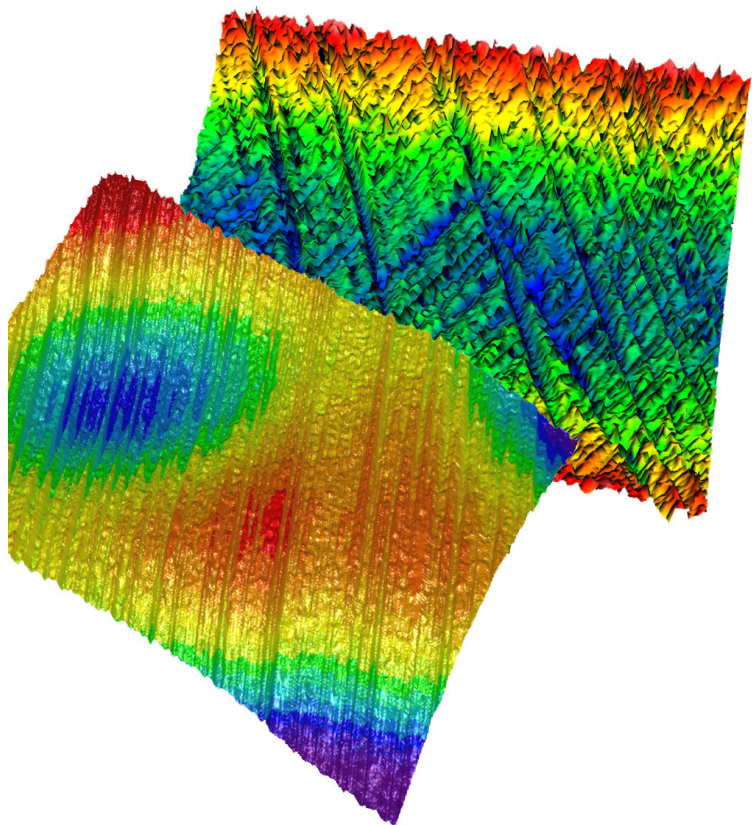


zygo[®]



Surface
Texture
Parameters

Understanding Surface Texture Parameters

Every part's surface is made up of texture and roughness which varies due to manufacturing techniques and the part structure itself. To understand a component's surface and to control the manufacturing process to the degree required in today's modern world, it is necessary to quantify the surface in both two and three dimensions.

Surface texture parameters can be grouped into these basic categories: Roughness, Waviness, Spacing, and Hybrid.

Terminology

Areal- A three dimensional surface area.

Cutoff Filter- Determines the wavelength at which the surface structure is differentiated between roughness and waviness data. Proper selection of the correct filter cutoff in software is critical to measurement accuracy. (λ_c)

Evaluation Length- The area from which data is obtained. It is a three dimensional area that corresponds to the instrument field of view, or a two dimensional profile that corresponds to the length of the slice as defined in the filled plot. (L_n)

Hybrid Parameters- These parameters are combinations of spacing and roughness parameters.

Mean Line- A straight line that is generated by calculating a weighted average for each data point resulting in equal areas above and below the line. Also known as center line.

Profile- A two dimensional slice through an area.

Roughness Parameters - The non-periodic finer irregularities in the surface texture which are inherent in the production process. These are a measure of the vertical characteristics of the surface.

Sampling Length- The area selected for assessment and evaluation of the roughness parameter having the cutoff wavelength. Any surface irregularities spaced farther apart than the sampling length are considered waviness. Also known as cutoff length. (L_r)

Spacing Parameters- A measure of the horizontal or lateral periodic characteristics of the surface.

Surface Texture- The topography of a surface composed of certain deviations that are typical of the real surface. It includes roughness and waviness.

Waviness Parameters - A larger component of surface texture upon which roughness is superimposed.



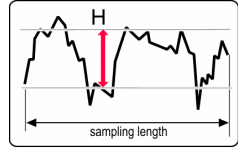
Some parameters show alternate names in parentheses.

Contents

| | |
|--|-------------|
| Roughness Parameters | <i>page</i> |
| H ISO Flatness Pt ISO R3z | 4 |
| R3z ISO Ra Rku Rq Rmax ISO Rp | 5 |
| Rpm ISO Rq Rt Rtm Rtm ISO | 6 |
| Rv Rvm ISO Ry Rz Rz ISO | 7 |
| SPt ISO SR3z ISO SRmax ISO SRpm ISO | 8 |
| SRtm ISO SRvm ISO SRz | 8 |
| SRz ISO SRzX SRzY | 9 |
| | |
| Waviness Parameters | |
| Wa Wq Wy | 9 |
| | |
| Spacing Parameters | |
| Pc Peak Density Peak Spacing S Sm | 10 |
| Summits Summit Density Summit Spacing | 10 |
| Valleys Valley Density Valley Spacing | 11 |
| | |
| Hybrid Parameters | |
| Δ_a Δ_q Δ_{tm} Ia Iq Iy | 11 |
| Rvolume RSurfAreaRatio | 12 |
| WSurfAreaRatio ISurfAreaRatio | 12 |
| Bearing Ratio Parameters | |
| Bearing Ratio (Tp) Rk Rk Midpoint | 12 |
| Rpk Rpk Threshold Rvk Rvk Threshold | 12 |
| Mr1 Mr2 V1 V2 Stp1 (%) Stp2 (%) | 13 |
| Stp3 (%) Upper Stp (%) Lower Stp (%) | 13 |
| Delta Stp (%) Stp1 Height Stp2 Height Stp3 Height | 14 |
| Upper Stp Height Lower Stp Height SHtp Mean SHtp | 14 |
| tp1 (%) tp2 (%) tp3 (%) Upper tp (%) Lower tp (%) | 15 |
| Delta tp (%) tp1 Height tp2 Height tp3 Height | 15 |
| Upper tp Height Lower tp Height Htp Mean Htp | 16 |
| Material Probability Parameters | |
| Rpq Rvq Rmq (%) Height UPL | 16 |
| Height LPL Height UVL Height LVL | 17 |
| Std UPL Std LPL Std UVL Std LVL | 17 |
| Other Hybrid Parameters | |
| Rsk | 17 |
| ACF | 18 |
| | |
| Selection of Cutoff Filter λ_c | 18 |

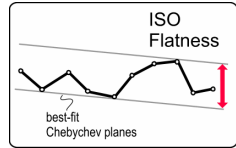
Roughness Parameters

H Swedish height. The roughness between two predefined reference lines. The upper line exposes 5% of the data, and the lower line exposes 90%. H is less sensitive to data spikes than R_t . Available for profile and areal data.

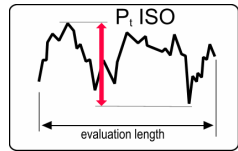


ISO Flatness

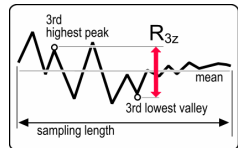
Areal flatness deviation. The measure of surface deviation from perfectly flat. It is the distance between two parallel planes obtained by applying a Chebychev fit to the surface data. The Chebychev fit is a mathematical technique that effectively uses two parallel planes to “squeeze” the surface data points from both inside and outside, adjusting the angle to minimize the distance between the planes.



Pt ISO Total peak-to-valley profile height. The distance between the highest peak and the deepest valley over the entire evaluation length. The profile data has form removed but is unfiltered.

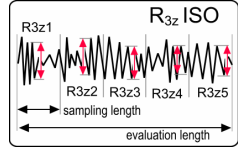


R_{3z} Base roughness depth. The distance between the third highest peak and the third lowest valley. A peak is a portion of the surface above the mean line and between center line crossings. Available for profile and areal data.

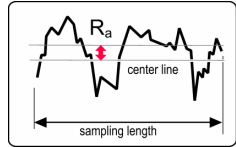


Roughness Parameters

R_{3z} ISO Base roughness profile depth. The height of the 3rd highest peak from the 3rd lowest valley per sampling length. The base roughness depth is found in five sampling lengths and then averaged.



R_a Arithmetical mean deviation. The arithmetic average of the absolute values of the roughness profile. Available for profile and areal data.

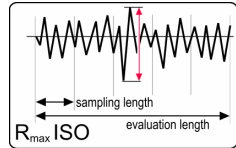


$$R_a = \frac{1}{L} \int_0^L |z(x)| dx$$

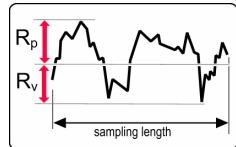
R_{ku} Kurtosis is a measure of the randomness of heights, and of the sharpness of a surface. A perfectly random surface has a value of 3; the farther the result is from 3, the less random and more repetitive the surface is. Surfaces with spikes are higher values; bumpy surfaces are lower. Available for profile and areal data.

$$R_{ku} = \frac{1}{n(R_q)^4} \sum_{i=1}^{i=n} (Y_i)^4$$

R_{max} ISO Maximum peak-to-valley profile height. The greatest peak-to-valley distance within any one sampling length.

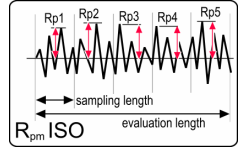


R_p (Peak) Highest peak. The maximum distance between the mean line and the highest point within the sample. It is the maximum data point height above the mean line through the entire data set. Available for profile and areal data.



Roughness Parameters

R_{pm} Mean peak profile height.
ISO The mean peak height based on one peak per sampling length. The single highest peak is found in five sampling lengths and then averaged.



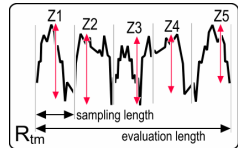
R_q (rms) Root-mean-square (rms) roughness. The average of the measured height deviations taken within the evaluation length or area and measured from the mean linear surface. Available for profile and areal data. R_q is the rms parameter corresponding to Ra.

$$R_q = \sqrt{\frac{1}{L} \int_0^L z^2(x) dx}$$

R_t (PV) Maximum peak-to-valley height. The absolute value between the highest and lowest peaks. Available for profile and areal data.

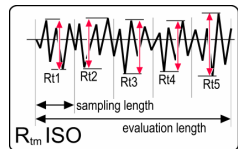
$$R_t = R_p + R_v$$

R_{tm} Mean peak-to-valley roughness. It is determined by the difference between the highest peak and the lowest valley within multiple samples in the evaluation area. For profile data it is based on five sample lengths. Available for profile and areal data.



$$R_{tm} = \frac{Z1 + Z2 \dots + Zn}{n}$$

R_{tm} (ISO) Mean peak-to-valley profile roughness. The mean peak-to-valley roughness based on one peak and one valley per sampling length. The single largest deviation is found in five sampling lengths and then averaged.

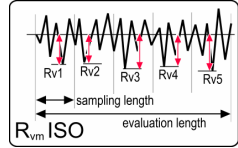


$$R_{tm} \text{ ISO} = \frac{Rt1 + Rt2 \dots + Rt5}{5}$$

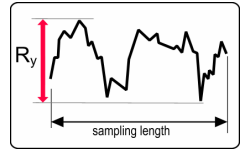
Roughness Parameters

**R_v
(Valley)** Lowest valley. The maximum distance between the mean line and the lowest point within the sample. It is the maximum data point height below the mean line through the entire data set. Available for profile and areal data. See R_p .

**R_{vm}
ISO** Mean valley profile depth. The mean valley depth based on one peak per sampling length. The single deepest valley is found in five sampling lengths and then averaged.

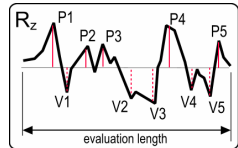


**R_y
(R_{max})** Maximum peak-to-valley roughness. The vertical distance between the top of the highest peak and the bottom of the deepest valley within the sampling length. It is the maximum of all the peak-to-valley values.

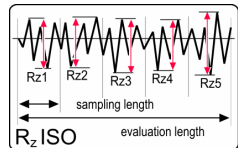


R_z Ten-point height. The average absolute value of the five highest peaks and the five lowest valleys over the evaluation length. Available for profile and areal data.

$$R_z = \frac{(P1 + P2 \dots P5) - (V1 + V2 \dots V5)}{5}$$



**R_z
ISO** Average peak-to-valley profile roughness. The average peak-to-valley roughness based on one peak and one valley per sampling length. The single largest deviation is found in five sampling lengths and then averaged. Identical to R_{tm} ISO.



Roughness Parameters



For S_ ISO parameters, a surface area is analyzed by fitting a minimum enclosing rectangle and applying a 5 x 5 sampling grid, for a total of 25 sampling areas. All sampling areas together make up the evaluation area.

SP_t
ISO Total peak-to-valley areal height. The distance between the highest peak and the deepest valley over the entire evaluation area.

SR_{3z}
ISO Base roughness areal depth. The height of the 3rd highest peak from the 3rd lowest valley per sampling area. The base roughness depth is found in each sampling area and then averaged.

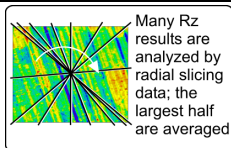
SR_{max}
ISO Maximum peak-to-valley height over the entire areal evaluation area.

SR_{pm}
ISO Mean peak areal height. The mean peak height based on one peak per sampling area. The single highest peak is found in each sampling area and then averaged.

SR_{tm}
ISO Mean peak-to-valley areal roughness. The mean peak-to-valley roughness based on one peak and one valley per sampling area. The single largest deviation is found in each sampling area and then averaged.

SR_{vm}
ISO Mean valley areal depth. The mean valley depth based on one peak per sampling area. The single deepest valley is found in each sampling area and then averaged.

SR_z Average radial peak-to-valley areal roughness. The average of the largest half of many individual Rz results determined by slicing the areal data array about its center through 360 degrees. The Rz results are sorted by magnitude and SR_z is calculated by averaging the largest 50% of the Rz values. A line-generation algorithm is used to determine the actual pixel-to-pixel path of each slice; there is no interpolation between pixels. SR_z covers the entire array, and due to its radial generation it is lay independent.



Roughness Parameters

SR_z Average peak-to-valley areal roughness. The average peak to valley roughness based on one peak and one valley per sampling area. The single largest deviation is found in each sampling area and then averaged.

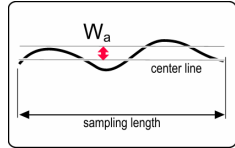
SR_{zX} The average of many individual R_z results, determined by slicing the data array in the x-axis. The individual R_z results are each based on a profile slice one pixel wide. SR_{zX} is based on the entire array. See SR_z.

SR_{zY} The average of many individual R_z results, determined by slicing the data array in the y-axis. The individual R_z results are each based on a profile slice one pixel wide. SR_{zY} is based on the entire array. See SR_z.

Waviness Parameters

W_a Arithmetical mean deviation. The arithmetic average of the absolute values of the waviness profile.

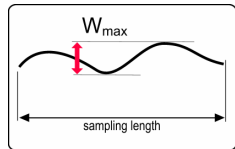
$$W_a = \frac{1}{L} \int_0^L |z(x)| dx$$



W_q The root-mean-square (rms) roughness of all points from a plane fit to the waviness data.

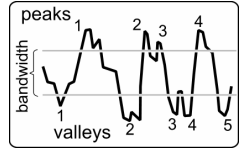
$$W_q = \sqrt{\frac{1}{L} \int_0^L z^2(x) dx}$$

W_y
(W_{max}) The maximum height of the waviness data.



Spacing Parameters

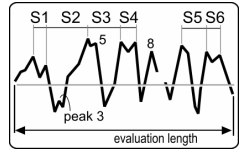
P_c (Peaks) Peak count or the number of peaks included in the analysis. A peak is defined as a data point whose height is above a software selected bandwidth.



Peak Density The number of peaks per unit area.

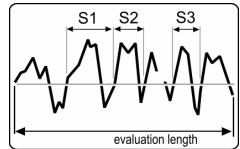
Peak Spacing The average distance between peaks.

S The average spacing between local peaks over the evaluation length. A local peak is the highest point between two adjacent minima. The average spacing for the example shown is calculated by:



$$S = \frac{S1 + S2... + S6}{6}$$

S_m The average spacing between peaks at the mean line over the evaluation length. A peak is the highest point between an upwards and downwards crossing of the mean line. It is calculated by summing all the peak spacing and dividing by the number of spaces.



Summits The number of summits included in the analysis. A summit is a point that is higher than the four nearest data points as determined by a software threshold value. The higher the threshold, the fewer and steeper the summits.

Summit Density The number of summits per unit area.

Summit Spacing The average distance between summits.

Spacing Parameters

| | |
|----------------|--|
| Valleys | The number of valleys included in the analysis. A valley is defined as a data point whose height is below a software selected bandwidth. See Pc. |
| Valley Density | The number of valleys per unit area. |
| Valley Spacing | The average distance between valleys. |

Hybrid Parameters

| | |
|------------------------------|--|
| Δ_a (Slope R_a) | The arithmetic average surface slope of the entire data matrix. Slopes are directly related to the reflective properties of the surface. They are useful for controlling cosmetic appearances of surfaces, as well as in controlling reflective surfaces. Results are available for overall slopes and in just the x or y axes. In mathematical symbols: |
|------------------------------|--|

$$\Delta_a = \frac{1}{L} \int_0^L \left| \frac{dy}{dx} \right| dx$$

| | |
|---------------------------------|---|
| Δ_q (Slope r_{ms}) | The geometric average slope of the entire data matrix. This result is similar to Δ_a except that individual slopes are averaged by the rms method rather than arithmetically, emphasizing more extreme slopes. Results are available for overall slopes and in just the x or y axes. |
|---------------------------------|---|

| | |
|------------------------------------|--|
| Δ_{tm} (Slope R_{tm}) | The average peak-to-valley slope of nine sample areas on the entire data matrix. Results are available for overall slopes and in just the x or y axes. |
|------------------------------------|--|

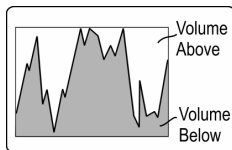
| | |
|-------|--|
| I_a | The average surface height, or average deviation, of all points from a plane fit to the input data. Input data is the data obtained by the instrument; it includes roughness and waviness information. |
|-------|--|

| | |
|-------|--|
| I_q | The root-mean-square deviation of all points from a plane fit to the input data. Input data includes roughness and waviness information. |
|-------|--|

| | |
|------------------------|---|
| I_y (I_{max}) | The maximum height of the input data. Input data includes roughness and waviness information. |
|------------------------|---|

Hybrid Parameters

R_{Volume} The volume of the roughness data as specified by software as above or below the surface.



$R_{\text{SurfAreaRatio}}$ The ratio of roughness surface area to the planar area occupied by the data.

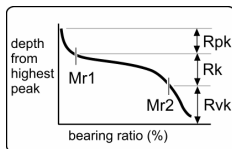
$W_{\text{SurfAreaRatio}}$ The ratio of waviness surface area to the planar area occupied by the data.

$I_{\text{SurfAreaRatio}}$ The ratio of input surface area to the planar area occupied by the data.

Bearing Ratio Parameters

Bearing Ratio (T_p) Bearing ratio is the ratio (expressed as a percentage) of the length of the bearing surface at any specified depth in the evaluation area. It simulates the effect of wear on a bearing surface. Bearing Ratio results are available for profile data (t_p) and surface area (St_p).

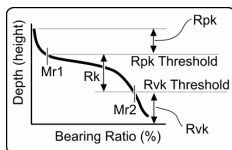
R_k Core Roughness Depth - The long term running surface which will influence the performance and life of the bearing surface.



R_k Midpoint The middle point of the R_k region; it is an absolute height.

R_{pk} Reduced Peak Height - The top portion of the surface that will be worn away in the run-in period.

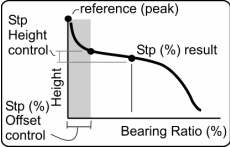
R_{pk} Threshold The threshold between the R_{pk} and R_k regions; it is an absolute height.



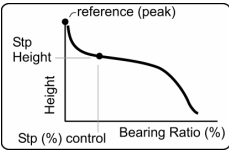
R_{vk} Reduced Valley Depth - The lowest part of the surface that retains lubricant.

R_{vk} Threshold The threshold between the R_k and R_{vk} regions; it is an absolute height.

Hybrid Parameters

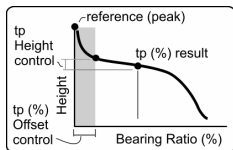
| | |
|---------------|---|
| M_{r1} | Peak Material Component - The material ratio at which R_{pk} and R_k meet. It represents the upper limit of the core roughness profile. This parameter is derived from the bearing ratio plot. |
| M_{r2} | Valley Material Component - The material ratio at which R_{vk} and R_k meet. It represents the lower limit of the core roughness profile. This parameter is derived from the bearing ratio plot. |
| V_1 | Volume 1 - the volume of the material that will be removed during the run-in period. Part of the bearing ratio analysis. |
| V_2 | Volume 2 - The potential volume of retained lubricant. Part of the bearing ratio analysis. |
| Stp1 (%) | <p>The areal bearing ratio (expressed as a percentage) at the height specified by the Stp1 Height control, relative to the selected Stp Reference location and Stp1 (%) Offset value.</p>  |
| Stp2 (%) | The areal bearing ratio (expressed as a percentage) at the height specified by the Stp2 Height control, relative to the selected Stp Reference location and Stp2 (%) Offset value. |
| Stp3 (%) | The areal bearing ratio (expressed as a percentage) at the height specified by the Stp3 Height control, relative to the selected Stp Reference location and Stp3 (%) Offset value. |
| Upper Stp (%) | The areal bearing ratio (expressed as a percentage) at the location specified by the Upper Stp Height control, relative to the selected Stp Reference location. |
| Lower Stp (%) | The areal bearing ratio (expressed as a percentage) at the location specified by the Lower Stp Height control, relative to the selected Stp Reference location. |

Hybrid Parameters

| | |
|-----------------------------|---|
| Delta Stp (%) | The difference in the areal bearing ratio (expressed as a percentage) between the Upper and Lower Stp (%) values. |
| Stp1 Height | The height of the areal bearing ratio curve where it intersects the percentage specified by the Stp1 (%) control, relative to the selected Stp Reference location. |
| |  |
| Stp2 Height | The height of the areal bearing ratio curve where it intersects the percentage specified by the Stp2 (%) control, relative to the selected Stp Reference location. |
| Stp3 Height | The height of the areal bearing ratio curve where it intersects the percentage specified by the Stp3 (%) control, relative to the selected Stp Reference location. |
| Upper Stp Height | The height of the areal bearing ratio curve at the location specified by the Upper Stp (%) control, relative to the selected Stp Reference location. |
| Lower Stp Height | The height of the areal bearing ratio curve at the location specified by the Lower Stp (%) control, relative to the selected Stp Reference location. |
| SH_{tp} | Height between two points on the areal bearing ratio curve as specified by the Upper Stp (%) and Lower Stp (%) controls. It is used to help determine material removal over multiple processes. |
| Mean SH_{tp} | The average of all the height values between the two points on the areal bearing ratio curve specified by the Upper Stp (%) and Lower Stp (%) controls. |

Hybrid Parameters

tp1 (%) The profile bearing ratio (expressed as a percentage) at the height specified by the tp1 Height control, relative to the selected tp Reference location and the tp1 (%) Offset control value.



tp2 (%) The profile bearing ratio (expressed as a percentage) at the height specified by the tp2 Height control, relative to the selected tp Reference location and the tp2 (%) Offset control value.

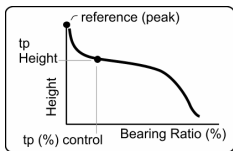
tp3 (%) The profile bearing ratio (expressed as a percentage) at the height specified by the tp3 Height control, relative to the selected tp Reference location and the tp3 (%) Offset control value.

Upper tp (%) The profile bearing ratio (expressed as a percentage) at the location specified by the Upper tp Height control, relative to the selected tp Reference location.

Lower tp (%) The profile bearing ratio (expressed as a percentage) at the location specified by the Lower tp Height control, relative to the selected tp Reference location.

Delta tp (%) The difference in the profile bearing ratio (expressed as a percentage) between the Upper and Lower tp (%) values.

tp1 Height The height of the profile bearing ratio curve where it intersects the percentage specified by the tp1 (%) control, relative to the selected tp Reference location.



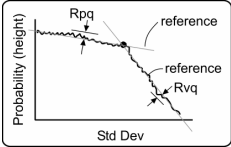
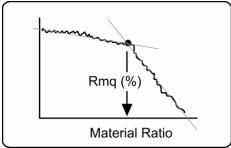
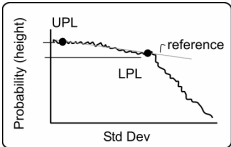
tp2 Height The height of the profile bearing ratio curve where it intersects the percentage specified by the tp2 (%) control, relative to the selected tp Reference location.

tp3 Height The height of the profile bearing ratio curve where it intersects the percentage specified by the tp3 (%) control, relative to the selected tp Reference location.

Hybrid Parameters

| | |
|-----------------|---|
| Upper tp Height | The height of the profile bearing ratio curve where it intersects the percentage specified by the Upper tp (%) control, relative to the selected tp Reference location. |
| Lower tp Height | The height of the profile bearing ratio curve where it intersects the percentage specified by the Lower tp (%) control, relative to the selected tp Reference location. |
| H_{tp} | Height between two points on the profile bearing ratio curve as specified by the Upper tp (%) and Lower tp (%) controls. |
| Mean H_{tp} | The average of all the height values between the two points on the profile bearing ratio curve specified by the Upper tp (%) and Lower tp (%) controls. |

Material Probability Parameters

| | | |
|--------------|--|---|
| R_{pq} | The root-mean-square average of the height deviations in the peak or plateau portion of the Material Probability plot. |  <p>The diagram shows a Material Probability plot with 'Probability (height)' on the y-axis and 'Std Dev' on the x-axis. A downward-sloping curve is shown. Two points are marked on the curve: one on the upper, flatter portion labeled 'R_{pq}' and one on the lower, steeper portion labeled 'R_{vq}'. Two horizontal dashed lines are labeled 'reference'.</p> |
| R_{vq} | The root-mean-square average of the height deviations in the valley portion of the Material Probability plot. This result is useful as a predictor of original surface roughness before the removal of more material in subsequent processes. See R_{pq} . | |
| R_{mq} (%) | The material ratio (expressed as a percentage) at the peak-to-valley transition. |  <p>The diagram shows a Material Probability plot with 'Material Ratio' on the x-axis. A downward-sloping curve is shown. A point is marked on the curve at the transition between the flatter upper portion and the steeper lower portion, labeled 'R_{mq} (%)'. A vertical arrow points from this point down to the x-axis.</p> |
| Height UPL | The height at the upper peak or plateau limit. UPL is set with inspectors in the Material Probability plot. |  <p>The diagram shows a Material Probability plot with 'Probability (height)' on the y-axis and 'Std Dev' on the x-axis. A downward-sloping curve is shown. Two points are marked on the curve: one on the upper, flatter portion labeled 'UPL' and one on the lower, steeper portion labeled 'LPL'. A horizontal dashed line is labeled 'reference'.</p> |

Hybrid Parameters

| | | |
|------------|---|--|
| Height LPL | The height at the lower peak or plateau limit in the Material Probability analysis. | |
| Height UVL | The height at the upper valley limit in the Material Probability analysis. | |
| Height LVL | The height at the lower valley limit. LVL is set with inspectors in the Material Probability plot. | |
| Std UPL | The standard deviation at the upper peak or plateau limit. UPL is set with inspectors in the Material Probability plot. | |
| Std LPL | The standard deviation at the lower peak or plateau limit in the Material Probability analysis. | |
| Std UVL | The standard deviation at the upper valley limit in the Material Probability analysis. | |
| Std LVL | The standard deviation at the lower valley limit. LVL is set with inspectors in the Material Probability plot. | |

Other Hybrid Parameters

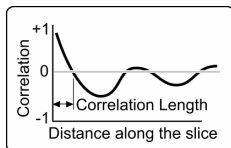
R_{sk} Skewness. A measure of symmetry of the profile about the mean line. Negative skew indicates a predominance of valleys, while positive skew indicates a “peaky” surface. Bearing surfaces should have negative skew.

$$R_{sk} = \frac{1}{n(R_q)^3} \sum_{i=1}^{i=n} (Y_i)^3$$

Hybrid Parameters

ACF
(Auto-covariance)

Autocorrelation function or Autocovariance. Used to determine the periodicity of a surface; it shows the dominant spatial frequencies along a cross section of the test surface. ACF is a measure of “self-similarity” of a profile - the extent to which a surface waveform pattern repeats. If the surface is random, the plot drops rapidly to zero. If the plot oscillates around zero in a periodic manner, then the surface has a dominant spatial frequency. Correlation Length is the length along the x-axis where the Autocovariance function first crosses zero.



$$ACF = \sum_{i=1}^{N-m} Y_i Y_{i+m}$$

Selection of Cutoff Filter λ_c

DIN EN ISO 4288, ASME B46.1

| Spacing (periodic) | Roughness (non-periodic) | | Cutoff λ_c (mm) | Sampling Length/ Evaluation Length |
|-----------------------|-----------------------------|----------------------|----------------------------|---------------------------------------|
| | Rz (μm) | Ra (μm) | | |
| Sm (mm) | Rz (μm) | Ra (μm) | λ_c (mm) | L_r / L_n (mm) |
| > 0.013...0.04 | > 0.025...0.1 | > 0.006...0.02 | 0.08 | 0.08 / 0.4 |
| > 0.04...0.13 | > 0.1...0.5 | > 0.02...0.1 | 0.25 | 0.25 / 1.25 |
| > 0.13...0.4 | > 0.5...10 | > 0.1...2 | 0.8 | 0.8 / 4 |
| > 0.4...1.3 | > 10...50 | > 2...10 | 2.5 | 2.5 / 12.5 |
| > 1.3...4 | > 50...200 | > 10...80 | 8 | 8 / 40 |

The Roughness Profile results are from high-pass filtering the primary profile according to the cutoff selection for λ_c (DIN EN ISO 4288, ASME B46.1). This results in the cut-off of the long-wave portion of the profile. The resulting parameters can be identified by R.

Compliance with International Standards

ZYGO is an industrial leader in surface texture metrology and complies with numerous international standards for surface texture parameters, including:

- ANSI The American National Standards Institute
- ISO International Standards Organization
- JIS Japanese Industry Standard

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