Surface Texture Parameters

2D Parameters

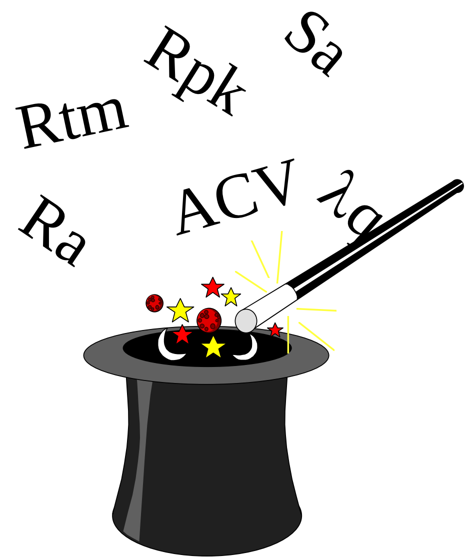
3D (Areal) Parameters

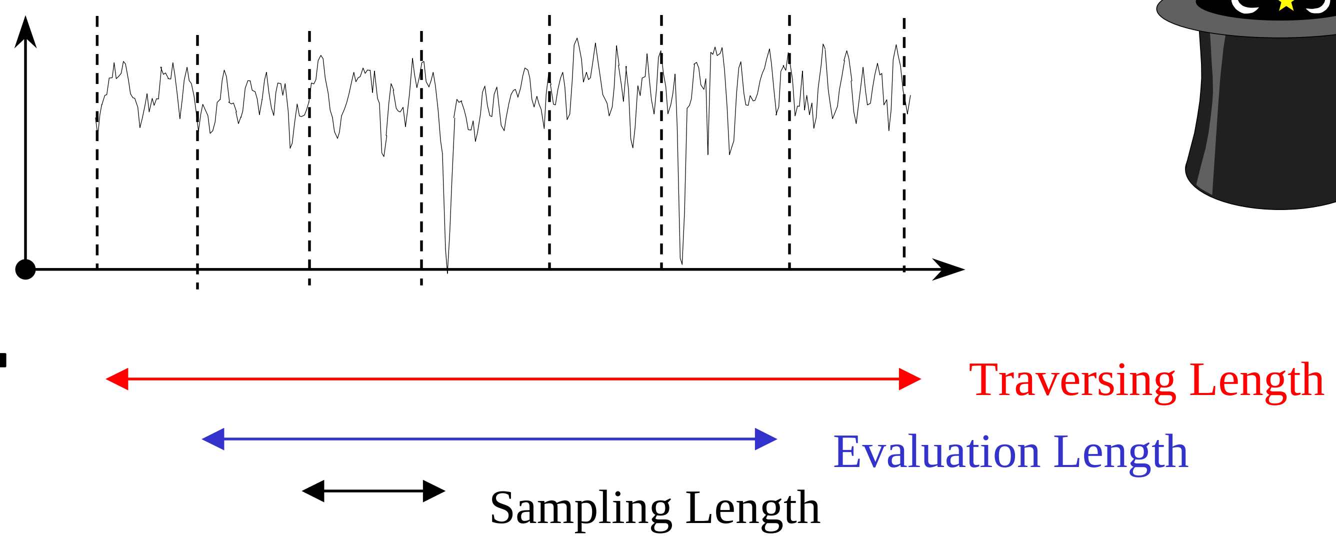
Surface Texture Parameters

- Once the surface is measured, need to develop parameters for control etc.
- Probably >100, 2D parameters introduced in the literature / standards over the years
- 3D work (Stout *etal.*), Identify 14+ key 3D parameters

The parameters <u>quantify</u> "information"

- Height ----- "Amplitude parameters" (e.g. Ra)
- Spatial ----- "Spacing parameters" (e.g. Sm)
- Height & Spatial ----- "Hybrid parameters" (e.g. λq)
- Function – Bearing Area (e.g. Rpk..)

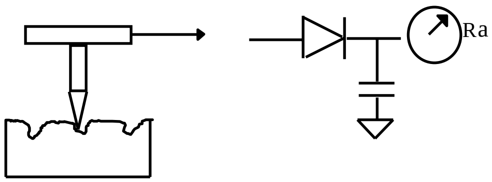




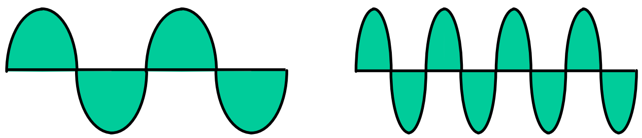
Surface Texture Parameters

Ra...Average Roughness

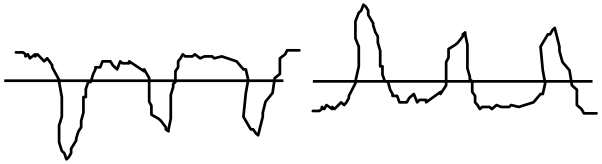
Why Ra?...”Standard” ......Limits of technology..circa 1930...



$$R_a = \frac{1}{A}\int_0^{Ly}\int_0^{Lx}|Z(x,y)|dxdy$$



Same
Ra!!



Same
Ra!!

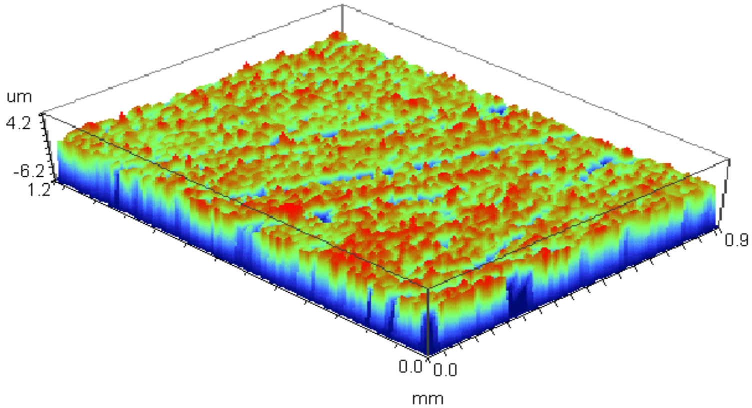
Why Not Ra?.....

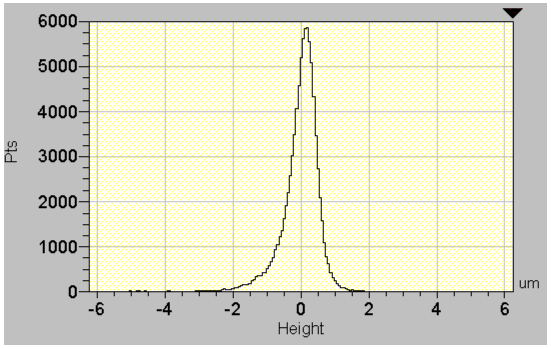
No spatial structure information

No difference between peaks/valleys

Surface Texture Parameters

Amplitude Parameters .. Rq, Rsk, Rku





Calculate the "moments" of the distribution:

Rq = "RMS", =

$$R_q = \sqrt{\frac{1}{A}\int_0^{Ly}\int_0^{Lx}(Z(x,y))^2 dxdy}$$

Rsk = Skew , Skewness =

$$R_{sk} = \frac{1}{Rq^3 A}\int_0^{Ly}\int_0^{Lx}(Z(x,y))^3 dxdy$$

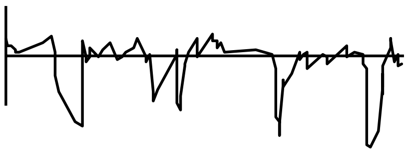
Rku = Kurtosis =

$$R_{ku} = \frac{1}{Rq^4 A}\int_0^{Ly}\int_0^{Lx}(Z(x,y))^4 dxdy$$

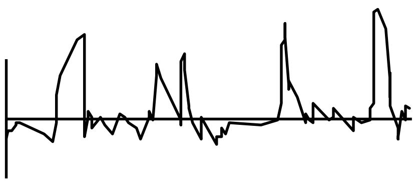
Surface Texture Parameters

Amplitude Parameters .. Rq, Rsk, Rku

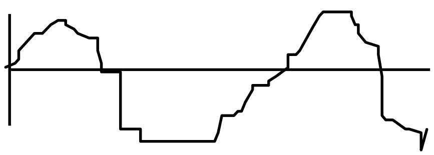
Rq=3, Rsk = 0, Rku=3, Gaussian Surface



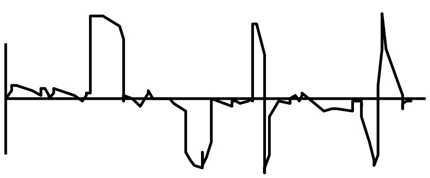
Rq=12, Rsk = -1, Rku=8, Negatively Skewed



Rq=12, Rsk = 1, Rku=8, Positively Skewed



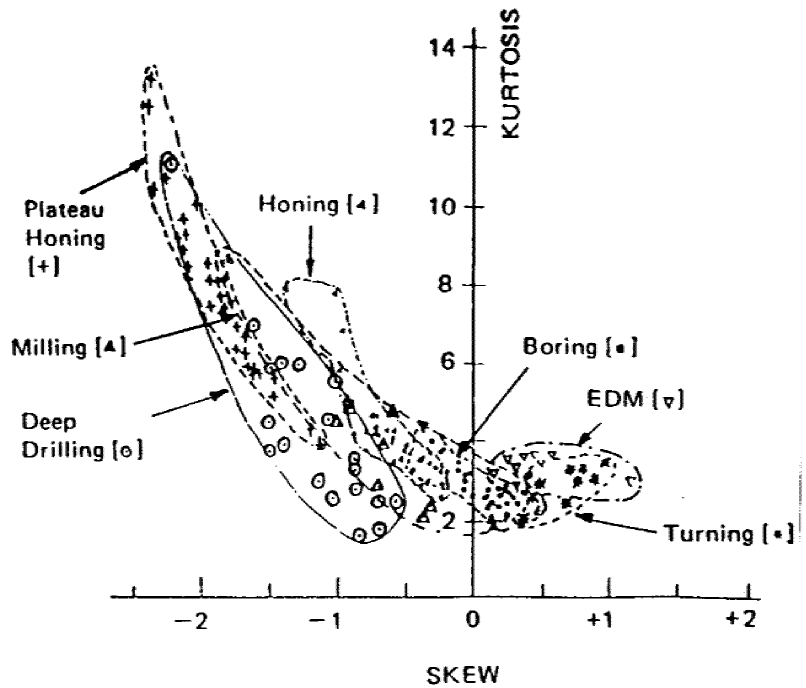
Rq=4, Rsk = 0, Rku=1.5, Slowly Varying



Rq=4, Rsk = 0, Rku=10, Extreme Peak/Valley

Surface Texture Parameters

Amplitude Parameters   Rq, Rsk, Rku



Why Rq, Rsk, Rku?...

”symmetry” of surface distribution..”statistics based”...

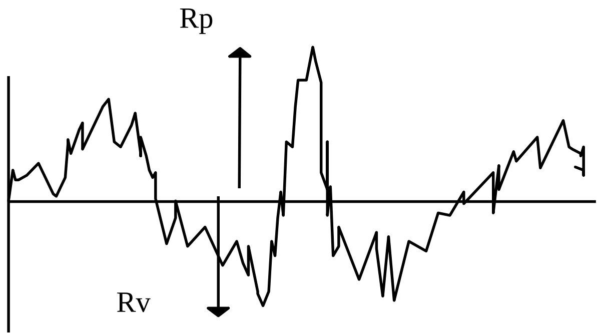
Why Not Rq,Rsk, Rku?.....

No spatial structure information

No difference between peaks/valleys (Rq, Rku)

Surface Texture Parameters

Peaks/Valleys .. Rp,Rv, Rt, Rz, Pc....



Rp = Highest Point From Mean Line

Rv=Lowest Point from Mean Line

Rt = Rp - Rv = Peak to Valley

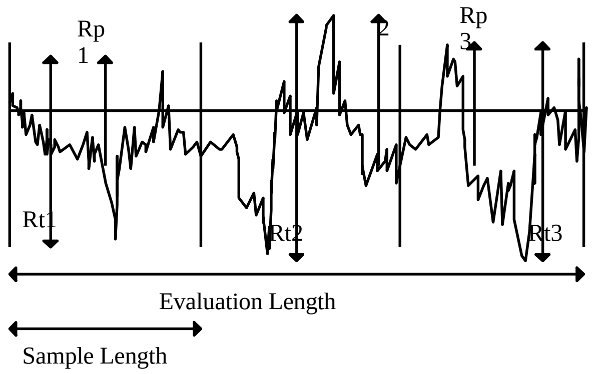
Rti = Highest - Lowest points from mean line in "ith" Sampling length

Rpi = Highest Peak from mean line in "ith" sampling length

Rpm= Average of all Rpi (If Average 5 then Rpm (DIN))

Rz = Average of all Rti (If Average 5 then Rz (DIN))

Rmax = Maximum Rti over evaluation length

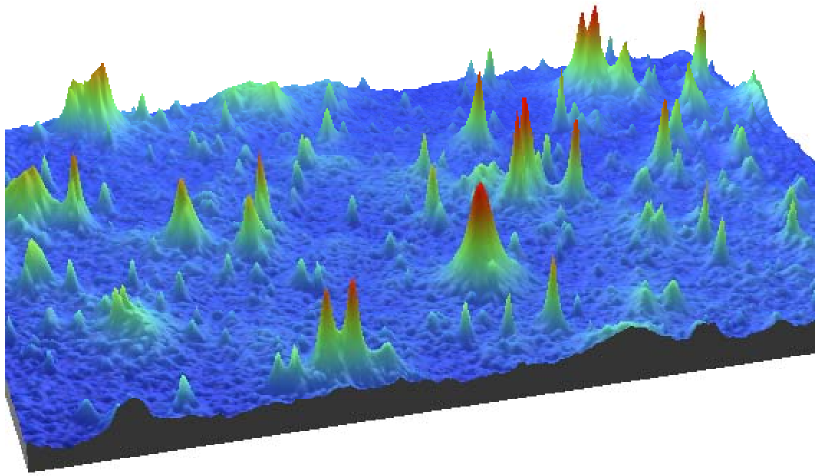


Surface Texture Parameters

Peaks/Valleys .. Rt, Rv, Rz, Pc. Summits.....

Why Peaks/Valleys...?

Bearing, Sealing, Appearanc
Coating Coverage

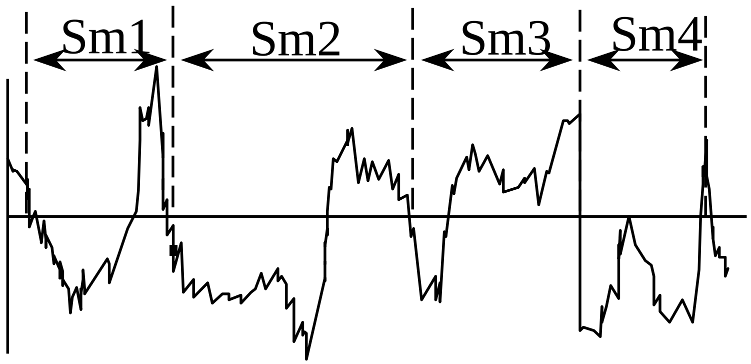


Why Not Peaks/Valleys...?.

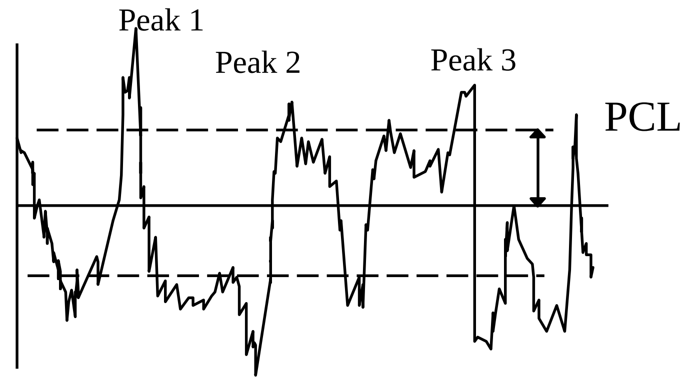
No spatial structure information
Potentially, Not repeatable (especially Rt, Rp, Rv...only ONE point!)
Threshold sensitive

Surface Texture Parameters

Spacing Parameters Sm, PCL



Sm = The Average of all Smi



PCL= Peak Count Level...Threshold
Peak = When profile intersects lower and upper PCL
Pc = Peak Density....peaks/unit length

Why Sm, Pc...?

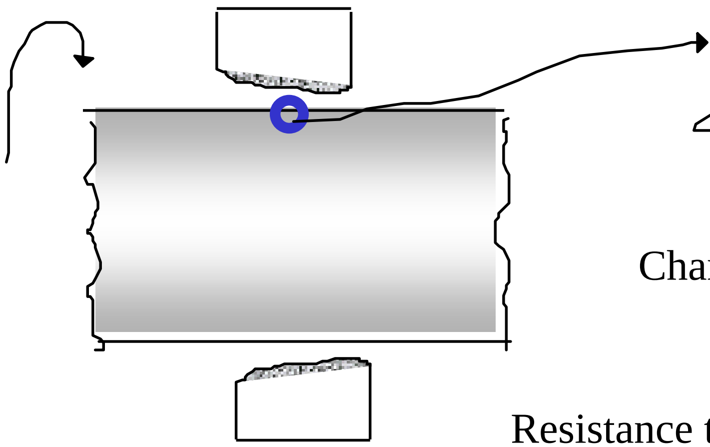
Sealing, Appearance, Adhesion
Sheet Steel...Forming release v.s. appearance

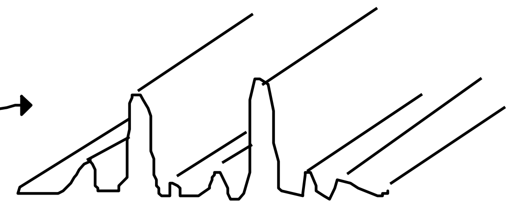
Why Not Sm, Pc...?.

No height information(Sm)

Surface Texture Parameters

Peaks/Valleys .. Rz, Pc. Sealing Systems...





Channels for Fluid Flow

Resistance to Flow, H is related to Pc and Rz..

$$H=(Pc/Rz)^3$$

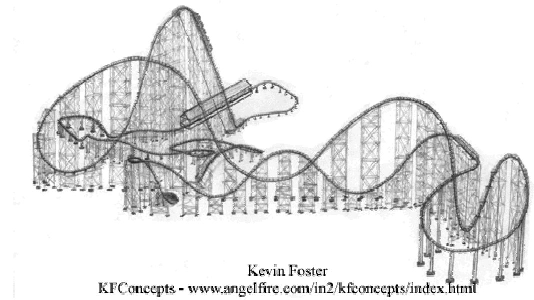
Higher Peaks/Deeper Valleys	Rz ↑	H ↓...	leaks
Wider Spacing of Peaks	Pc ↓	H ↓...	leaks

Goal: Minimize Channels for flow..

Ronald A. Lavoie, Stop Shaft Leaks with better surface Finish, Quality , July 1994.

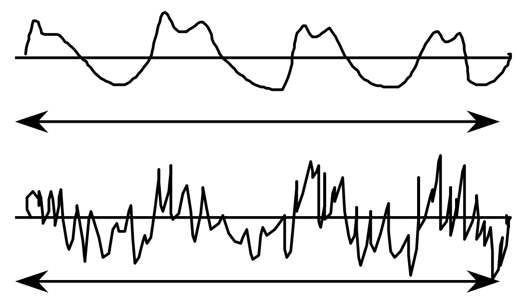
Surface Texture Parameters

Hybrid Parameters...Slope, Δq, λq



Slope – 2D Profile

$$\Delta_q = \sqrt{\frac{1}{L}\int_0^L \left(\left|dZ(x)/dx\right|\right)^2 dx}$$

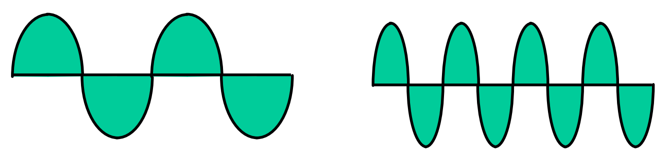


Low Δq

High Δq

“Average Wavelength Weighted By Amplitude”

$$\lambda q = 2\pi Rq/\Delta q$$

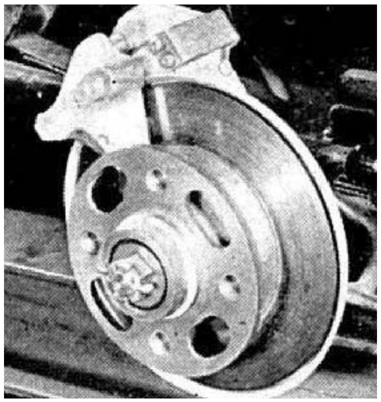


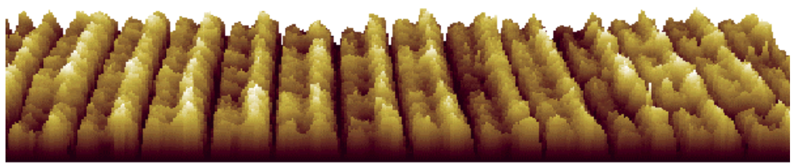
λq=4 λq=2

Surface Texture Parameters

Hybrid Parameters...Slope, Δq, λq

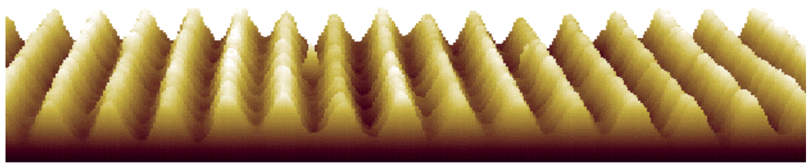
Problem: Brake Rotor Ra “inspec” …some work ..some have NVH issues
Solution: Quantify the surfaces – Spec additional texture parameters Δq
Solution: Identify cause of texture variation..(materials? tools? setup?)





Ra: In spec

Δq: Low

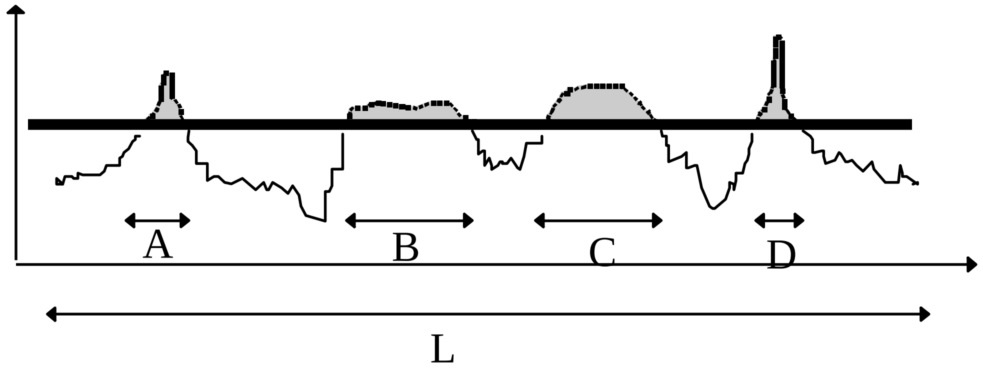


Ra: In spec

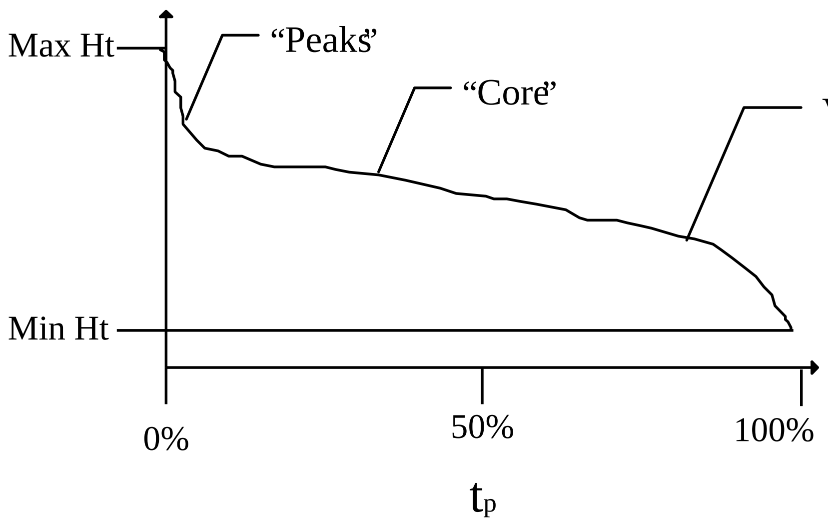
Δq: High

Surface Texture Parameters

Functional Parameters ..
Bearing Area Rpk, Rk, Rvk....



tp =100% x (A + B + C + D)/L



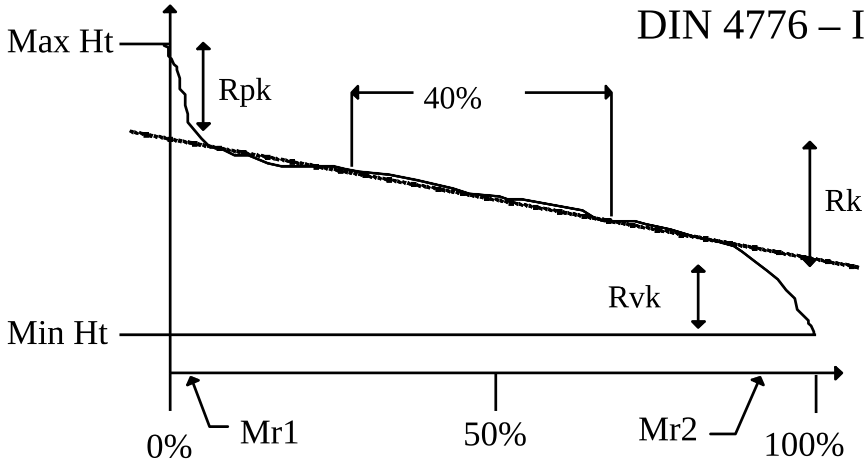
E. J. Abbott and F.A. Firestone, Specifying Surface Quality, Mechanical Engineering, Vol. 55,September 1933.pp. 569-572.

Surface Texture Parameters

Functional Parameters ..

Bearing Area Rpk, Rk Rvk....

DIN 4776 – ISO 13565-2

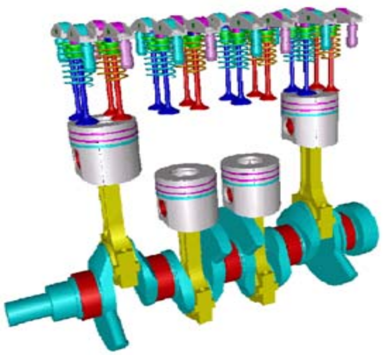


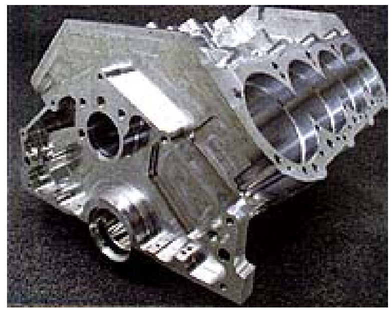
Rpk = “Peak Height” .. First Region of contact
Rk = “Core Height”... “working” Region ..”Base”
Rvk = “Valley Depth” ... “Lubricant Retention Region”
Mr1 = “1st Material Ratio”... “Peak Material”
Mr2 = “2nd Material Ratio” ... “Valley Material”
V_0 = Rvk(100-Mr2)/200......”Retention Volume”

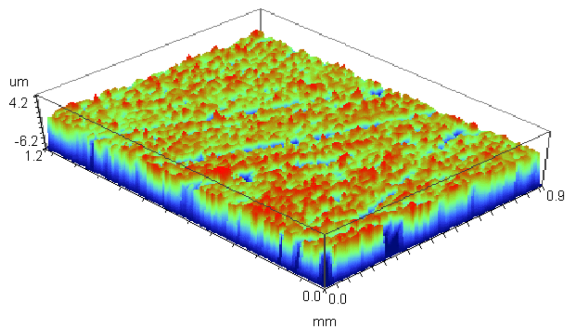
Surface Texture Parameters

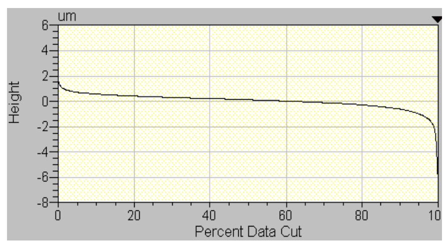
Functional Parameters ..

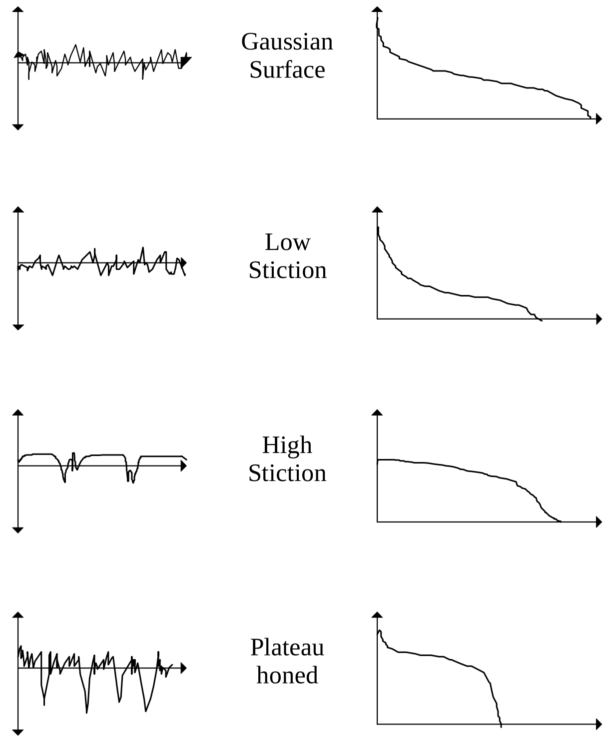
Bearing Area Rpk, Rk Rvk....











Why Rpk, Rk, Rvk...?

"Bearing, Sealing"...also ratio's Rpk/Rk etc.
differentiates peaks/core/valley

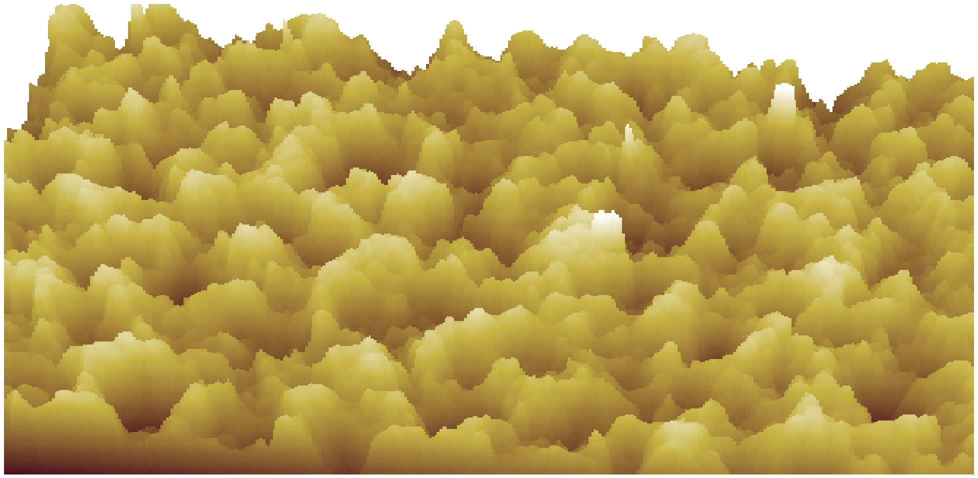
Why Not Rq,Rsk, Rku?.....

No spatial structure information

3D Surface Texture Metrology

History….

1930's – First "2D" instruments for texture – analogue, charts etc.
1960's – Digital Computers – parameter development – 3D machines
1968 – The Properties and Metrology of Engineering Surfaces –Oxford.
1979 – 1st of Triennial International Conferences
1990's – Workshops – indicating a need to standardize 3D parameters
2000's – SurfStand, AutoSurf, CalStand…New ISO standard "WG16"



3D Texture Parameters

THE UNIVERSITY OF BIRMINGHAM

THE UNIVERSITY OF WARWICK

University of HUDDERSFIELD

Dr. David Whitehouse

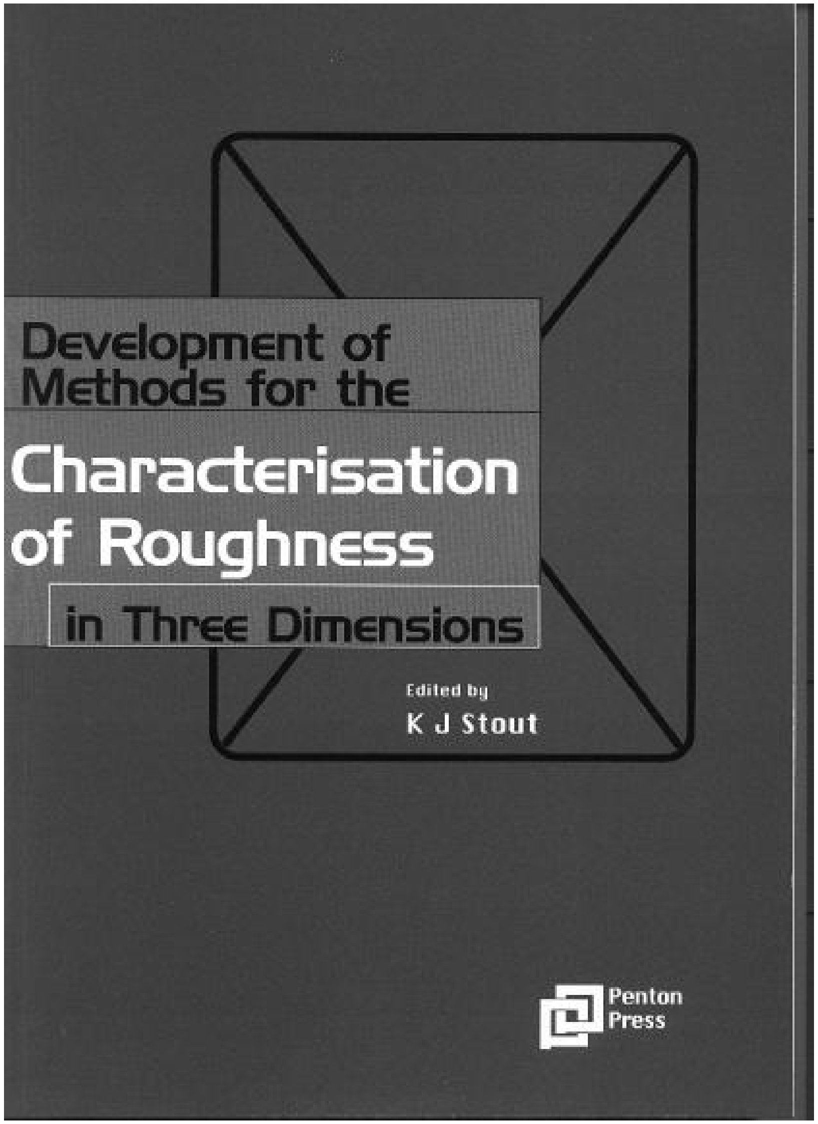
Dr. Ken Stout

Dr. Liam Blunt

Dr. Paul Scott

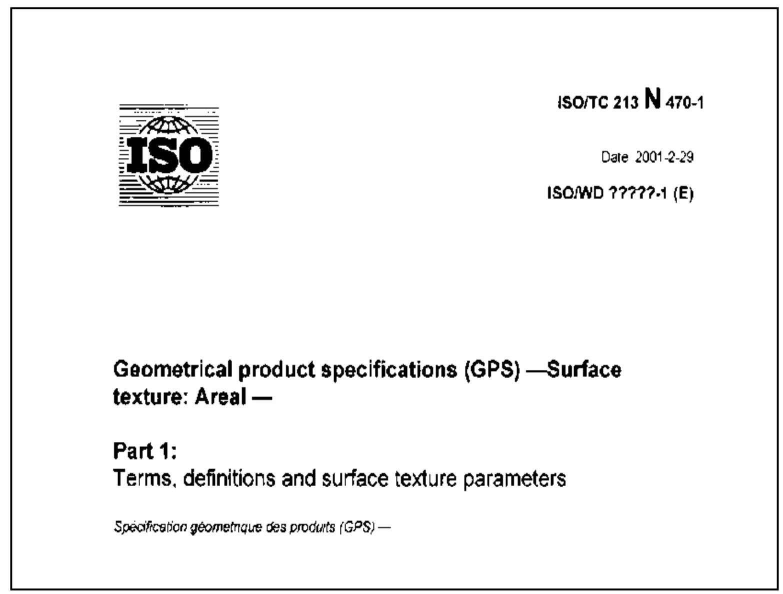
Dr. Xianqqian Jiang

"The Birmingham 14" **3D Texture Parameters** "S" Parameters



Parameters:

1) Amplitude
2) Spatial
3) Hybrid
4) Area & Volume
5) Functional


ISO/TC 213 N 470-1

Date 2001-2-29

ISO/WD ?????-1 (E)

Geometrical product specifications (GPS) —Surface texture: Areal —

Part 1:
Terms, definitions and surface texture parameters

Spécification géometnque des produits (GPS) —

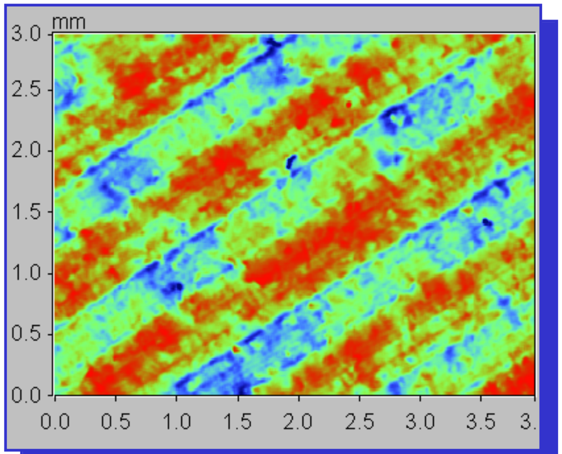
ISBN 1 8571 8023 2

"The Birmingham 14" **3D Texture Parameters** "S" Parameters

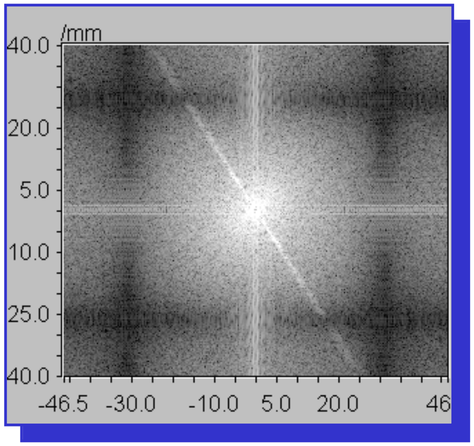
3D Surface Measurement

(many devices contact/non contact devices)

- Sampling area, Evaluation Area etc…
    - Typical Array (1, 2, 5, 10, 20, 50, …..) x (1, 2, 5…) nm, µm, mm
- Filters – "under development"
    - Gaussian Filter with 50% transmission at specified spatial frequency

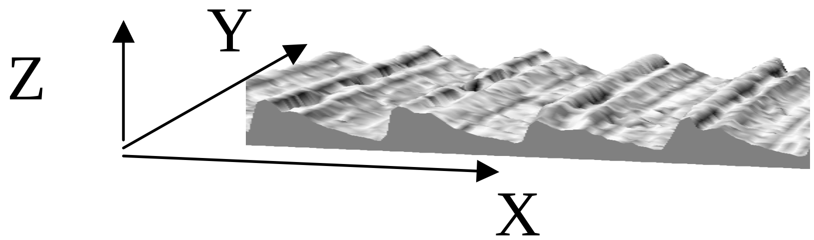


Milled Surface



Frequency Spectrum

"The Birmingham 14" **3D Texture Parameters** "S" Parameters



Amplitude Parameters

Sq: The Root-mean-square deviation of the surface (RMS of height distribution)

$$S_q = \sqrt{\frac{1}{A}\int_0^{Ly}\int_0^{Lx}(Z(x,y))^2\,dxdy}$$

Ssk: Skewness of surface height distribution

$$S_{sk} = \frac{1}{Sq^3 A}\int_0^{Ly}\int_0^{Lx}(Z(x,y))^3\,dxdy$$

Sku: Kurtosis of surface height distribution

$$S_{ku} = \frac{1}{Sq^4 A}\int_0^{Ly}\int_0^{Lx}(Z(x,y))^4\,dxdy$$

Amplitude Parameters - Peak & Hill / Valley and Dale

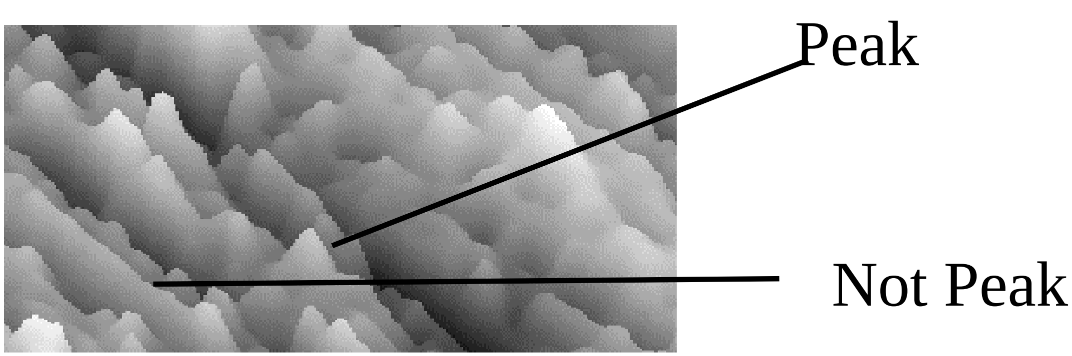
Sz: Ten Point Height of the Surface (8 nearest neighbor)

$$S_z = \frac{\sum_1^5 |PeakHeights| + \sum_1^5 |ValleyDepths|}{5}$$

- •Peak = A point on the surface which is higher than all other points within a neighborhood
- •Hill = Region around a peak such that all maximal upward paths end at the peak
- •Valley = A point on the surface which is lower than all other points within a neighborhood
- •Dale = Region around a valley such that all maximal downward paths end at the valley

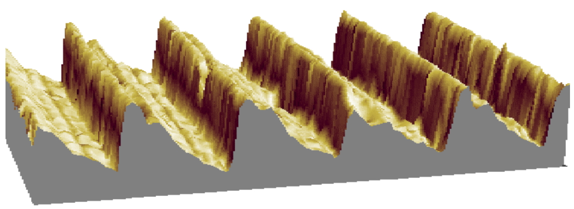
Sds: Density of Summits

$$S_{ds} = \frac{Number - of - Peaks}{Area}$$

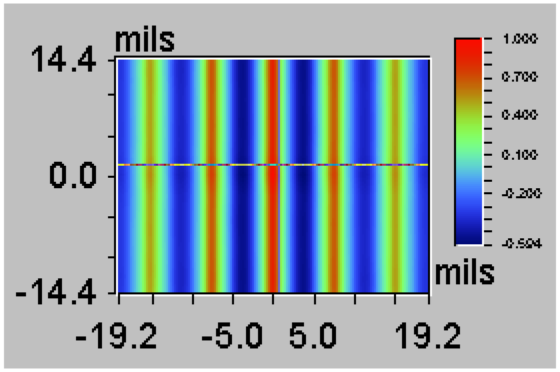


"The Birmingham 14" **3D Texture Parameters** "S" Parameters

AutoCovariance Function (ACF)

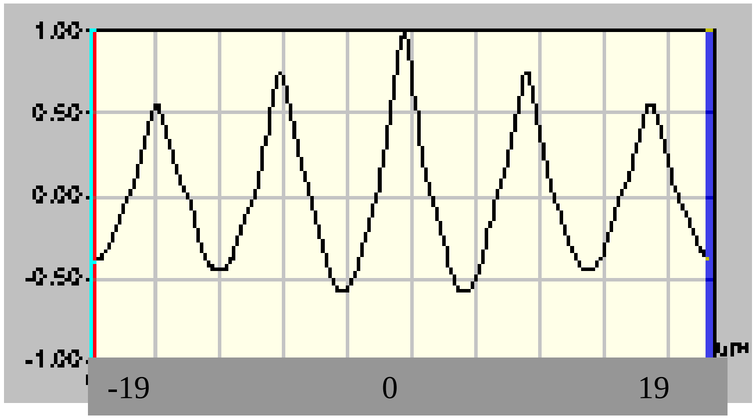


Turned Surface

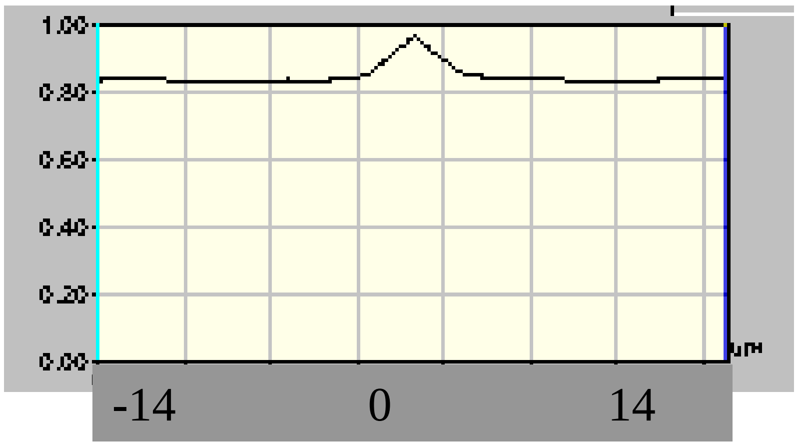


ACF of Turned Surface

X ACF Profile



Y ACF Profile



"The Birmingham 14"

3D Texture Parameters

"S" Parameters

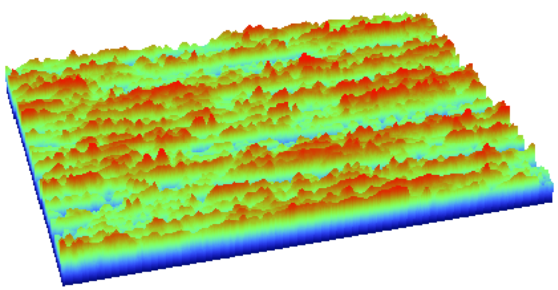
Spatial Parameters

Str: Texture Aspect Ratio

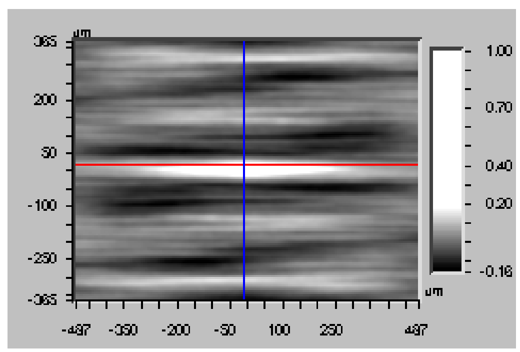
$$S_{tr} = \frac{Length-of-fastest-decay(0.2)-of-ACF-in-any-direction}{Length-of-slowest-decay(0.2)-of-ACF-in-any-direction}$$

Sal: Fastest Decay Autocorrelation Length

$$S_{al} = length-of-fastest-decay-of-ACF-to-0.2-In-Any-Direction$$

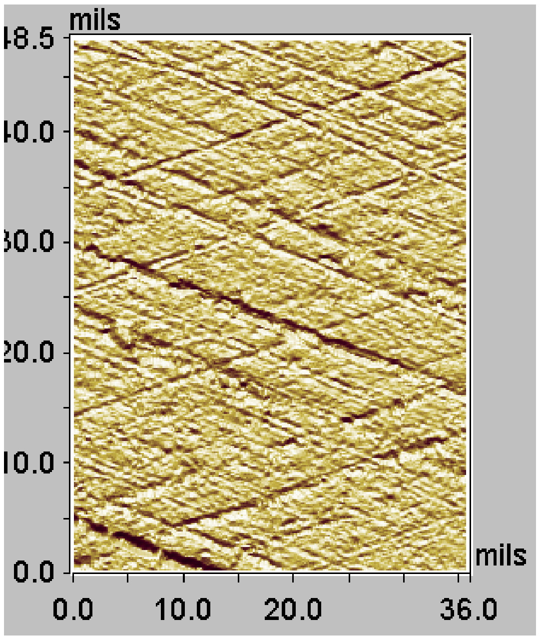


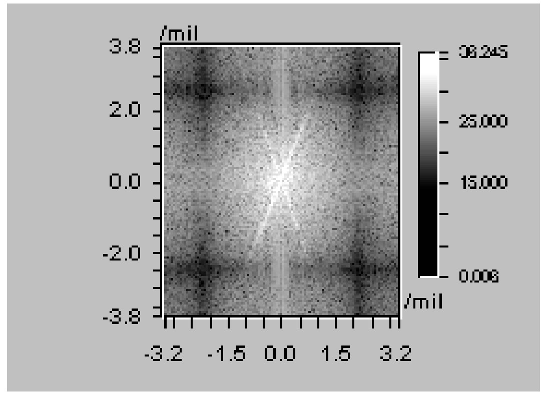
Ground Surface



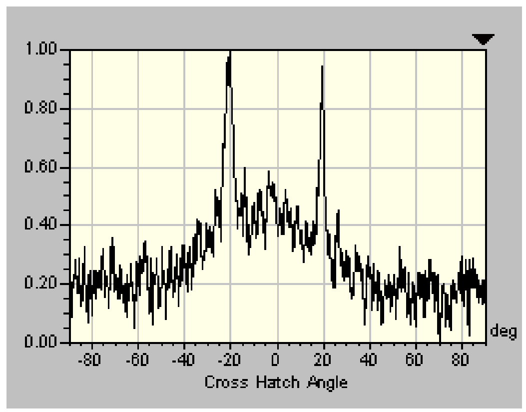
ACF of Ground Surface

Spatial Parameters
Angular Power Spectral Density Function (APSDF)





Power Spectrum

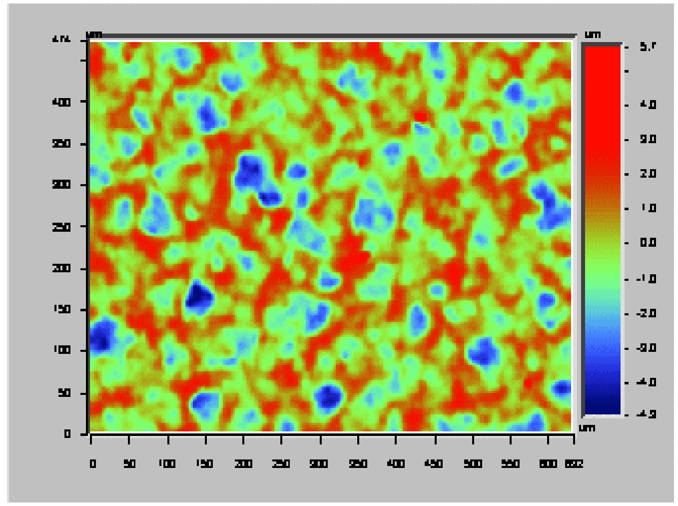


Angular Power Spectrum

Std: Texture Direction of Surface

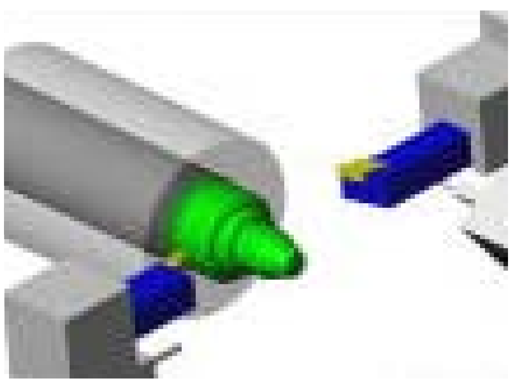
$$S_{td} = Major - direction - of - Lay - Derived - From - APSD$$

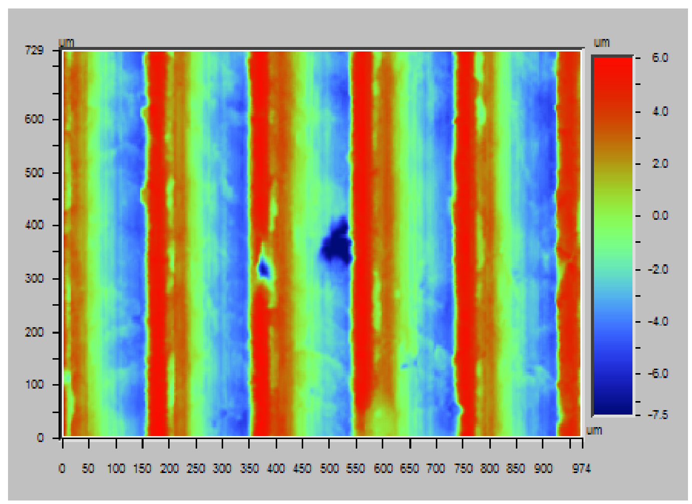
3D Texture Parameters



Str = 0.85
Std = ***

Shot Peened Surfaces

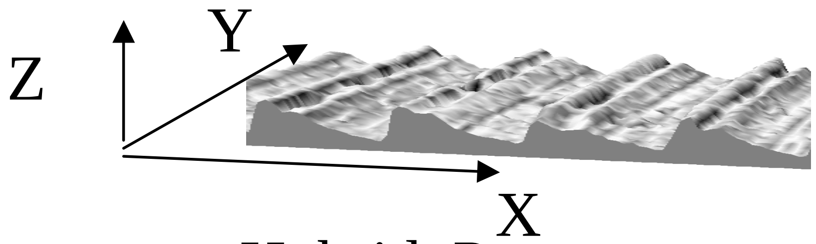




Str = 0.05
Std = 0.00 deg

Turned Surfaces

"The Birmingham 14" **3D Texture Parameters** "S" Parameters



Hybrid Parameters

SΔq: Root-Mean_Square Surface Slope

$$S\Delta q = \sqrt{\frac{1}{A}\int_0^{Lx}\int_0^{Ly}\left(\frac{\partial Z(x,y)}{\partial x}\right)^2 + \left(\frac{\partial Z(x,y)}{\partial y}\right)^2 dydx}$$

Ssc: Mean Summit Curvature - evaluated for <u>each summit</u> and then averaged over the area

Based on a Summit (nearest neighbors?)

$$Ssc = \frac{1}{A}\int_0^{Lx}\int_0^{Ly}\left(\frac{\partial^2 Z(x,y)}{\partial x^2}\right) + \left(\frac{\partial^2 Z(x,y)}{\partial y^2}\right) dydx$$

Hybrid Parameters

Sdr: Developed Surface Area Ratio

$$Sdr = \frac{(Total - Surface - Area - of - All - The - Triangles) - (Lx \bullet Ly)}{Lx \bullet Ly}$$

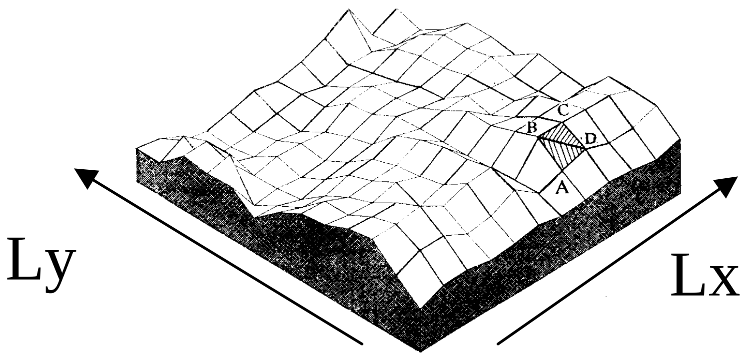


Fig. 12.10 Schematic diagram of the developed area.

……Fractals…

Christopher A. Brown, William A. Johnsen, Kevin M. Hult, Scale-sensitivity, Fractal Analysis and Simulations, Int. J. Mach. Tools Manufact. Vol 38, Nos 5-6, pp. 633-637, 1998

“The Birmingham 14” — **3D Texture Parameters** — “S” Parameters

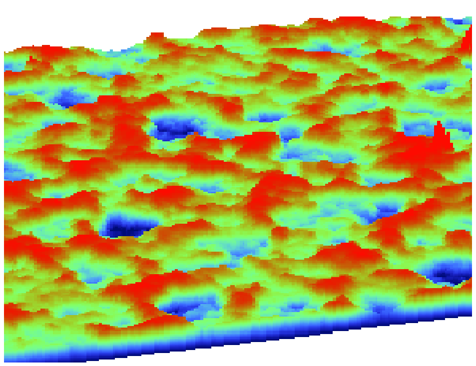
Functional Parameters for Bearing and Fluid Retention Properties

Index Family

- Display Bearing Area Curve with mean plane = 0
- Display Bearing Area Curve height, h= TrueHeight/ Sq   (“normalized height”)

Sbi: Surface Bearing Index

$$Sbi = \frac{Sq}{Trueheight(0.05)} = \frac{1}{h(0.05)}$$



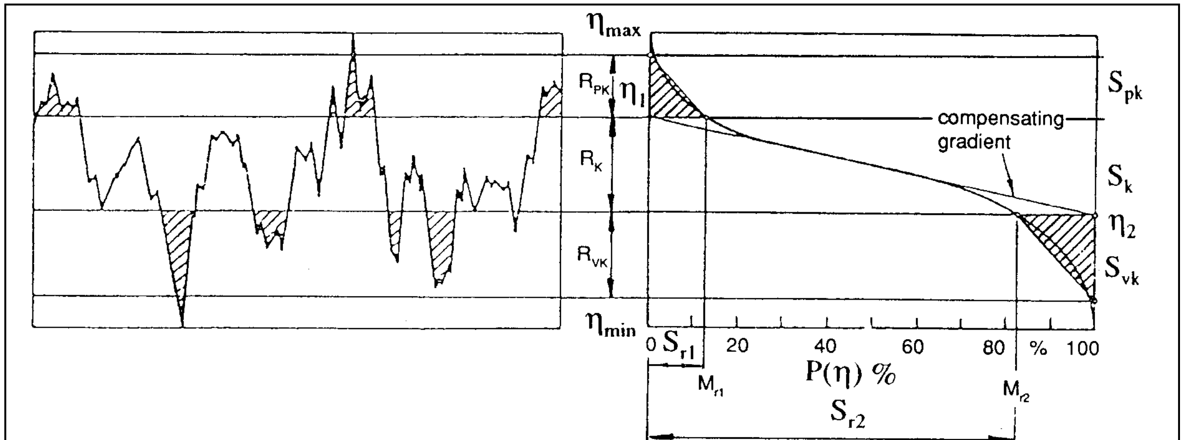


Fig. 12.16 DIN 4776 parameters in 3-D.

For Gaussian, *Sbi*=0.61 , High *Sbi* = good bearing surface

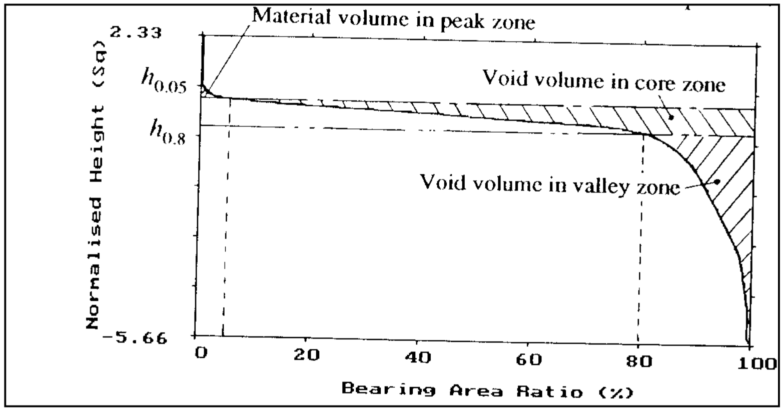
"The Birmingham 14" **3D Texture Parameters** "S" Parameters

Functional Parameters for Bearing and Fluid Retention Properties

Index Family

Sci: Core Fluid Retention Index

$$Sci = \left(\frac{V_v(h_{0.05}) - V_v\,(h_{0.80})}{A} \right) \div Sq$$



For Gaussian, Sci = 1.56, smoother = smaller *Sci*

Svi: Valley Fluid Retention Index

$$Svi = \left(\frac{V_v\,(h_{0.80})}{A} \right) \div Sq$$

For Gaussian, Svi = 0.11, Good Fluid Retention = larger *Svi*

Vv(h) is the void Volume at h, Vm(h) is the material Volume at h

"The Birmingham 14 + 3" 3D Texture Parameters "S" Parameters

Functional Parameters for Bearing and Fluid Retention Properties

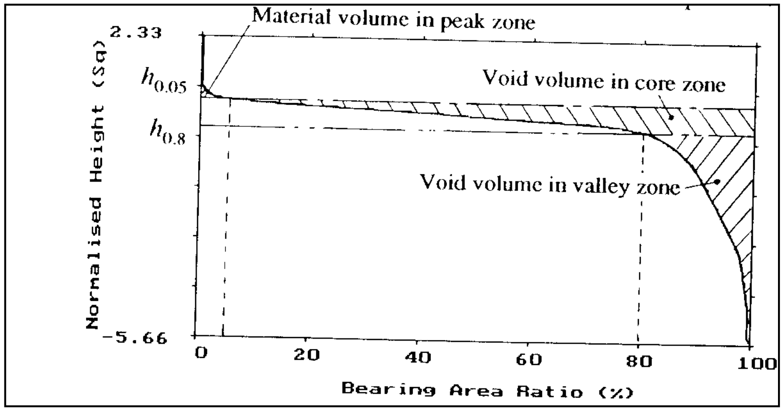
Volume Family

Sm: Surface Material Volume – Volume from top to 10% bearing area

$$Sm = \left(\frac{V_m(h_{0.10})}{A} \right)$$

Sc: Core Void Volume – Volume enclosed 10%-80% bearing area

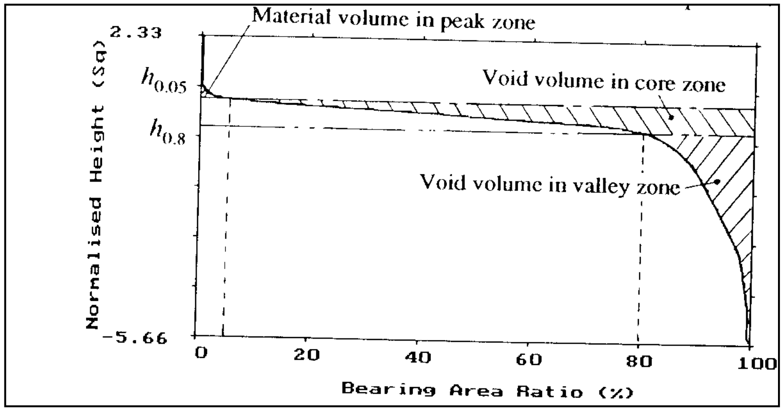
$$Sc = \left(\frac{V_v(h_{0.10}) - V_v(h_{0.80})}{A} \right)$$

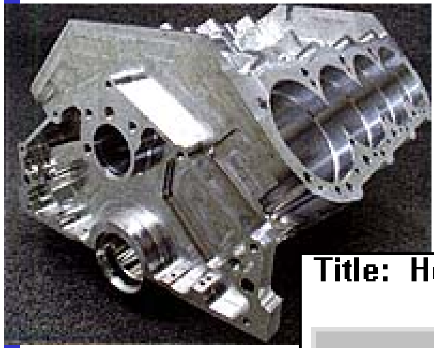


Functional Parameters for Bearing and Fluid Retention Properties
Volume FAMILY

Sv: Surface Void Volume – Volume from 80% to 100% bearing area

$$Sv = \left(\frac{V_v(h_{0.80}) - V_v(h_{1.00})}{A} \right)$$





3D Texture Parameters

Title: Honed Cylinder **Note:**

S Parameter Analysis

Amplitude Parameters

Sa: 286.40 nm

Sq: 456.44 nm

Ssk: -3.46

Sku: 27.13

Sz: 3.34 um

Spatial Parameters

Sds: 317.5306 /mm2

Str: 0.08

Sal: 23.28 um

Std: -70.00 deg

StdMinor: 71.00 deg

Hybrid Parameters

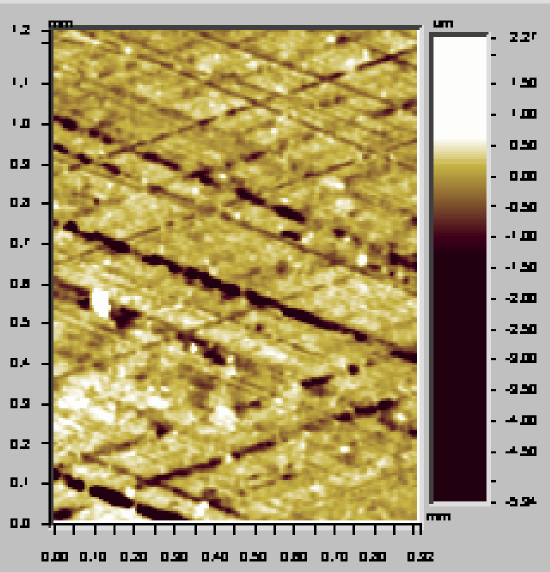
Sdq: 2.86 deg

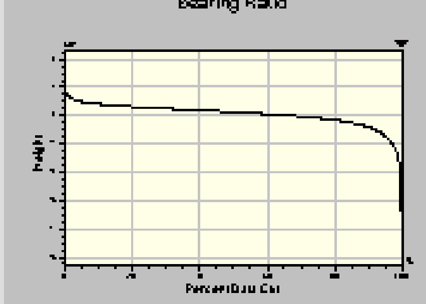
Ssc: 6.83 /mm

Sdr: 0.12438972 %

Functional Parameters

Index Family	Volume Family
Sbi: 0.991	Sm: 0.000013 mm3/mm2
Sci: 0.817	Sc: 0.000296 mm3/mm2
Svi: 0.187	Sv: 0.000085 mm3/mm2





Processed Options:

Terms Removed:

Cylinder & Tilt

Filtering:

Low Pass

"The Birmingham 14 + 3 +" 3D Texture Parameters "S" Parameters

Amplitude

Sa: The average deviation of the surface
Sq: The Root-mean-square deviation of the surface
Ssk: Skewness of surface height distribution
Sku: Kurtosis of surface height distribution
Sz: Ten Point Height of the Surface

Spatial

Sds: Density of Summits
Str: Texture Aspect Ratio
Sal: Fastest Decay Autocorrelation Length
Std: Texture Direction of Surface

Hybrid

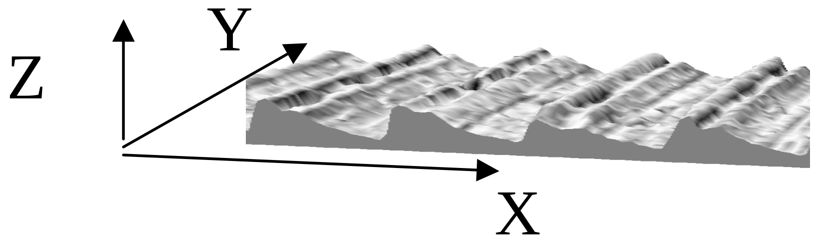
SΔq: Root-Mean_Square Surface Slope
Ssc: Mean Summit Curvature
Sdr: Developed Surface Area Ratio

Functional

Sbi: Surface Bearing Index
Sci: Core Fluid Retention Index
Svi: Valley Fluid Retention Index

Sm: Surface Material Volume
Sc: Core Void Volume
Sv: Valley Void Volume

“The Birmingham 14” **3D Texture Parameters** “S” Parameters



<u>Future Direction</u>

Improving definition of the “14” (e.g. summits etc.)

New “Tribology” parameters – reservoirs- flow connectibility

Contact Mechanics – asperity shape unloaded/loaded,saddle points, ridges, valleys, peaks etc.

Surface Texture Parameters

References

Surface Texture (Surface Roughness, Waviness and Lay)
ANSI/ASME B46.1, 1995, American Society of Mechanical Engineers,
NY, New York 10017.

Leigh Mummery, Surface Texture Analysis The Handbook, Hommelwerke GmbH, 1992

H. Dagnall, Exploring Surface Texture, Rank Taylor Hobson, 1986.

D. J. Whitehouse, Handbook of Surface Metrology, Institute of Physics, Bristol, 1994.

K. J. Stout, P.J. Sullivan, W. P. Dong, E. Mainsah, N. Luo, T Mathia, and
H. Zahouni, The Development of Methods for the Characterisation of Roughness in
Three Dimensions.Publication no. EUR 15178 EN, ISBN 0 7044 13132, ECSC-EEC-EAEC,
Brussels-Luxembourg and Authors, 1993

DIN 4776. 1990, Measurement of Surface Roughness; parameters Rk, Rpk, Rvk, Mrq, Mr2,
for the description of the material portion (profile bearing length ratio) in the Roughness Profile;
Measuring conditions and evaluation procedures.