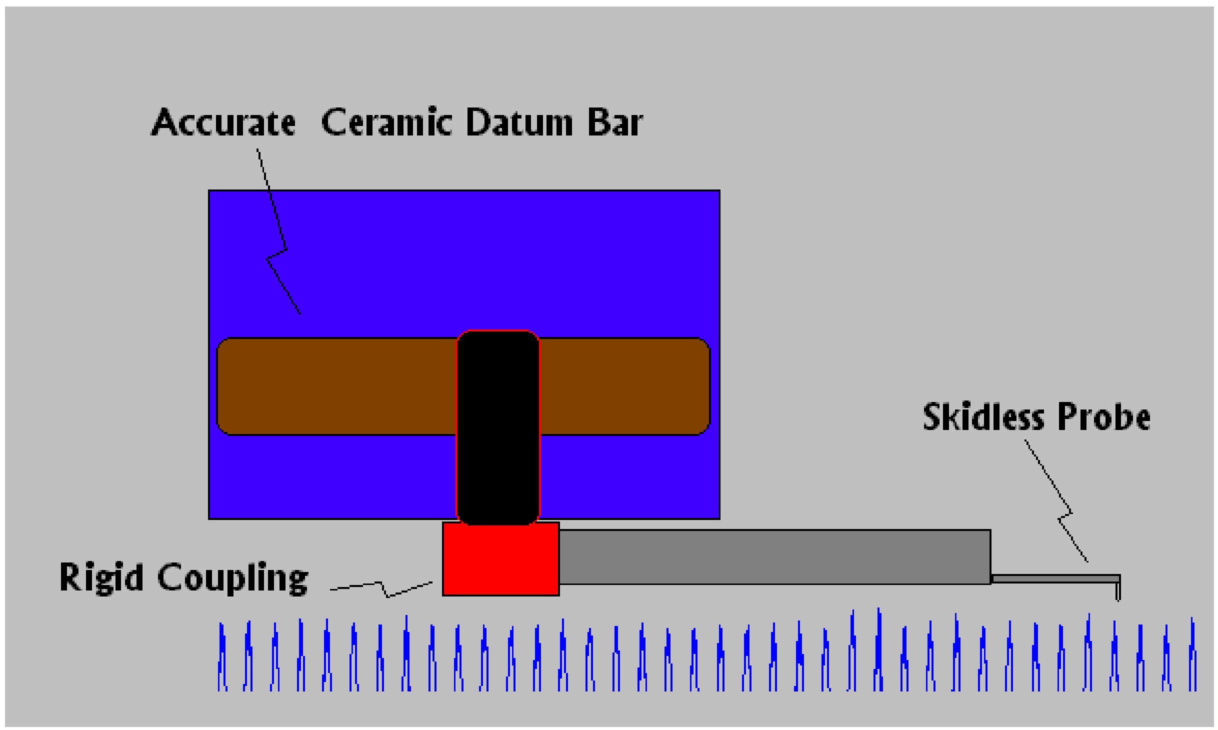
The Skid

- The skid mechanically filters waviness



Skidless Measurement

- Skidless Measuring instruments are used to measure both Roughness and Waviness
- No Skid means you can measure in confined areas
- Skidless Systems are prone to vibration



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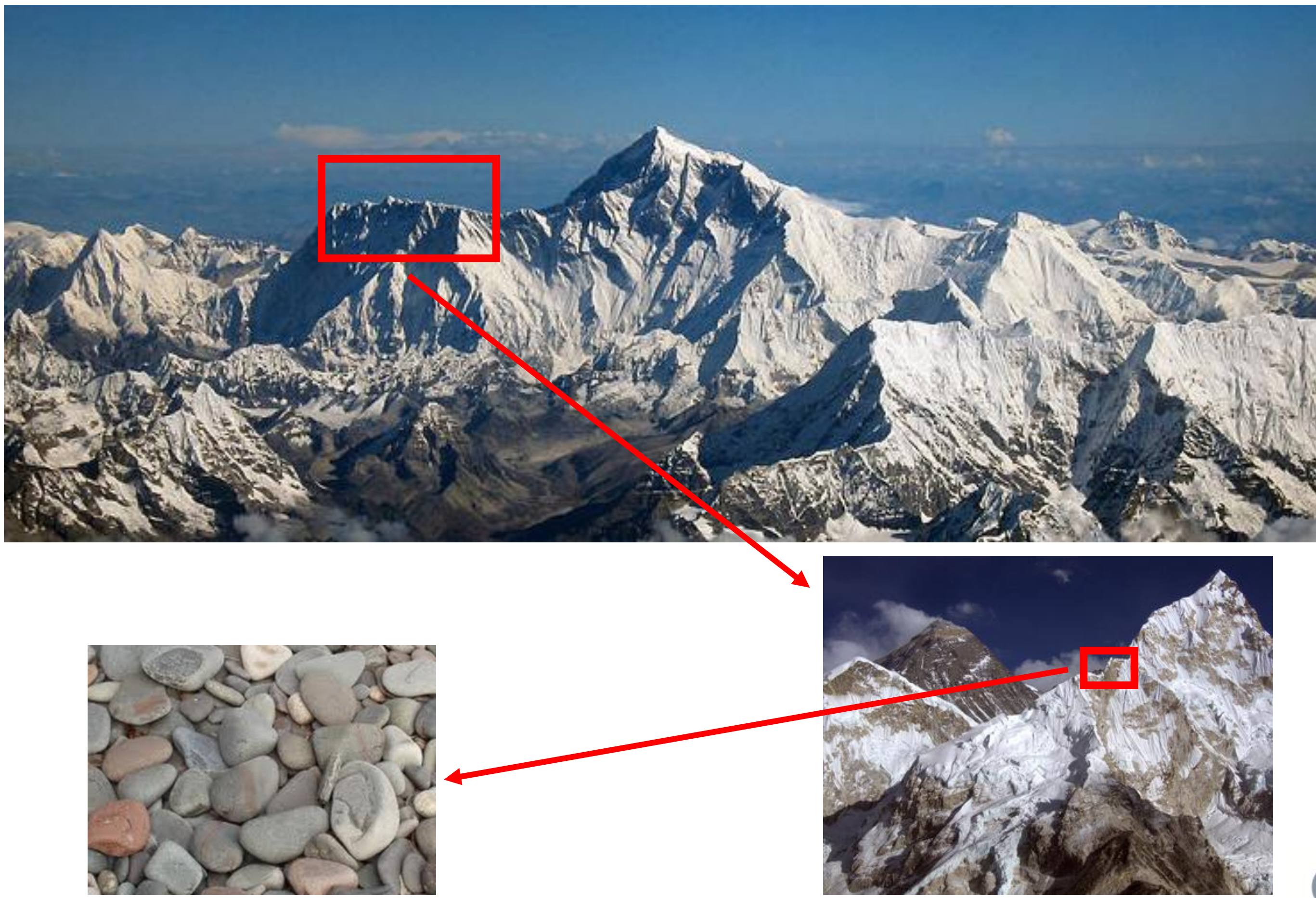
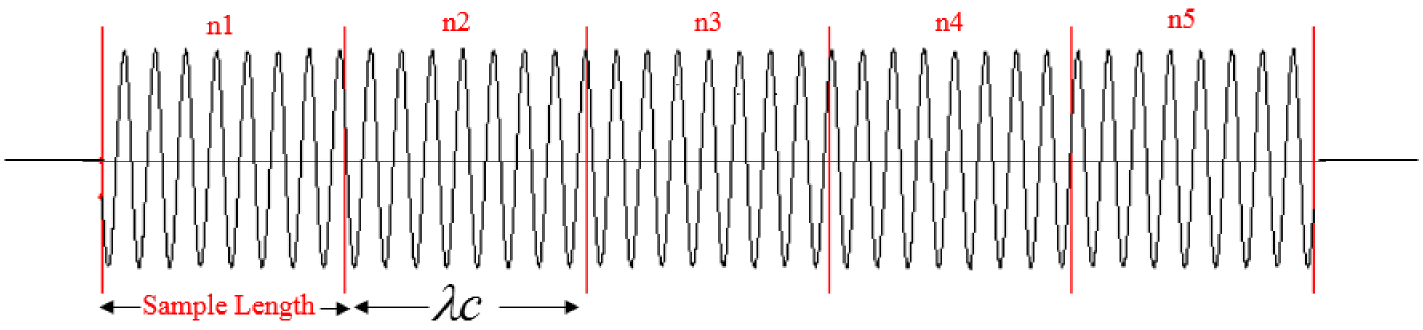
λs



Cutoff, λc, sampling length



Ra Range						Sampling length (ℓ)		Evaluation length (ℓn)	
(0.006)	<	Ra	≦	0.02	μm	0.08	mm	0.4	mm
0.02	<	Ra	≦	0.1	μm	0.25	mm	1.25	mm
0.1	<	Ra	≦	2.0	μm	0.8	mm	4	mm
2.0	<	Ra	≦	10.0	μm	2.5	mm	12.5	mm
10.0	<	Ra	≦	80.0	μm	8	mm	40	mm

Default Cutoff - Lc

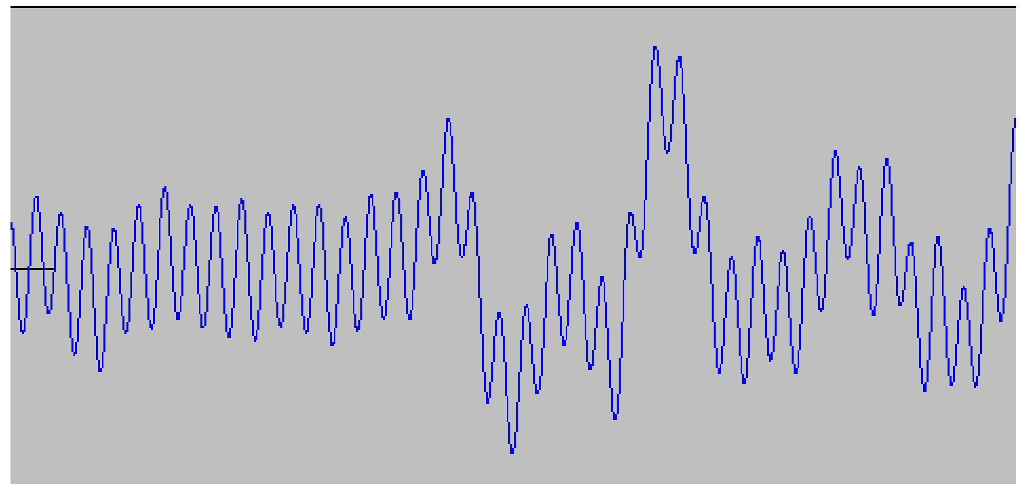
Ra	Lc	Lm
0 - .8µ”	.003	.015
.8 – 4µ”	.010	.050
4 – 80	.030	.150
80 – 400	.100	.500
400 & up	.300	1.5

B46.1-2002 3.3.20

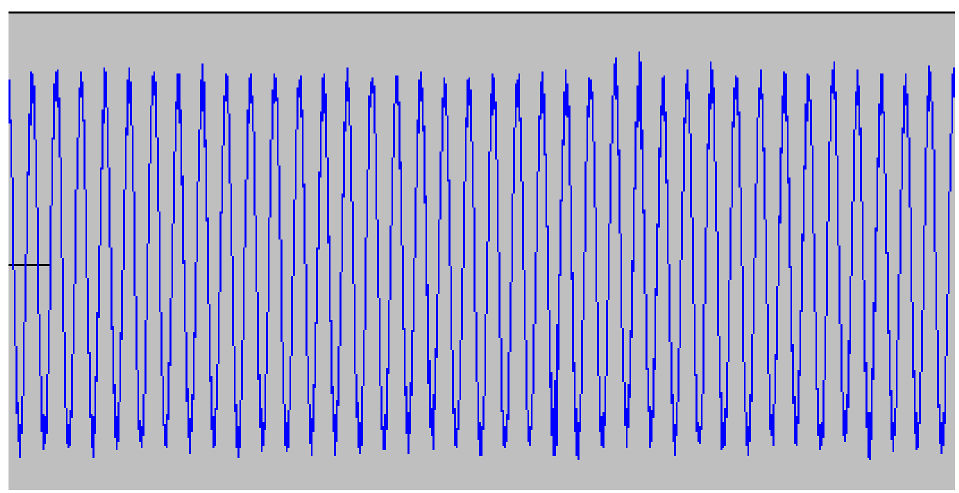
“Roughness filter cutoff length is determined in part by the x and z aspects of the surface under evaluation as related To the intended function of the surface. The roughness filter cutoff length should be chosen by the designer in light of the Intended function of the surface. When choosing the appropriate roughness filter cutoff, one must be cognizant that The surface features not measured within the roughness cutoff bandwidth may be quite large and may affect the intended Function of the surface…..”

Lc Filter Distortion

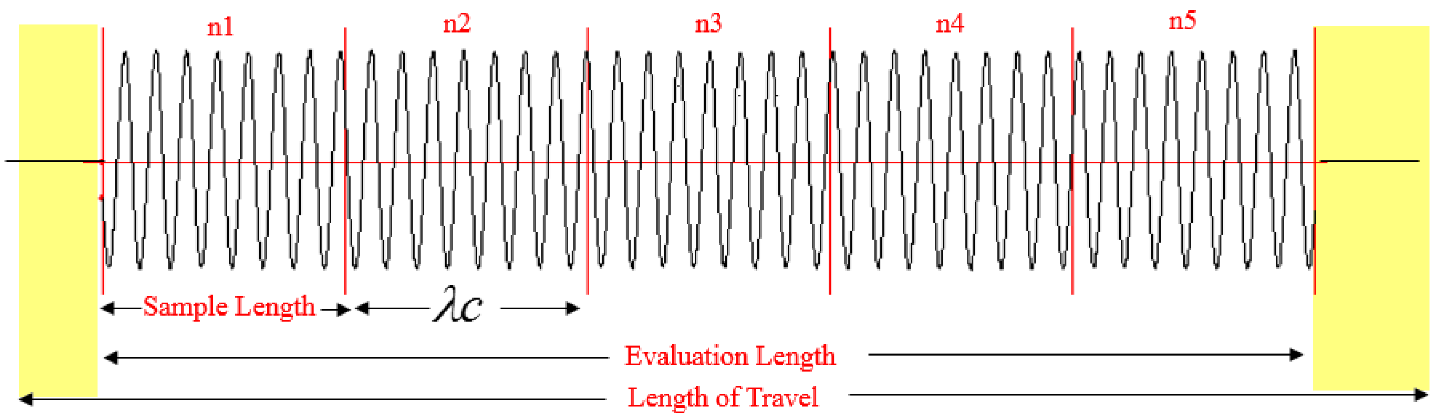
•Wrong Cutoff



•Right Cutoff



Pre and Post



n1
n2
n3
n4
n5
Sample Length
λc
Evaluation Length
Length of Travel

Filter Types

- **Gaussian** **50% Wavelength transmission, Digital Filter, Less Error, Default**
- **2RC 75 PC** **Emulated 75% pass RC filter, Phase Corrected, Prone to Gibbs**
- **2RC 75** **Emulated 75% pass RC filter, Non-Phase Corrected, Prone to Gibbs, Most common in older equipment**
- **Gaussian λs** **50% Digital Filter, ISO BandPass, Less Prone to Stylus and Equipment Variation**
- **Gauss Spline** **50% Digital Filter, ISO BandPass, Less Prone to Stylus and Equipment Variation, Little or No Edge Effects**

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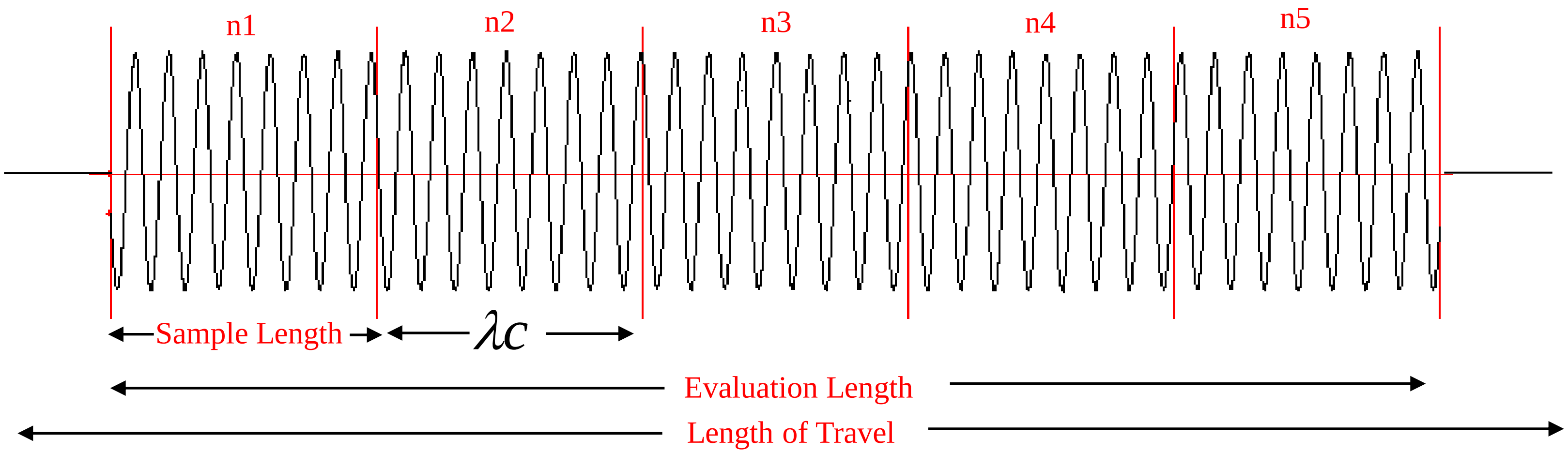
Terminology



$$Lm = \lambda c * 5$$

$$Lt = \lambda c * 5 + \frac{\lambda c}{2}_{pre} + \frac{\lambda c}{2}_{post}$$

Length of Travel is the total measured length. Commonly referred to as Lt

Sample Length is a segment of the measured profile used in determining localized occurrences. Always equal to the cutoff length. Referred as L,lr,ln,le, but not limited to.

Cutoff Length is the window size used to filter the measured profile. Always equal to the sample length. Commonly referred to as lc, lamda c, λc

N is number of sampling lengths. Sometimes referenced with subscripts.

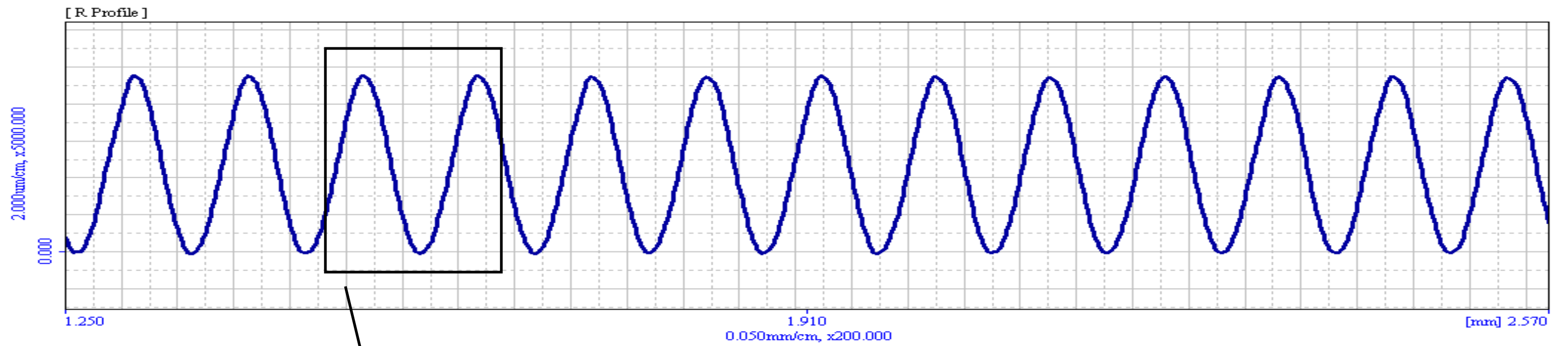
Evaluation Length is total of all the sampling lengths used in an evaluation. Commonly referred to as lm

Pre and Post Lengths is starting and ending lengths used in filtered evaluations. A minimum of lc/2 for gaussian, lc for RC. Commonly referred as lr, start length, end length

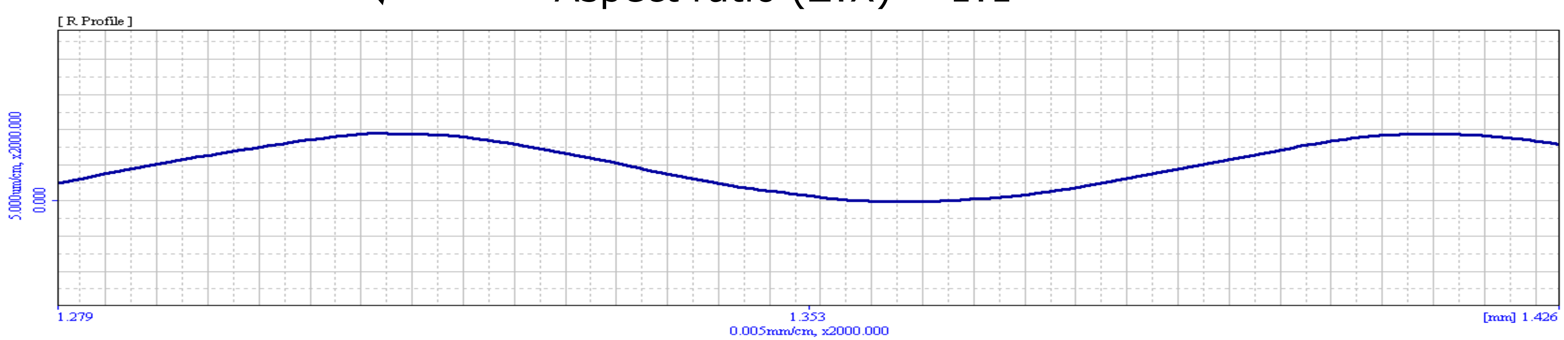
ASPECT RATIO

Graphical representations of surfaces are scaled much greater vertically than horizontally for the purpose of illustrating vertical deviations.

Aspect ratio (Z:X) = 25:1



Aspect ratio (Z:X) = 1:1



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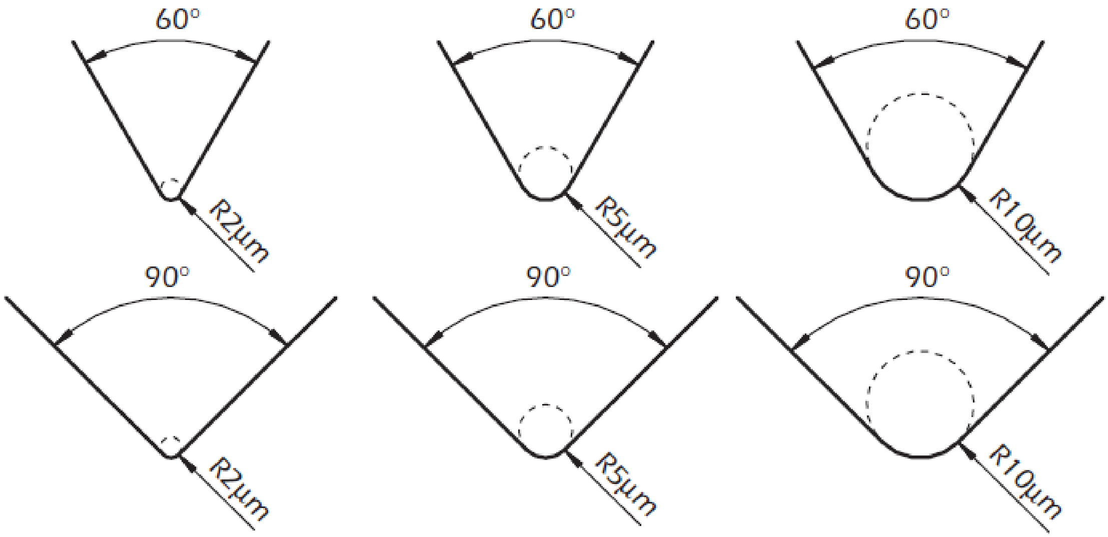
Stylus

Stylus Shape

An ideal shape stylus is a conic stylus with a spherical tip.
Tip radius: rtip = 2 μm, 5 μm, 10 μm
Taper angle of cone: 60°, 90°
In ideal surface roughness testers, the taper angle of each cone is 60°unless otherwise specified.



Stylus

Relationship between a Cutoff Value and a Stylus Tip Radius

The following table lists the relationship between a roughness profile cutoff value λc, stylus tip radius rtip, and cutoff ratio λc/λs.

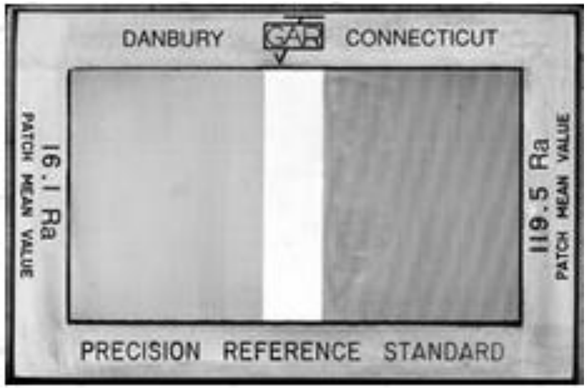
λc mm	λs µm	λc/λs	Maximum rtip µm	Maximum sampling length µm
0.08	2.5	30	2	0.5
0.25	2.5	100	2	0.5
0.8	2.5	300	2 [Note 1]	0.5
2.5	8	300	5 [Note 2]	1.5
8	25	300	10 [Note 2]	5

Note 1: For the surface under the condition of Ra>0.5µm or Rz>3µm, a significantly large error will not usually occur in a measured result even if a stylus of rtip= 5µm.

Note 2: If a cutoff value ls is 2.5µm or 8µm, the attenuation characteristic due to the mechanical filtering effect of a stylus with the recommended tip radius appears outside the defined pass band. Therefore, a small error in a stylus tip radius or shape does not affect parameters calculated from measurements.
If a specific cutoff value is required, the ratio must be defined.

Calibration

- Calibrate only when needed, verify as frequently as possible
- ASME says calibration is necessary if verification varies by 10% or more, if using 116uin expect ±2uin on a new patch
- Use High side of standard to calibrate gain, Low side to verify diamond



Equipment Correlation

- What most effects correlation?
- Setup must be exactly the same - Cutoff Length, Filter Type, Stylus Radius, Measuring Speed, Data Density
- Use the same master to calibrate all instruments

Parameter Groups

- Averaging Parameters - Ra, Rq

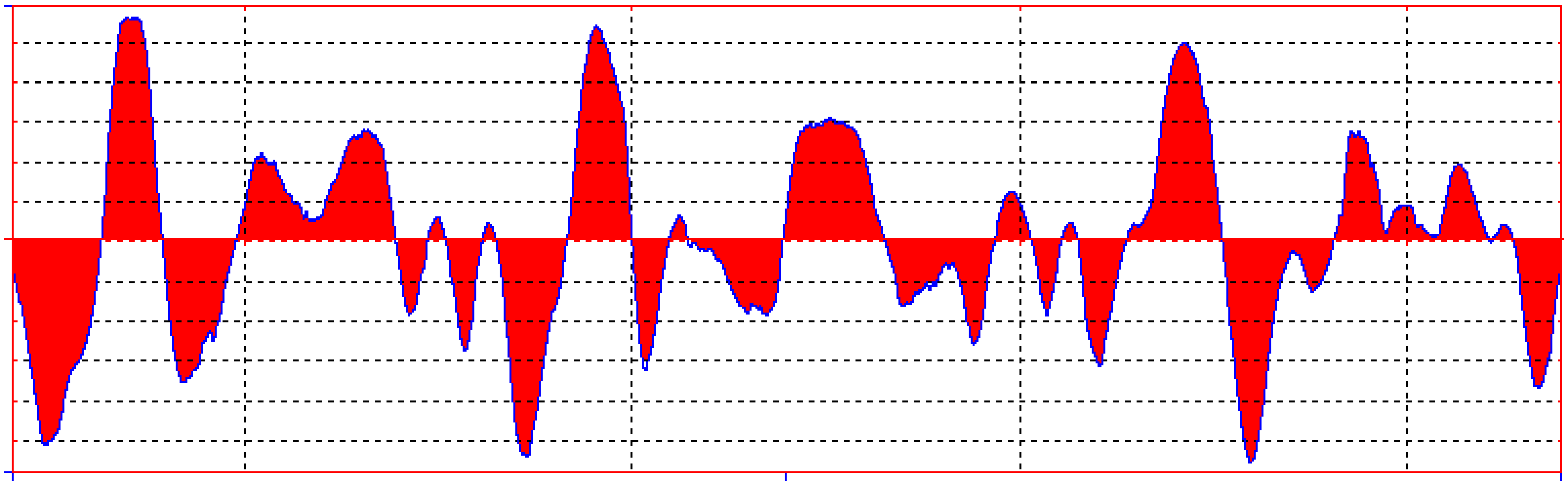
- Extreme Amplitude Parameters – Rz, Rt, Rp, Rv,Ry,Wt,Pt
    - Peak to Valley Height
    - Single Flaw

- Spatial and Slope Parameters – Pc, Rdq, Sm

- Bearing Ratio Parameters – tp, tpi, mr, mrd, mrc
    - Rk Family, Rpq, Rvq, Rmq

- Length Ratio\ Scale Parameters
    - Lo, Lr
    - Fractals

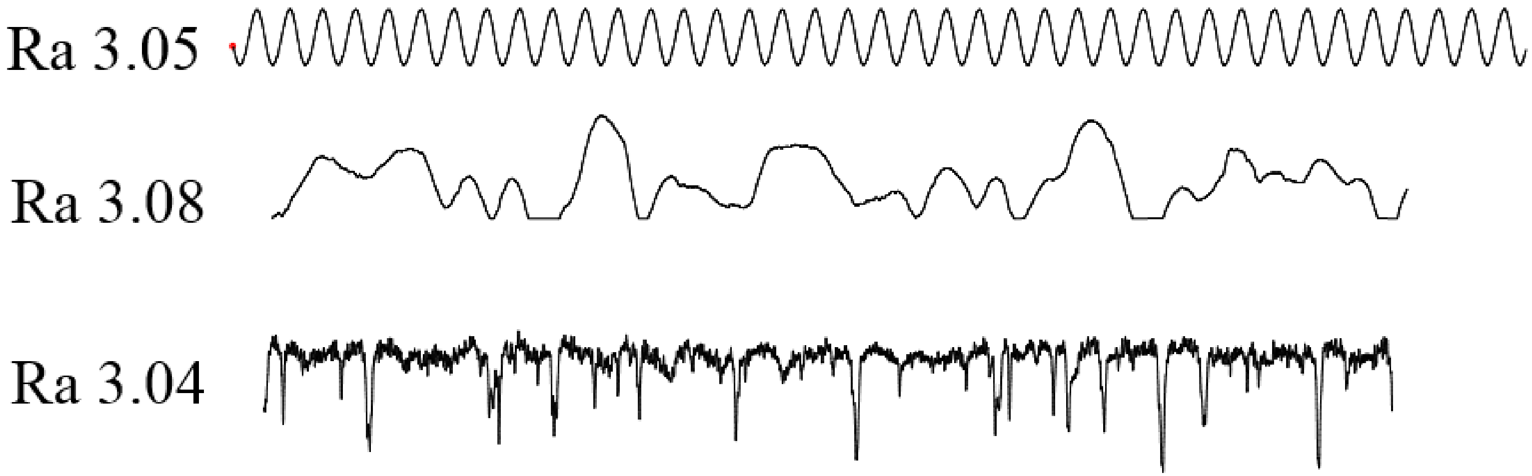
Ra- Average roughness of the evaluated profile



Ra is the arithmetic mean of the absolute values of the profile deviations (Yi) from the mean line.

$$Ra = \frac{1}{n}\sum_{i=1}^{n}\left|Yi\right|$$

Same Surface?



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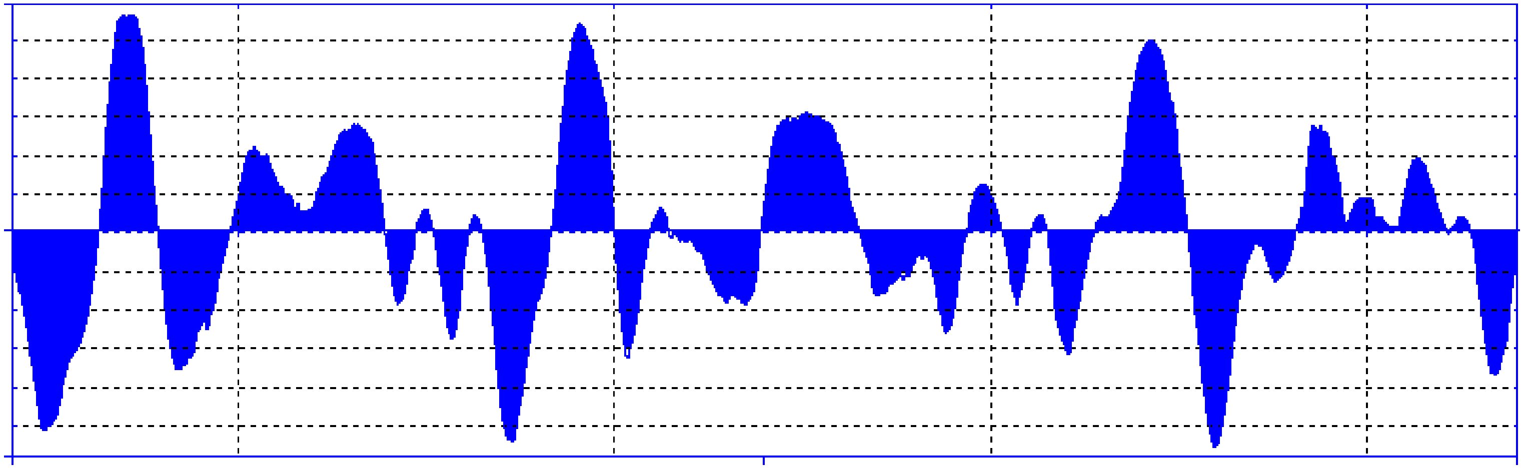
Rq- Mean square roughness



More sensitive to peaks and valleys than Ra, but less robust. Commonly referred to as RMS

$$Rq = \sqrt{\frac{1}{N}\sum_{1}^{N} |Z^2(n)|} \qquad R_q \approx \sqrt{\frac{Z_1^2 + Z_2^2 + \dots + Z_n^2}{n}}$$

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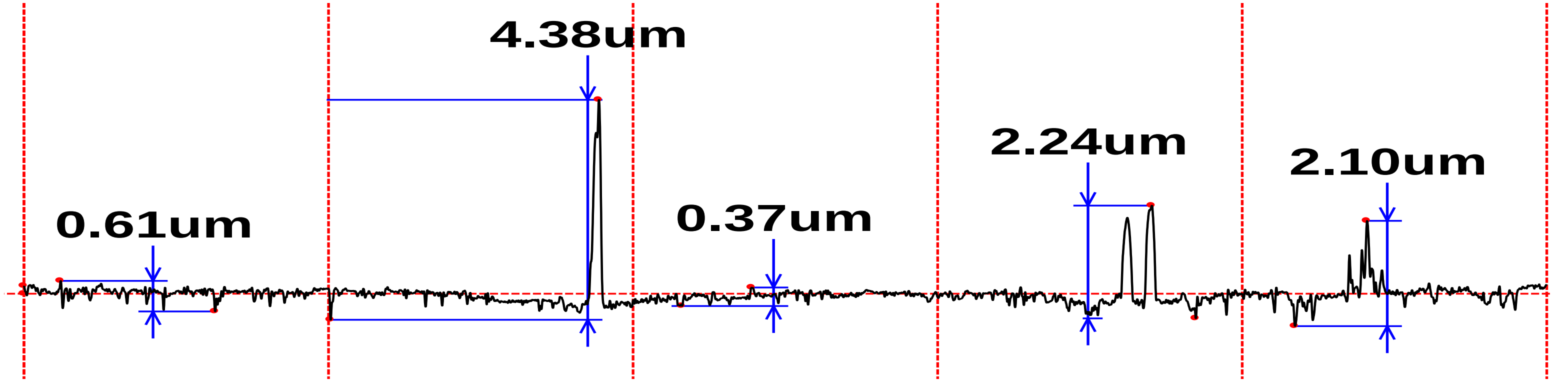
Rz- Average peak to valley height

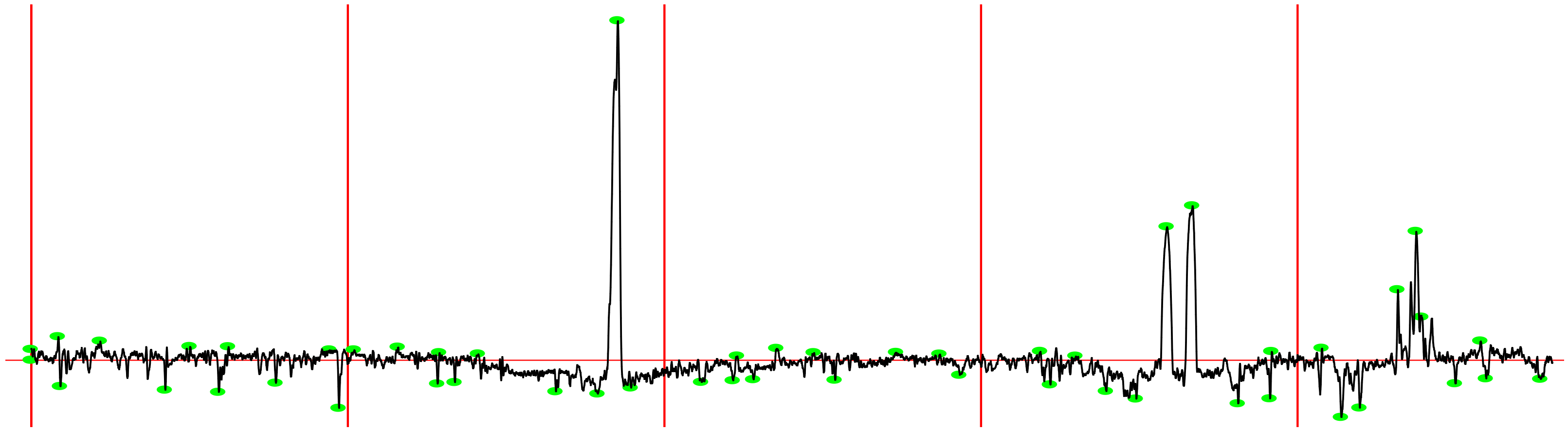


$$Rz = \frac{1}{N}\sum_{1}^{N} Z(n)_{\max} - Z(n)_{\min}$$

$$N = 5$$

- Most versatile process control parameter
- Very sensitive to process changes
- Relatively Robust
- Usage Milled, Turned, Ground, Lathe, Polished Surfaces
- Common usage for DIN/New ISO/ASME

Rz (JIS/Old ISO)- Ten point average peak to valley height.

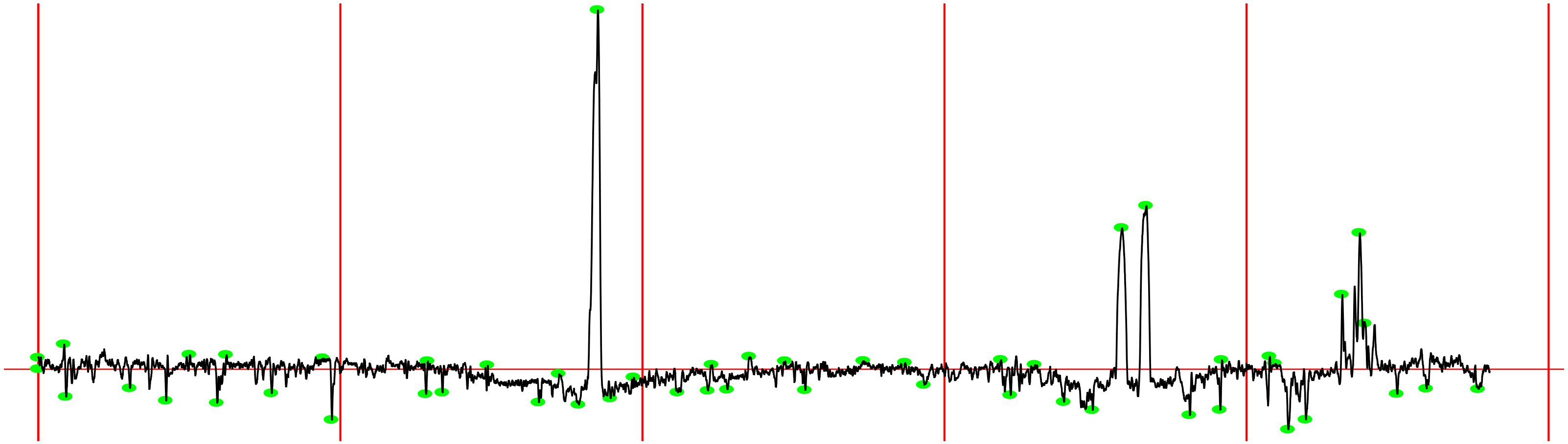


$$Rz = \frac{1}{Ni} \sum_{1}^{N} \sum_{1}^{i} Z(i)_{\max} - Z(i)_{\min}$$

$$N = 5, i = 5$$

- Sensitive to process changes
- Robust
- Usage Milled, Turned, Ground, Lathe, Polished Surfaces
- No longer commonly used

Rc- Average peak to valley height with no limit to the amount of peaks and valleys

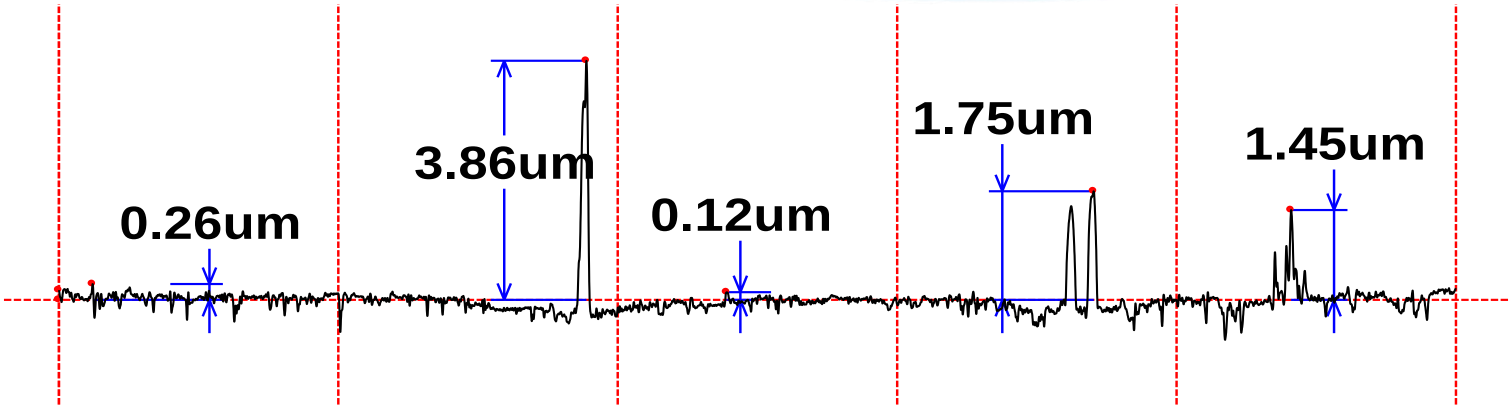


$$Rc = \frac{1}{N}\sum_{1}^{N} Z(n)_{max} - Z(n)_{min}$$

$$N = NumberofPeaks \,\&\, Valleys$$

- Potential process control parameter
- Very sensitive to process changes
- Most Robust of Amplitude Parameters
- Possible Milled, Turned, Ground, Lathe, Polished Surfaces
- Not commonly used, DIN

Rp- Maximum peak height

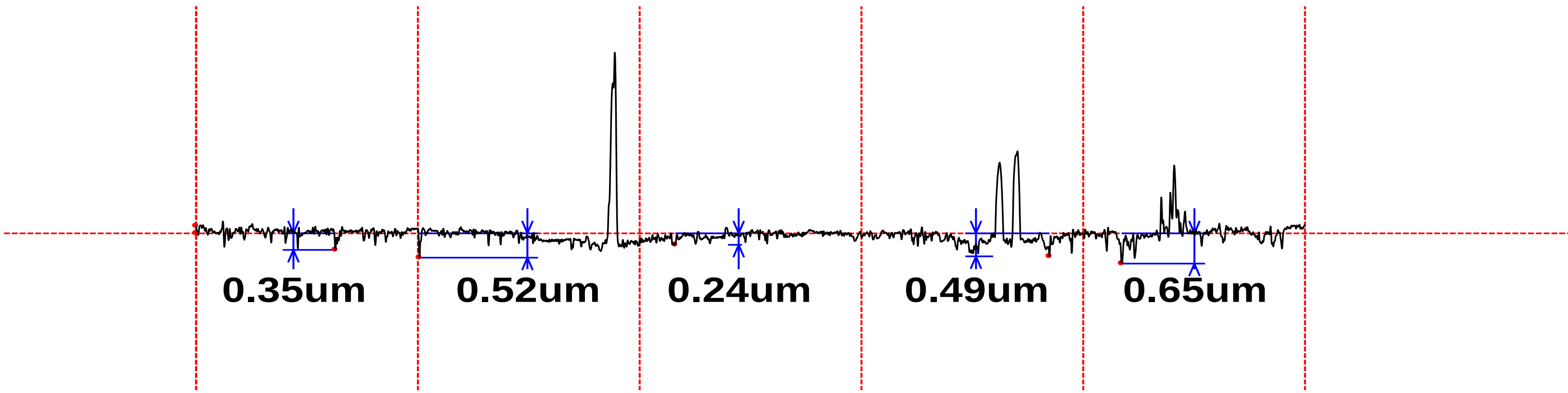


$$Rp = \frac{1}{N}\sum_{1}^{N} Z(n)_{\max}$$

$$N = 5$$

- Monitor Witness Marks / Clean-up
- Sensitive to process changes
- Usage Ground, Polished, Honed Surfaces
- Common usage for DIN/New ISO
- Rp is the single largest peak in ASME B46.1

Rv- Maximum valley depth

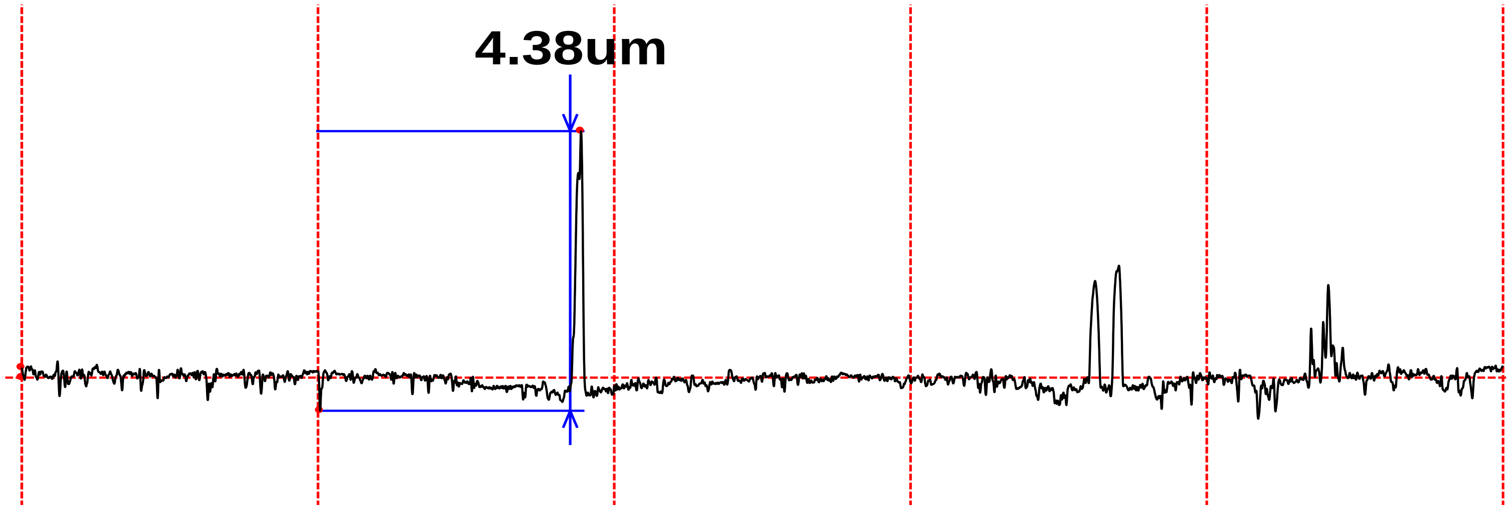


$$Rv = \frac{1}{N}\sum_{1}^{N} Z(n)_{\min}$$

$$N = 5$$

- Not sensitive to process changes
- Relatively Robust
- Susceptible to inherent material qualities/ porosity
- Great scratch identifier
- Usage Ground,Polished, Honed Surfaces

Ry/Rz1max- Max local peak to valley height.



$$Ry = Z(n)_{\max} - Z(n)_{\min}$$

$$N = 5$$

- Single Flaw Parameter
- Very sensitive
- Max type

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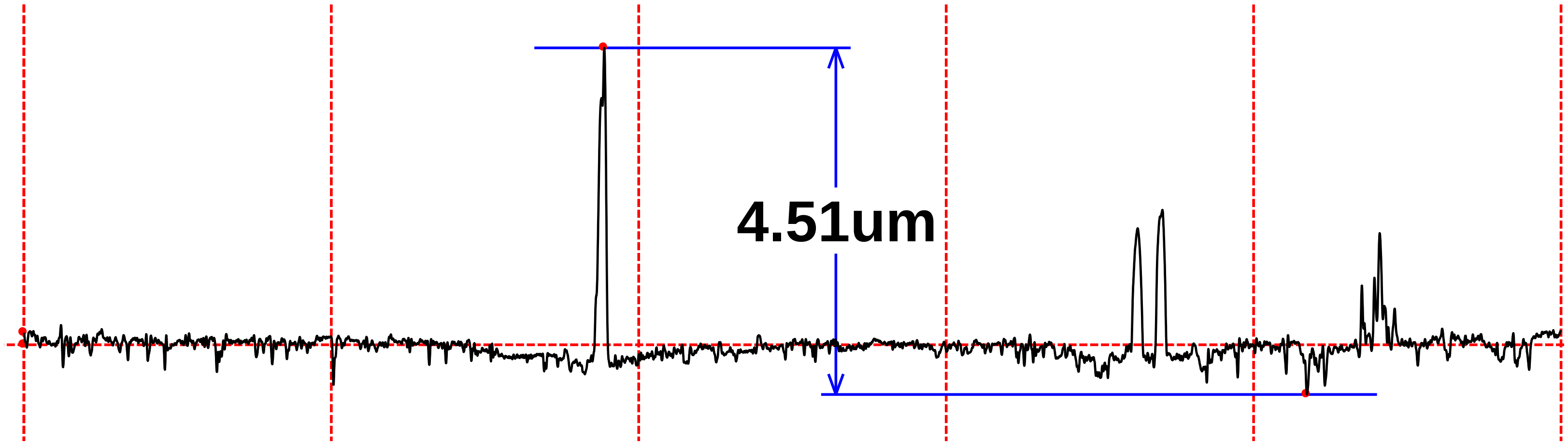
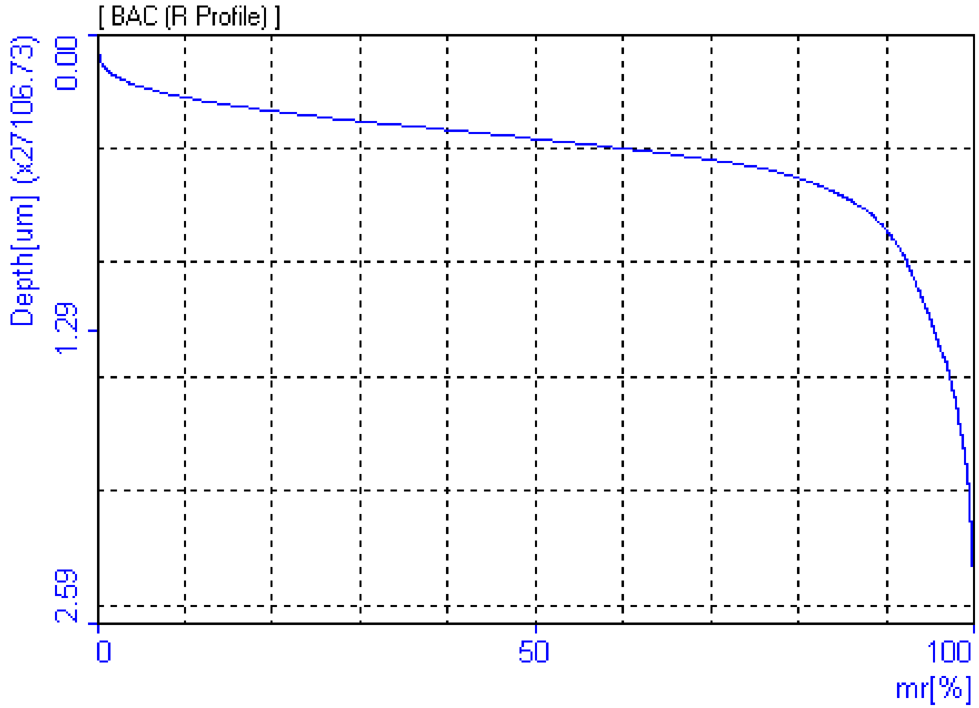
Rt- Largest peak to valley height.



$$Rt = Z_{\max} - Z_{\min}$$

- Very sensitive to anything
- Least Robust
- Single Flaw Parameter
- All Type

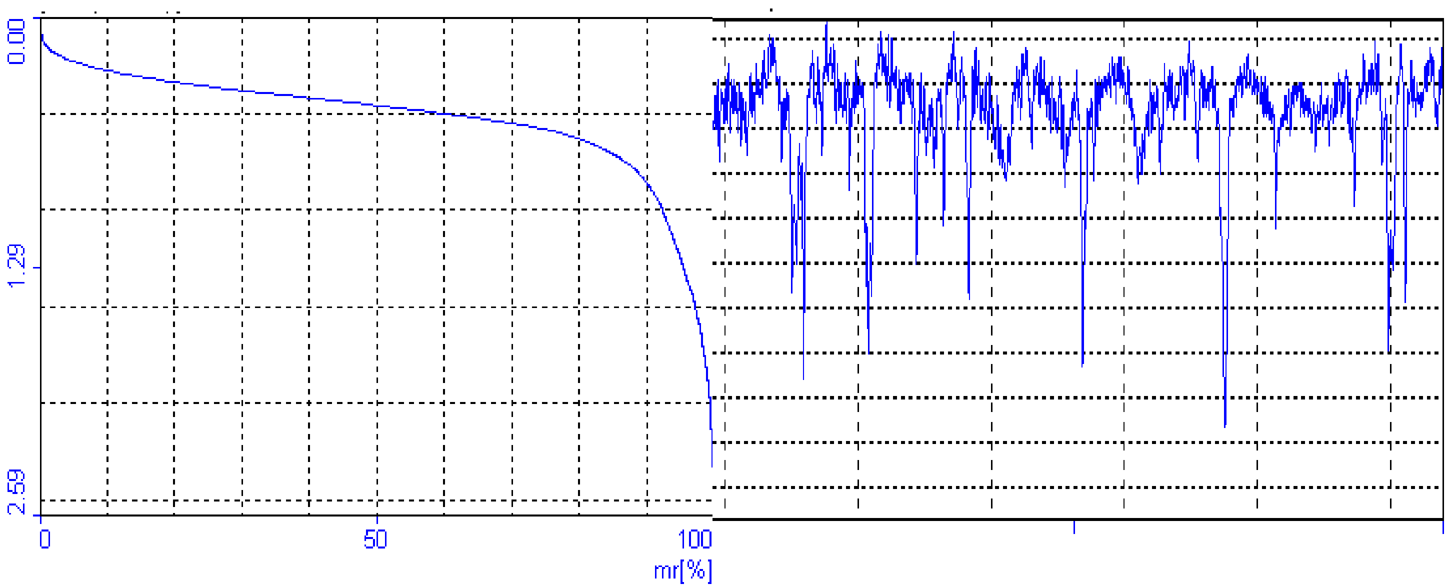
Bearing Area Curve (BAC)



- Used primarily for the analysis of load carrying surfaces
- A.k.a. – Wear Curve, Abbott-Firestone curve,

Abbott Curve (Firestone dropped after tire problems), Tp Curve

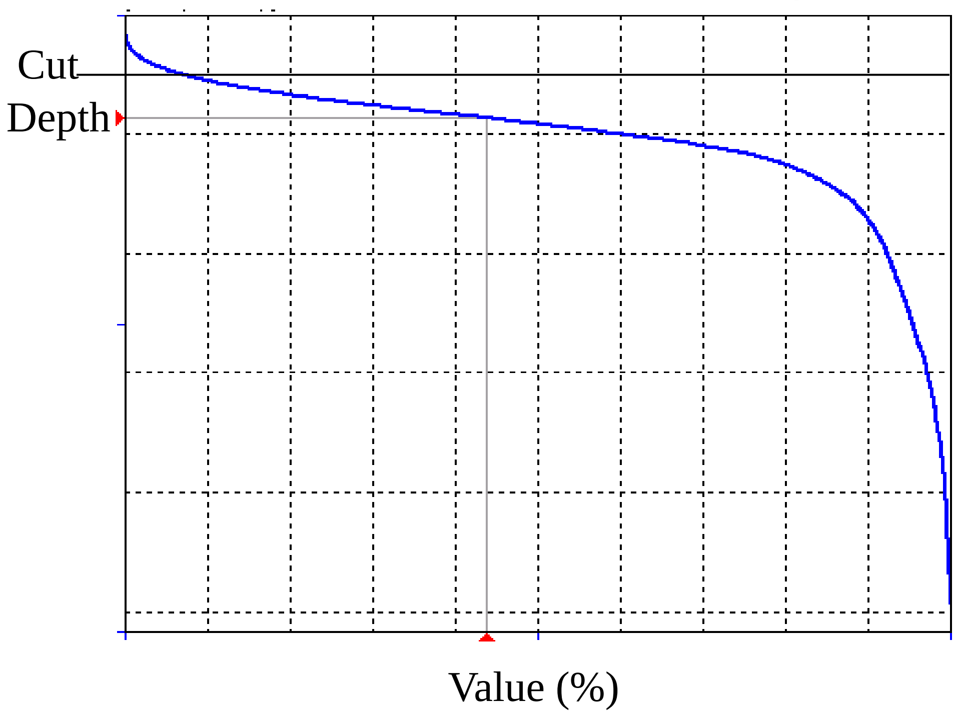
Bearing Area Curve (BAC)



•A Graph of the Material Distribution

•Simply the cumulative distribution of the measure data points

Material Ratio

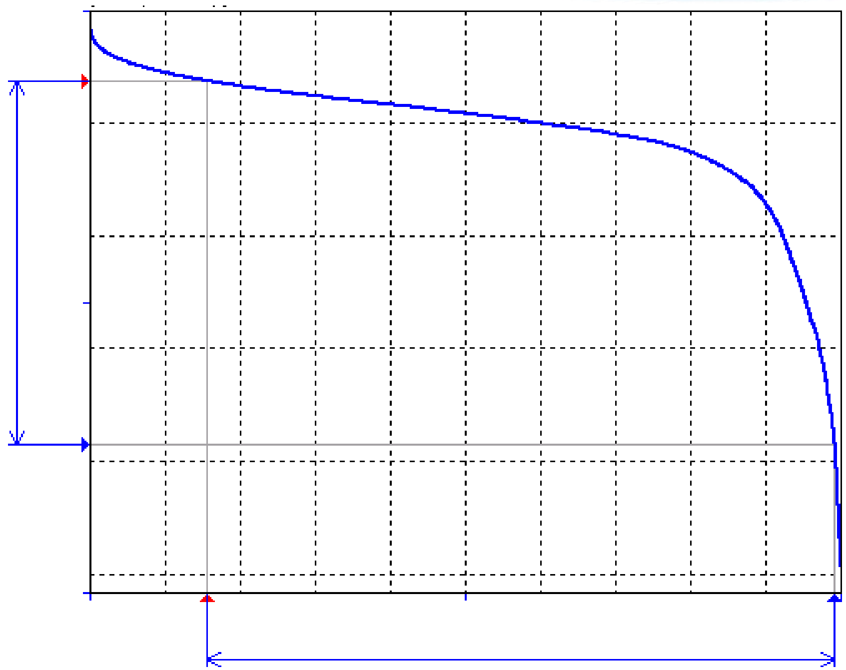


Typically a Cut is specified in %

Depth in µm

The calculated Mr (tp) value is %

Htp / dc



The differences in depth between two specified percentages
Referred to as the reference depth and slice depth
Used to help guarantee a particular shaped distribution. I.e. flat

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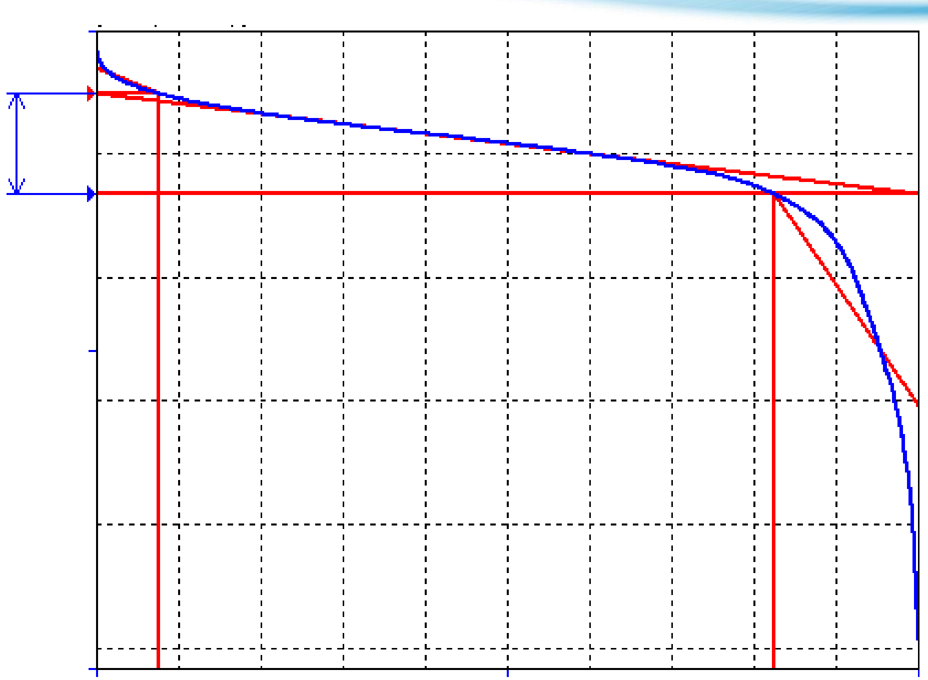
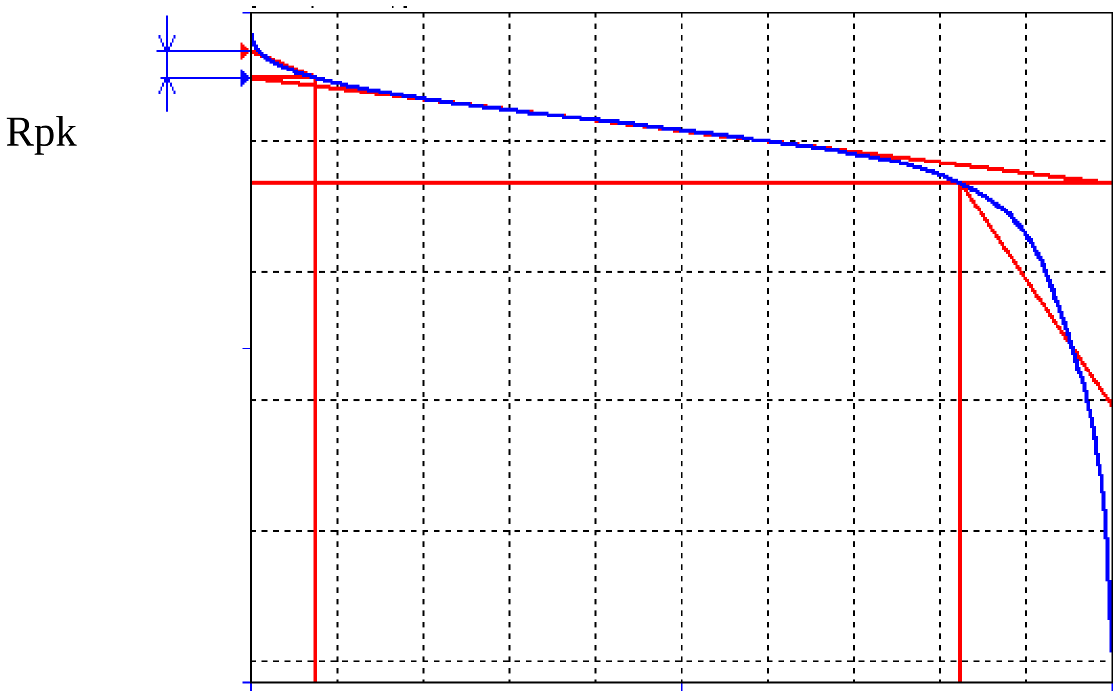
Rk



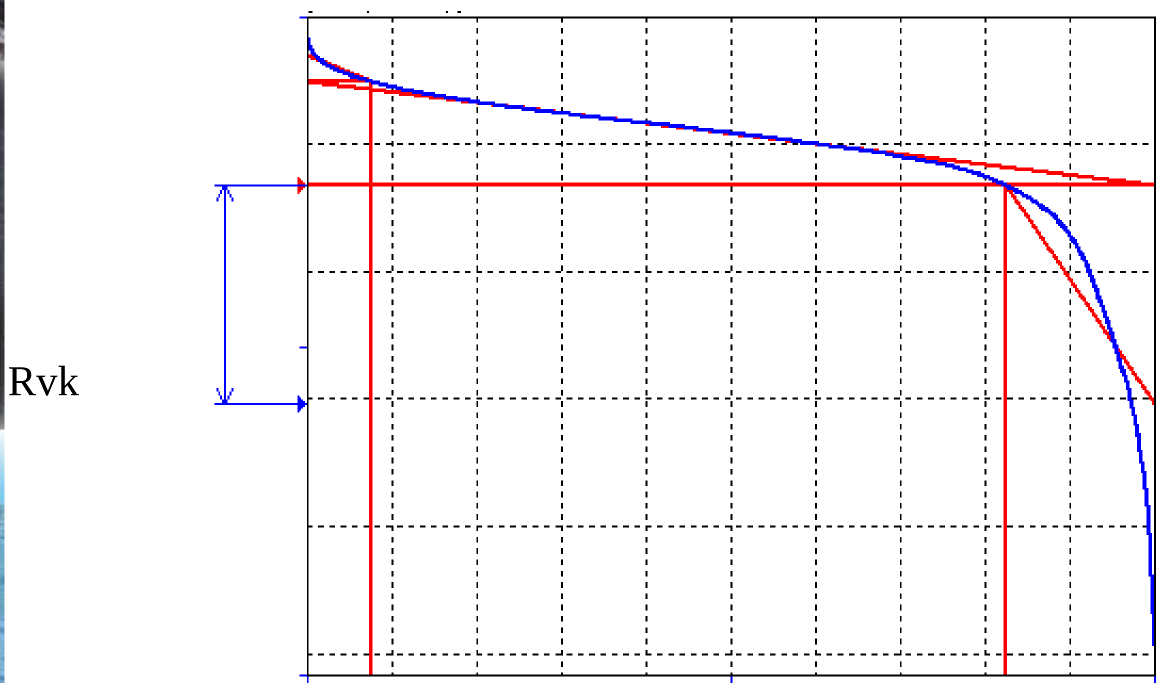
- Rk is the core roughness, determined by convolving a 40% line across the Bearing Area Curve
- A three line fit used to quantify the shape of the BAC
- Developed for Surfaces with a strong plateau characteristic

Rpk



•Rpk is the reduced peak heigth protruding up from the core roughness
•Used to assure peakless surface with good break in qualities

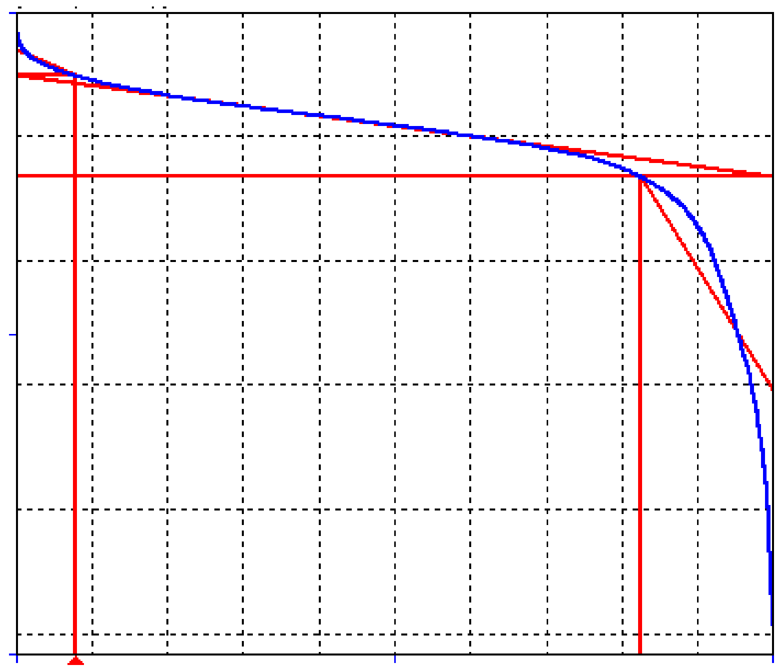
Rvk



•Rvk is the reduced valley depth protruding down from the core roughness

•Used to assure adequate valleys for liquid retention, heat dissipation, and removed material reservoirs

Material Ratio 1

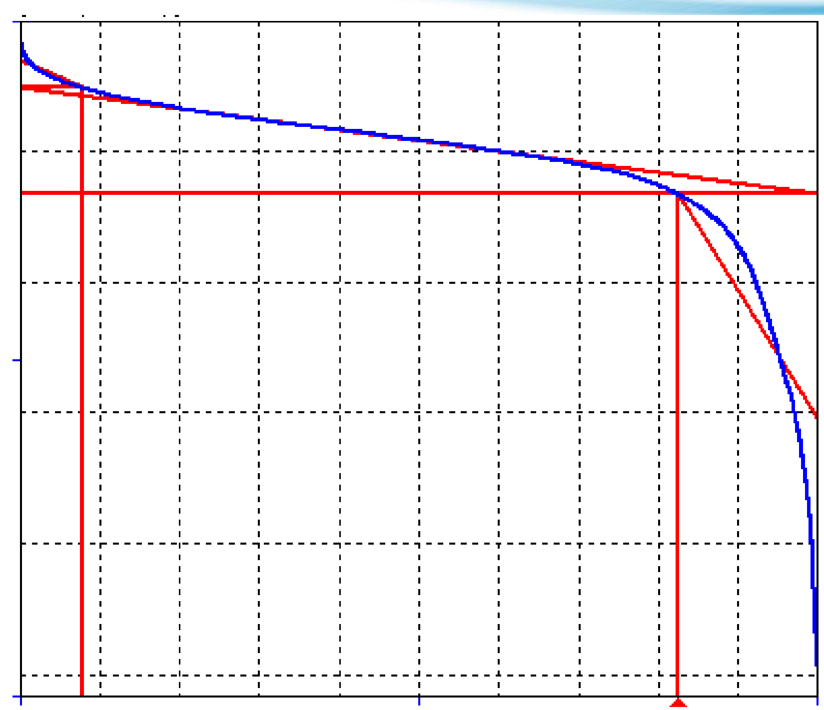


Mr1

- Mr1is the material ratio 1 which is a measure of the amount of peaks
- Used to monitor peak removal

Mitutoyo Corporation
80th Anniversary
Since 1934

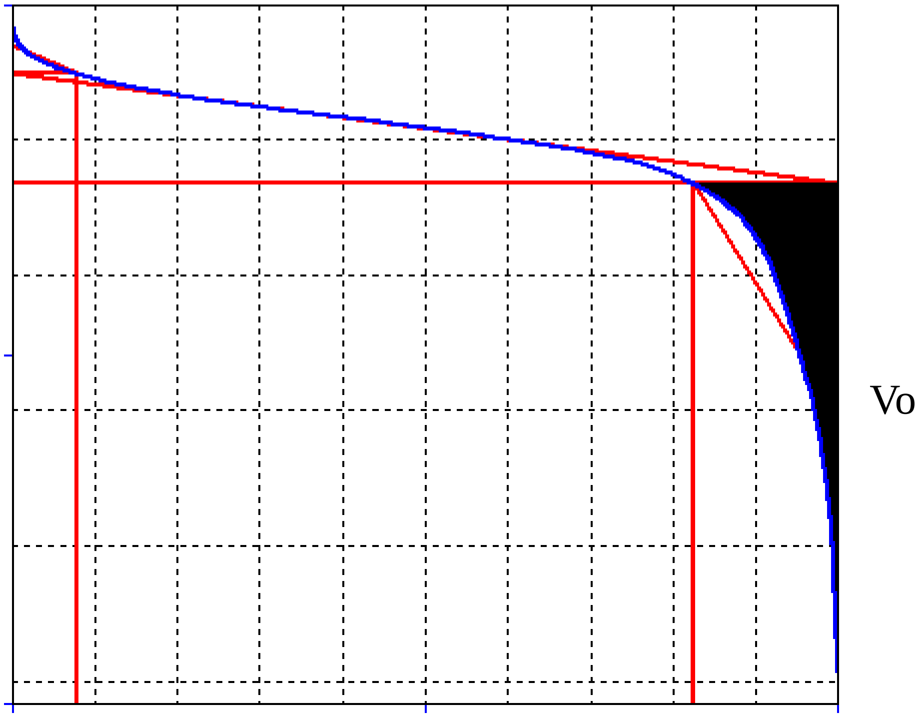
Material Ratio 2



•Mr2 is the material ratio 2 which is a measure of the amount of peaks and bearing surface, exclusive of valleys

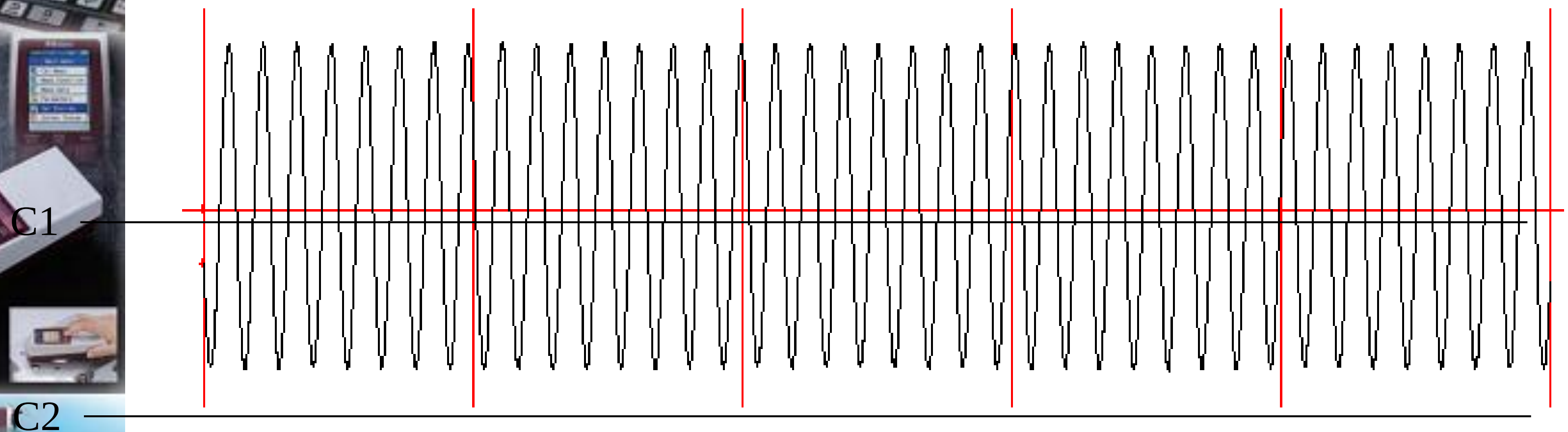
•Used to monitor material removal and valley volume

Vo / A2



- Vo is a measure of valley volume
- Oil Retention

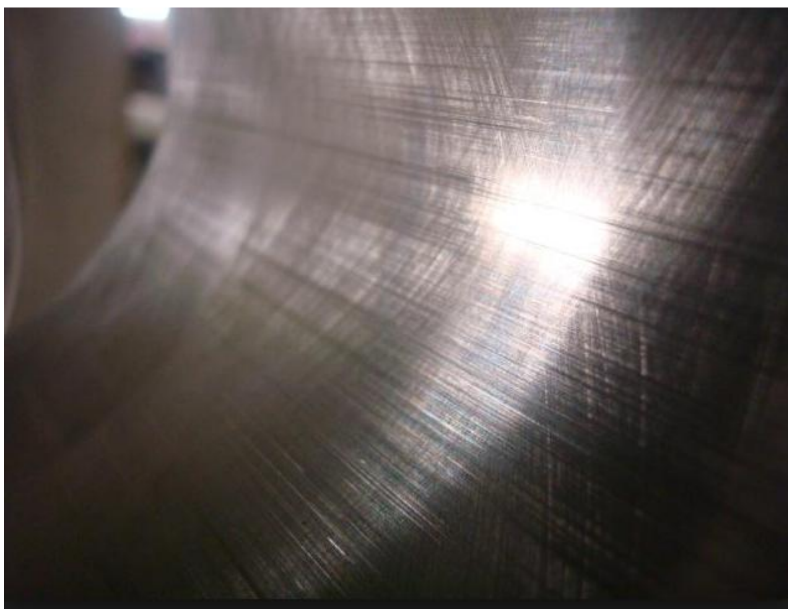
Pc, HSC, Sm, S

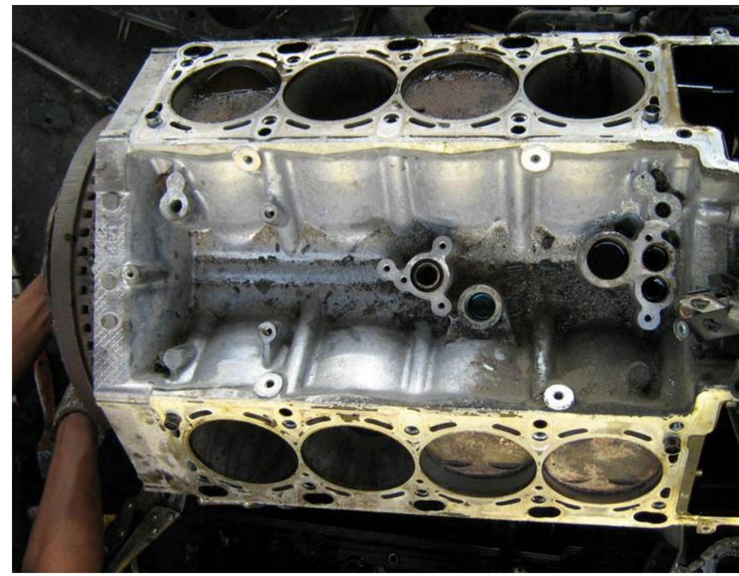


- Pc - a measure of the number of peaks per cm (or inch), used to determine texture/aesthetics/adhesion/paintability
- HSC – Pc with only an upper threshold
- Sm, S - Average Peak Spacing

Cylinder Bore

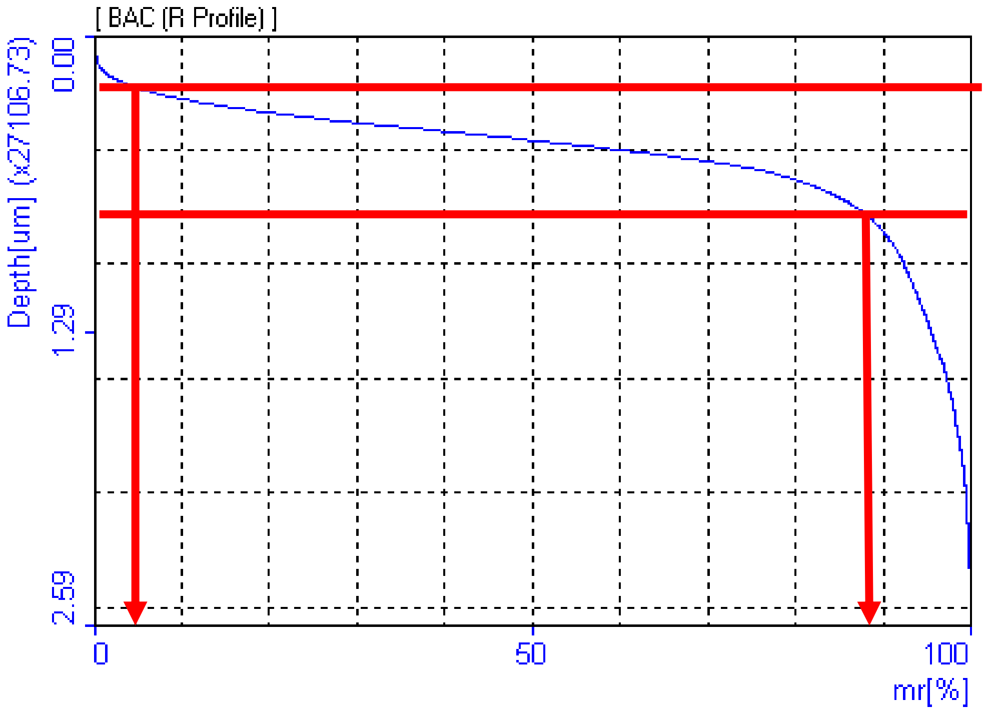
Rmr= 75% max c=0.5um from a 5% reference line





Rmr

Rmr= 75% max c=0.5um from a 5% reference line



Custom Callouts

Rz1max 120um
Rpmax 90um
Rvmax 30um
2.5mm Lc
12.5mm Le

No more than 3 failures allowed per test