WYKO Surface Profilers Technical Reference Manual

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Metrology Group

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Document Conventions

General Conventions

- Your system hardware operates with the WYKO® Vision32™ software application under Microsoft® Windows NT™. You can also run WYKO Vision32 independently of hardware under Microsoft Windows 95™ or NT.

  WYKO Vision32 follows all Windows 95/NT commands and conventions of use. If you need a refresher on how to work in the Windows 95 or NT environment, please refer to your Windows software guide.

- When text indicates that you should enter a key combination (such as ALT-A), press and hold down the appropriate command key (in this case ALT) and then press the other indicated key.
- You can perform three basic actions with the buttons on your mouse: *clicking*, *double-clicking*, and *dragging*. To *click*, press and release the mouse button. To *double-click*, press and release the mouse button twice in rapid succession. To *drag*, press and hold down the mouse button while you move the mouse across your desktop.
- Menus are listings of commands or functions that are available to you at certain times. To open a menu, position the mouse pointer over a menu bar title and click on it with the mouse. A menu will pop down from the menu bar. You can then select a command from the menu by clicking on it.
- Shortcut menus are available by clicking with the *right* mouse button on a plot (such as the 3D, Contour, or Profile plot). You can then select options from the shortcut menu that appears.
- In this manual, the commands you select from pop-down menus are displayed in the following format: **Hardware » Measurement Options**. The double arrow symbol (») indicates menu flow as it cascades down from the menu title.

Typeface Conventions

This manual uses certain typeface conventions that provide visual cues to help you more easily locate and identify information.

boldface	Menu titles, commands, icons, and check box and button names are shown in **boldface** type.
italic type	*Italic type* indicates new terms, title and heading references, and shows emphasis.
`monospace type`	Code examples and commands that you must type in exactly as they appear are shown in `monospaced type`.
Small Capitals	Hardware placards and keyboard key labels are shown in Small Capitals (such as Esc, Enter, Alt, etc.).
Notes	Notes contain information that can assist you in using the equipment. An example is shown below:

☞ If you do not want to use the existing configuration file, you will need to set up a configuration file of your own.

CAUTIONS	Whenever you see a **CAUTION**, there is a possiblity that data will be lost, or there is some specific action you must perform for the system to work properly. An example is shown below:

CAUTION

If you do not specifically save your changes using the Save command, they will be lost.

WARNINGS	Whenever you see a warning, there is the possibility of personal injury or equipment damage. An example is shown below:

WARNING

Failure to follow these precautions could result in electrical shock or damage to equipment circuitry.

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Chapter 1

How the Wyko Surface Profilers Work

This chapter explains how Wyko surface profilers measure both smooth and rough surfaces. It also discusses system performance, and provides a list of additional technical references.

Theory of Operation

Wyko surface profiler systems are non-contact optical profilers that use two technologies to measure a wide range of surface heights. Phase-shifting interferometry (PSI) mode allows you to measure smooth surfaces and small steps, while vertical scanning interferometry (VSI) mode allows you to measure rough surfaces and steps up to several millimeters high.

PSI Mode

Phase-shifting interferometry (PSI) is not a new technique. Wyko has used it for several years to accurately measure smooth surfaces. In phase-shifting interferometry, a white-light beam is filtered and passed through an interferometer objective to the test surface. The interferometer beamsplitter reflects half of the incident beam to the reference surface within the interferometer. The beams reflected from the test surface and the reference surface recombine to form interference fringes. These fringes are the alternating light and dark bands you see when the surface is in focus. Figure 1-1 shows a diagram of an interference microscope.

During the measurement, a piezoelectric transducer (PZT) linearly moves the reference surface a small, known amount to cause a phase shift between the test and reference beams. The system records the intensity of the resulting interference pattern at many different relative phase shifts, and then converts the intensity to wavefront (phase) data by integrating the intensity data.

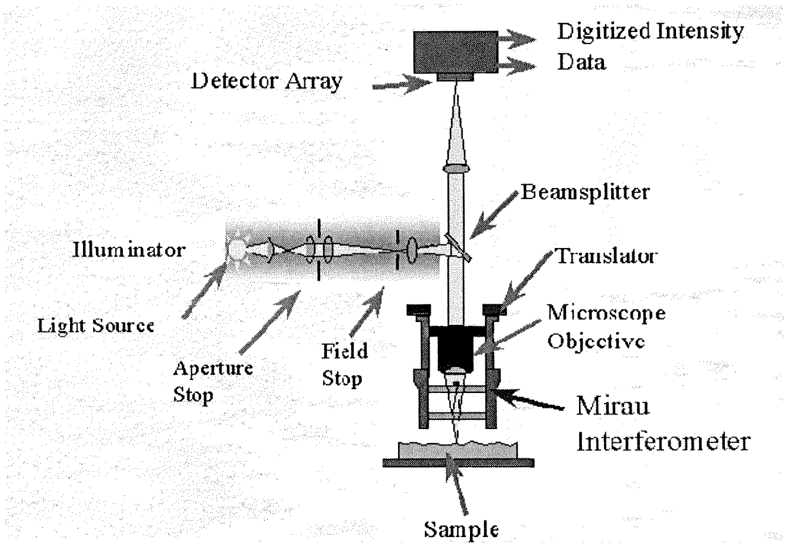

Figure 1-1. An Interference Microscope

The phase data are processed to remove phase ambiguities between adjacent pixels, and the relative surface height can be calculated from the phase data as follows:

$$h(x, y) = \frac{\lambda}{4\pi}\phi(x, y)$$

where λ is the wavelength of the source beam, and $\phi(x,y)$ is the phase data.

This technique for resolving surface heights is reliable when the fringe pattern is sufficiently sampled. When the surface-height difference between adjacent measurement points is greater than $\lambda/4$, height errors in multiples of $\lambda/2$ may be introduced and the wavefront cannot be reliably reconstructed. Thus, conventional phase-shifting interferometry is limited to fairly smooth, continuous surfaces. To resolve rougher surfaces, Wyko surface profilers use vertical-scanning interferometry techniques.

VSI Mode

A newer technique than PSI, vertical scanning interferometry was developed at Wyko[1]. The basic interferometric principles are similar in both techniques: light reflected from a reference mirror combines with light reflected from a sample to produce interference fringes, where the best-contrast fringe occurs at best focus. However, in VSI mode, the white-light source is filtered with a neutral desnity filter, which preserves the short coherence length of the white light, and the system measures the degree of fringe modulation, or coherence, instead of the phase of the interference fringes.

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[1] Patent Numbers 5,133,601; 5,204,734; 5,355,221

In VSI, the irradiance signal is sampled at fixed intervals as the optical path difference (OPD) is varied by a continuous translation of the vertical axis through focus. Low-frequency components are first removed from the signal; the signal is rectified by square-law detection, then filtered. Finally, the peak of the low-pass filter output is located and the vertical position that corresponds to the peak is recorded. To increase the resolution of the measurement beyond the sampling interval, a curve-fitting interpolation technique is used.

The interferometric objective moves vertically to scan the surface at varying heights. A motor with feedback from an LVDT (linear variable differential transformer) precisely controls the motion. Because white light has a short coherence length, interference fringes are present only over a very shallow depth for each focus position. Fringe contrast at a single sample point reaches a peak as the sample is translated through focus. As seen in Figure 1-2, the fringe contrast, or modulation, increases as the sample is translated into focus, then falls as it is translated past focus.

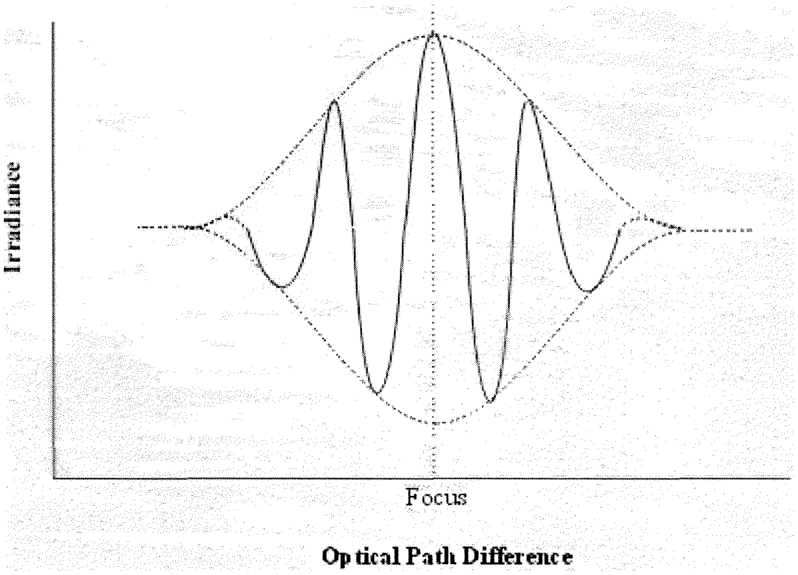


Figure 1-2. Fringe Contrast through Focus

The system scans through focus (starting above focus) as the camera captures frames of interference data at evenly-spaced intervals. As the system scans downward, an interference signal for each point on the surface is recorded. The system uses a series of advanced computer algorithms to demodulate the envelope of the fringe signal. Finally the vertical position corresponding to the peak of the interference signal is extracted for each point on the surface. A block diagram of the algorithm used in VSI is shown in Figure 1-3.

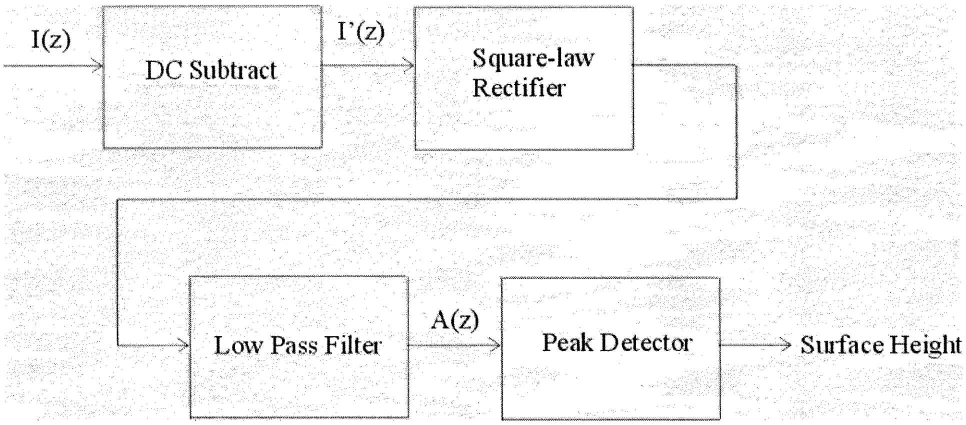


Figure 1-3. VSI Algorithm

Operational Differences Between PSI and VSI

It is important that you understand the differences between the two measurement techniques so you know when and how to use each technique.

The differences between VSI and PSI mode are summarized below. The significance of these differences is explained in the sections following the summary.

Table 1-1. Operational Differences Between PSI and VSI Measurement

VSI	PSI
Neutral Density filter for white light	Narrow bandwidth filtered light
Vertically scans — the objective actually moves through focus	Phase-shift at a single focus point — the objective does not move
Processes fringe modulation data from the intensity signal to calculate surface heights	Processes phase data from the intensity signal to calculate surface heights

Why Do VSI and PSI Use Different Types of Light?

The light for both techniques originates from a white-light source; however, it is filtered during PSI measurements to produce red light at a nominal wavelength of 632 nm. VSI measurements use a neutral density filter, preserving the short coherence length of the white light.

Because white light has a short coherence length, the fringe contrast is highest at best focus but falls off rapidly as you move away from focus. *A white-light source works best for vertical-scanning interferometry* because the technique requires high modulation at a precise focus point.

On the other hand, white-light focusing does not work well for phase-shifting interferometry. If you were to use white light during a measurement, a single high-contrast fringe (the zero order fringe) would fill most or all of the array. Because the contrast drops off rapidly on either side of this fringe, the intensity modulation would be low in some regions when phase-shifting occurs. *A filtered light source works best for phase-shifting interferometry* because it has a longer coherence length than white light, so high-contrast fringes are present through a larger depth of focus. This increases the accuracy of your measurements, especially when the objective has a short depth of focus or the sample has tilt that cannot be removed easily.

☞ You can experiment with different types of light while focusing and finding fringes. If you have trouble finding fringes, use red light so more fringes will be visible. If you want to verify the precise focus location, use white light and center the highest-contrast fringe. Be certain to return to the proper measurement filter before taking the measurement.

How Do Scanning and Focusing Differ for PSI and VSI?

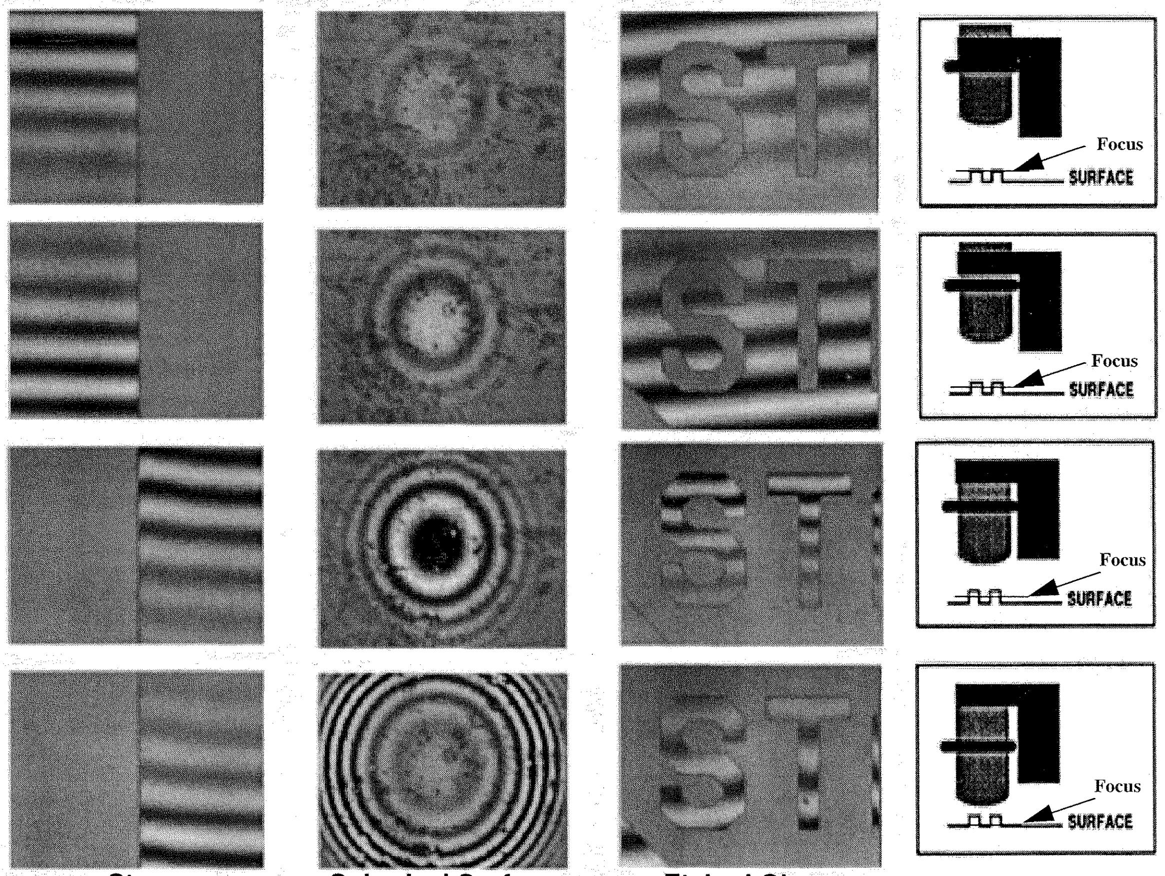
In phase-shifting interferometry, the objective does not move through focus. Instead, you focus on the sample so the region of interest is at precise focus, then you make the measurement. During the measurement, the PZT causes a slight shift between the reference and sample beams. The measurement is very quick.

You can find precise focus by using unfiltered white light and looking for the zero-order fringe. When you center this high-contrast fringe, you are at precise focus. (Be certain to switch to filtered light to make the measurement.)

In vertical-scanning interferometry, the internal optical assembly and the magnification objective move through focus in a controlled manner. The detector measures the modulation corresponding to every focus point on the surface as the objective moves vertically. Before you start the measurement, you position the objective at or slightly above focus. After starting the measurement, the system scans downward a specified amount. You must make sure this amount covers the vertical distance you want to scan. The measurement takes a few seconds.

As the system scans through focus, you will see how the focus of the image changes. The plane in which the highest-contrast fringe is visible is the plane at which focus is the most precise, and this plane changes as the surface is scanned. Figure 1-4 shows how fringes would look on various samples as the system moves downward through focus. The top frame shows focus on the highest features; the bottom frame shows focus on the lowest features.

☞ In PSI mode, you can use the **Autofocus** option to automatically focus the objective on the sample. During an autofocus measurement, the objective moves up a specified distance from rough focus, then scans down through focus (up to 100 μm) until the highest-contrast fringe is detected. Since the focal plane changes during a VSI measurement, Autofocus is unnecessary.



Step Spherical Surface Etched Glass

Figure 1-4. Fringe Progression on Various Samples

VSI + PSI

For some samples with both smooth and rough surface features, you can use the two modes together in the same measurement. The combined measurement mode is VSI + PSI mode. VSI + PSI mode works well for samples such as step heights, where the vertical resolution of VSI is required to measure the abrupt height change, and the lateral resolution of PSI is required to resolve the fine features on the surface of the step. VSI + PSI mode is intended for samples in which the height change between adjacent pixels is greater than 160 nm—it does not work for samples with gradual surface height changes.

When you measure a step height sample with VSI + PSI mode, the system first makes a PSI measurement to resolve the surfaces of the steps. Then the system automatically switches to VSI mode and makes another measurement to determine the relative heights of the steps. The program performs a step height adjustment on the PSI data according to the VSI step height data, then discards the VSI data. The result is accurate and repeatable step height and surface roughness data.

System Performance

The following sections briefly describe the range, resolution, and accuracy of your profiler system.

The performance of you system depends to some extent on your measurement technique. To obtain optimum system performance, always use a well-calibrated system and consistent measurement techniques.

Range

Range refers to the greatest vertical distance the profiler can accurately measure. The limits of dynamic range for each mode are listed in Table 1-2. These two modes allow you to measure a wide range of smooth and rough surfaces.

In PSI, six intensity frames of data are recorded as the PZT is moved a distance of $\pi/2$, or $\lambda_0/4$[2], between each frame. The system determines phase data from the intensity data, then calculates surface heights. The surface height data is then integrated to remove 2π effects. If the surface is smooth and continuous, such that integration errors are not encountered, the resulting data is used directly to generate the surface map.

PSI is reliable for smooth surfaces in which the height change between two adjacent points is not more than approximately 160 nm ($\lambda_0/4$ for a nominal measurement wavelength of 640 nm). If you try to use PSI mode for higher steps, you will see integration errors (lines of discontinuity) in your data.

Table 1-2. Measurement Range for PSI and VSI Measurements

Mode	Range
PSI	160nm
VSI	2mm

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[2] λ_0 is the center wavelength of the bandpass filter, usually approximately 632 nm.

VSI is reliable for rougher surfaces, because the range is limited only by the scan length allowed by the internal linear translator.

Resolution

Resolution refers to the smallest distance the Wyko surface profilers can accurately measure. It can be in terms of lateral or vertical resolution.

Lateral Resolution

Lateral resolution is a function of the magnification objective and the detector array size you choose. Each magnification objective has its own optical resolution based on the magnification and numerical aperture (NA) of the objective. Optical resolution refers to the smallest surface feature the objective can distinguish.

If you select an objective and array configuration in which the detector sampling interval is much smaller than the optical resolution, you will be *oversampling* the surface. In this case, the resolution is optically limited. The resulting surface map may show blurry images because the features cannot be resolved optically. Generally, you should select a configuration in which the detector sampling interval is larger than the optical resolution. In this case, the resolution is limited by the detector. However, if the detector sampling interval is considerably larger than the optical resolution, you will be *undersampling* the surface, which could result in undetected surface features.

Vertical Resolution

Each mode has different resolution limits. Resolution values for PSI and VSI are listed in Table 1-3. The values are in terms of R_q and are based on measurements of a smooth surface (R_q of 1.5Å or less).

Table 1-3. Vertical Resolution of PSI and VSI

Mode	Vertical Resolution	
	Single Measurement	Multiple Measurements (Averaged)
PSI	3 Å	1 Å
VSI	3 nm	<1 nm

When you consider resolution, you must also consider the techniques you use when making the measurement. As you can see in Table 1-3., you get better resolution when you average multiple VSI measurements.

You can determine the vertical resolution of you system by taking the difference of two measurements from the same location on the sample. The resolution data is essentially the noise limit of you system, or the lowest vertical resolution you can obtain at that time. It should be a near-flat profile with an R_q value approaching the non-averaged values in Table 1-2.

☞ Making a difference measurement is sometimes referred to as "checking the repeatability." If the result shows a significant difference, the two measurements are not very repeatable.

To get the best resolution from your Wyko surface profiler, always use consistent and correct measurement techniques. Also make sure environmental noise is minimized by setting up the system as described in your operator's guide.

Accuracy

Accuracy refers to how closely a measured value matches the true value. It is determined relative to a known, traceable standard. You can check your system's accuracy by measuring a standard (such as a step height standard) and comparing the result to the true value. Veeco recommends you use a known standard that is traceable by NIST.

Accuracy can be compromised by measurement technique, miscalibration, and aberrations in the interferometer's optics. Make sure your system in well-calibrated by checking the calibration periodically and recalibrating if necessary. During VSI calibration, the measured value of a known step height standard is compared to the true value of the step height. If there is a deviation, the scanning mechanism corrects itself accordingly. During PSI calibration, a super-smooth mirror is measured to verify that the PZT is shifting the correct amount.

To correct for aberrations in the interferometer's optics, you can generate a measurement of the internal reference mirror and subtract it from your measurements. This removes aberrational effects, which are significant for very smooth surfaces. (In VSI mode, the option to subtract a reference is not available because the coarser vertical resolution masks the effects of optical aberrations in the system. Guidelines for determining when reference subtraction is beneficial are provided in Table 4-1, later in this manual. For more information about generating and subtracting a reference file. see the Setup Guide for your system.

Additional References

If you would like more information about interferometry, profiler technology, or system performance, refer to the literature listed below. Contact Veeco Metrology for literature not published in trade journals.

☞ Some of the following literate was written from experimental work performed with earlier versions of Wyko optical surface profilers. Because current profiler technology is based partly on earlier technology, the principles still apply.

Katherine Creath, "An Introduction to Phase-measurement Interferometry," WYKO Corporation Application Note 87-004, June, 1987.

"RST Linearity," WYKO Corporation Application Bulletin, 1993.

Paul J. Caber, "Optimization of the Linearity and Accuracy of RST Plus Measurements," poster paper presented at American Society of Precision Engineers, Seattle, WA, November, 1993.

Paul J. Caber, Stephen J. Martinek, and Robert J. Niemann, "A New Interferometric Profiler for Smooth and Rough Surfaces," *Proc. SPIE* 2088, October, 1993.

James C. Wyant, "How to Extend Interferometry from Rough-Surface Tests," *Laser Focus World*, 131-133, September, 1993.

Paul J. Caber, "Interferometric Profiler for Rough Surfaces," *Appl. Opt.* 32(19):3438-3441, July, 1993.

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Chapter 2

Surface Parameters

Wyko surface profiling systems compute several surface parameters that provide information about roughness and the surface profile. This chapter defines these parameters and discusses how you might be able to use them to learn more about your sample or manufacturing processes.

Introduction

This introductory section will familiarize you with some common surface topography and surface profile terms before we discuss the individual surface parameters.

Surface Topography

Surface topography is the three-dimensional representation of geometric surface irregularities. A surface can be curvy, wavy, rough, or smooth depending on the magnitude and spacing of the peaks and valleys, and how the surface is produced. Some general terms associated with topography and texture are roughness, waviness, and form.

- Roughness relates to the closely-spaced irregularities left on a surface from a production process, such as machining.
- Waviness is the component of texture upon which roughness is super-imposed. It relates to the more widely-spaced irregularities. Waviness can result from deflections or vibrations in an individual machine.
- Form relates to the general shape of a surface, as in a ball bearing where the surface has curvature (bow). It is the deviation from the nominal surface. Undesired form characteristics can be the result from insufficient rigidity in supporting the sample during the production process.

Roughness and waviness constitute surface texture, but form does not. In order to examine the finer detail in a surface, you must separate the form component. (Your profiler system provides a way to do this. For more information, see *Terms Removal* on page 4-2.)

Surface texture[1] is a key factor affecting the functionality and reliability of certain components. Surface measurement can be a diagnostic tool for monitoring the processes that produced the component. For example, the effectiveness of a grinding process can be gauged by the surface texture of the ground part.

In a sense, the surface texture is a "fingerprint" of the manufacturing process. Surface texture is very sensitive to changes in production. For example, changes in the composition of the material or the hardness of the surface, tool wear, strains in the material, and environmental factors can all affect the surface texture. If you change the manufacturing process, you will change the surface texture.

Surface texture refers to the locally limited deviations of a surface from the ideal intended geometry of the part. The deviations can be categorized on the basis of their general patterns.

"Surface texture includes closely spaced random roughness irregularities and more widely spaced repetitive waviness irregularities. American National Standard B46.1-1985 defines it as the repetitive or random deviation from the nominal surface that forms the three-dimensional topography of the surface. As such, it includes roughness, waviness, lay, and flaws. ..."[2] (See Figure 2-1.)

Roughness is a measure of the fine, closely spaced, random irregularities of surface texture caused by cutting tool marks, the grit of grinding wheels, and other process-related actions.

Waviness is a measure of the wider-spaced repetitive irregularities caused by vibration, chatter, heat treatment, or warping strains.

"In addition to roughness and waviness, surface texture exhibits directional patterns. The predominant direction of surface irregularities is called lay. Lathe turning, milling, drilling, and grinding typically produce surfaces that have pronounced lay. Sand casting, peening, and grit blasting all produce surfaces with irregularities that show no discernible direction at all. Such surfaces are said to have nondirectional (unidirectional), particulate, or protuberant lay."[3]

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[1] The terms *surface texture*, *surface roughness*, and *surface topography* are generally used interchangeably. The term *surface finish* is more vague than the other terms, and refers to the overall description of the surface including the texture, the flaws, the materials, and any coatings applied. The term *does not include* errors of form. Therefore, the terms *texture* and *roughness* are generally preferred to *finish*.

[2] "The Many Faces of Surface Texture," by George H. Schaffer, American Machinist & Automated Manufacturing, June 1988.

[3] Ibid.

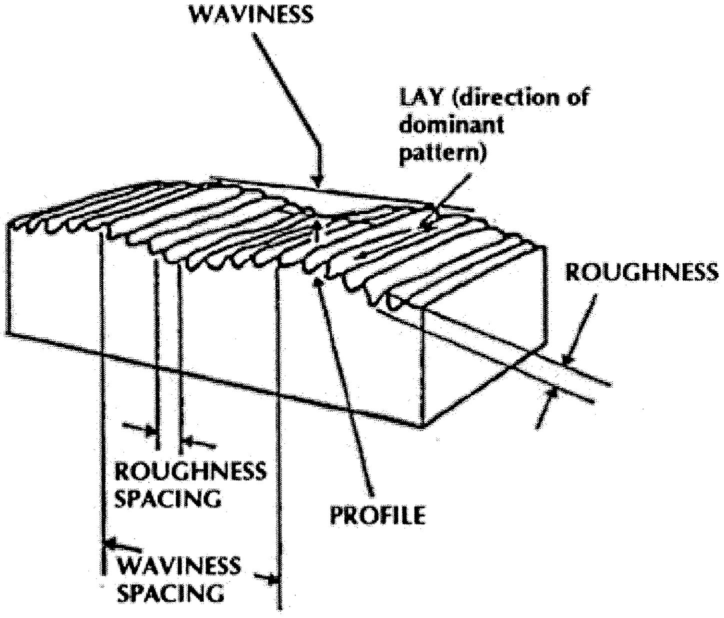

Figure 2-1. Surface Characteristics and Terminology

Surface texture cannot really be measured directly; a unique value cannot be assigned to every different surface. However, you can measure some of the inherent characteristics, or parameters, of surface texture. The main question is, "What are you interested in when you measure surface texture?" There are three basic categories into which surface texture parameters fall. The following category definitions are also from the Schaffer article:

- "*Amplitude parameters* are determined solely by peak heights or valley depths (or both) of profile deviations, irrespective of their spacing along the surface. They can refer to roughness (typically designated as R parameters) or waviness (typically designated as W parameters).
- *Spacing parameters* are determined solely by the spacing of profile deviations along the surface.
- *Hybrid parameters* are determined by amplitude and spacing in combination."[4]

Figure 2-2, taken from ANSI B46.1, shows the ranges of surface roughness that can be obtained from various standard engineering production methods. These range from shaping, drilling, and electrical discharge machining (which produce very rough surface finishes) down to lapping and polishing (which produce very smooth surface finishes). The metric unit micrometer (μm) and the English microinch (μin) are both widely used in surface metrology, and are both supported by the Wyko surface profiler systems.

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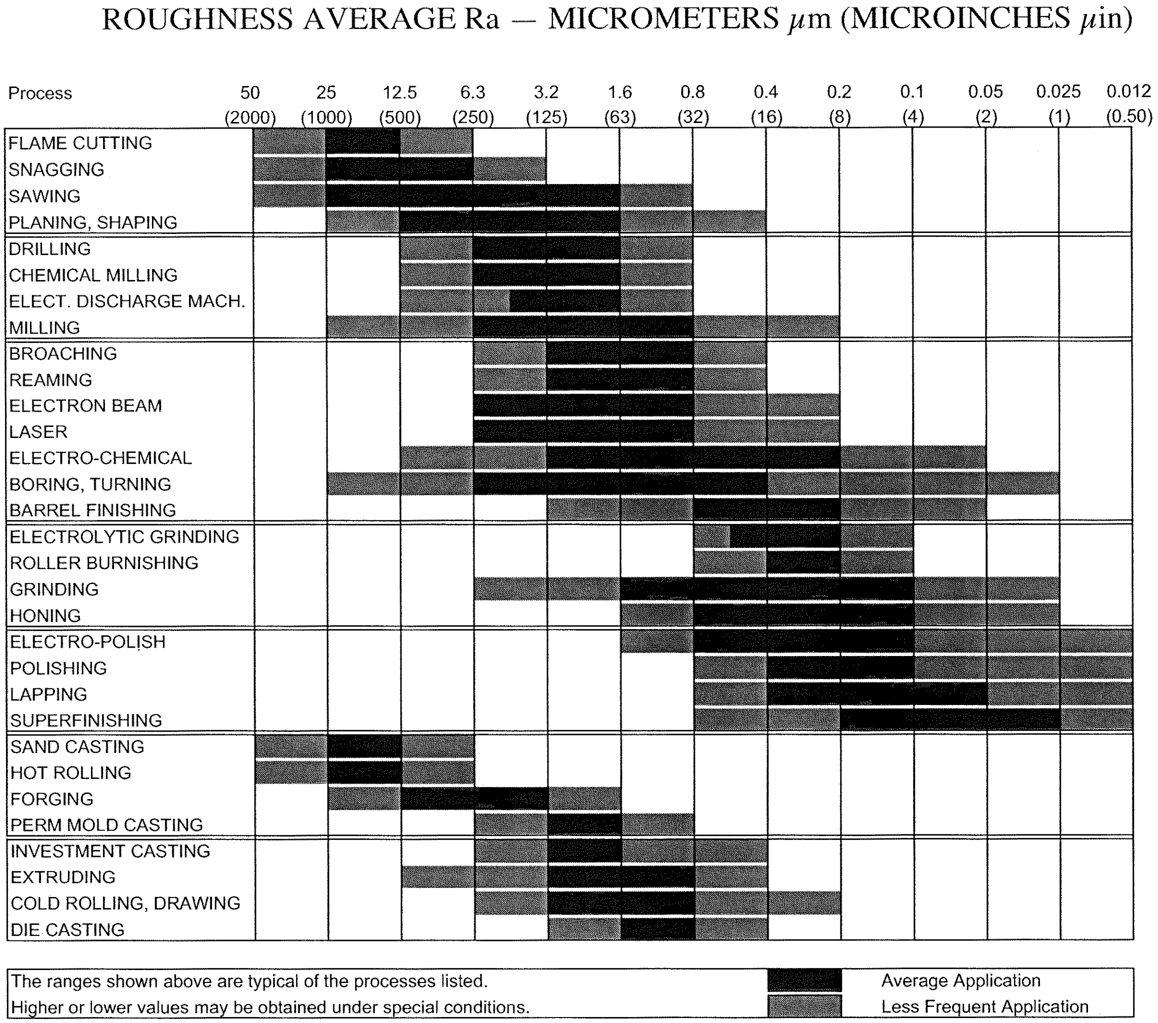
[4] Ibid.



The ranges shown above are typical of the processes listed.
Higher or lower values may be obtained under special conditions.

Figure 2-2. Surface Roughness Produced by Common Production Methods (from ANSI Standard B46.1-1985)

Types of Surface Statistics

R (Roughness) statistics were originally defined as 2-D parameters which were defined in national and international standards. These statistics were widely adapted for measuring 3-D surfaces, though a standard was never created to define their 3-D usage.

Usually you cannot define a surface or process with a single parameter. You will typically use multiple parameters in meaningful combination based on an application's functional requirements.

Surface Definitions

This section defines terms used in the definition of surface statistics.

- The **sample interval** is the spatial separation of the sampling points.
- The **sample length** is the physical length of a sampled profile.
- The **sample area** is the actual sampled dataset.
- The **evaluation length** contains one or more sampling lengths, usually consecutive.
- The **reference mean line** is the datum within the profile to which the measurement is related. The reference mean line is determined by calculating the average of all the heights in the profile. The reference mean plane is the three-dimensional reference surface to which all points in the dataset are related.
- The **profile height function**, Z(x) or Z(x,y), is the function used to represent the point-by-point deviations between the measured profile or surface and the reference mean line or plane.
- **AACF** is the Areal Autocorrelation Function, which describes the general dependence of the values of the data at one position on the values at another position. It provides basic information about the spatial relation and dependence of the data.
- **ADF** (*amplitude distribution function)* **curve** is a histogram of profile height data versus the amplitude density.

Amplitude Parameters

R_a

R_a represents the *roughness average*, the arithmetic mean of the absolute values of the surface departures from the mean plane.

The digital approximation for three-dimensional $R_{a\text{ is}}$:

$$R_a = \frac{1}{MN}\sum_{j=1}^{M}\sum_{i=1}^{N}|Z_{ji}|$$

where M and N are the number of data points in the X and Y direction, respectively, of the array, and Z is the surface height relative to the reference mean plane.

Uses

R_a is normally used to describe the roughness of machined surfaces. Is is a stable, easily implemented parameter, useful for detecting general variations in overall surface height characteristics and for surveillance of an established manufacturing process. When R_a changes, it usually signifies something has changed in the process, such as the tool, the coolant, the material, etc.

Advantages and Disadvantages

With average roughness, the effect of a single spurious, non-typical peak or valley will be averaged out and have only a small influence on the value. This statistic cannot detect differences in spacing or the presence or absence of infrequently occurring high peaks and deep valleys; therefore, they give no information as to the shape of the irregularities or surface.

The problem with using average roughness to evaluate surface texture is that surfaces are complex and parts with different functions require different profiles. R_a averagea out the detail needed to quantify and analyze complex engineered surfaces. In fact, it is possible to see markedly different surfaces between samples with the same R_a.

R_q

R_q represents the *root mean square (RMS) roughness*, obtained by squaring each height value in the dataset, then taking the square root of the mean.

The digital approximation for the three-dimensional R_q is given by:

$$R_q = \sqrt{\frac{1}{MN} \sum_{j=1}^{M} \sum_{i=1}^{N} Z^2(x_i, y_j)}$$

☞ The parameters “RMS” and “R_q” are equivalent in Wyko Vision32 and are computed using the same equation.

Uses

RMS roughness is generally used to describe the finish of optical surfaces. It has statistical significance because it represents the standard deviation of the surface heights, and it is used in the more complex computations of skew and kurtosis (described later in this chapter).

Advantages and Disadvantages

RMS roughness cannot detect differences in spacing or the presence or absence of infrequently occurring high peaks and deep valleys; therefore, these statistics give no information as to the shape of the irregularities or surface. A surface with a high spatial frequency may have the same R_q as a surface with a low spatial frequency, but may behave radically differently.

Because height values are squared in the calculation, the RMS roughness statistics are more sensitive to peaks and valleys than average roughness statistics. This makes it a better parameter for discriminating between different types of surfaces.

If a surface contains no large deviations from the mean surface, the RMS roughness and average roughness will be similar. However, if there are appreciable numbers of large bumps or holes, the RMS roughness will be larger than the average roughness.

If the surface is wavy, i.e., has roughness components of long surface spatial wavelengths, the RMS roughness value will in general depend on the size of the data array. The RMS roughness value depends on the following:

- The area of the surface profile (maximum surface spatial wavelength)
- The surface area being averaged for each measurement (lateral resolution)
- The distance between data points (sampling interval).

RMS roughness is very repeatable; therefore, you may look for changes in R_q to indicate a change in the manufacturing process. If this value changes dramatically, then you can surmise that something in the manufacturing process has changed.

R_p

R_p, *maximum profile peak height*, is the distance between the highest point of the surface and the mean surface, for the entire dataset.

Uses

The peaks in a surface profile provide information about friction and wear on a part.

Advantages and Disadvantages

Because R_p is a single extreme height (peak) value, it is not a very repeatable parameter. It may be a true peak or it may be a particle of dust or an atypical bump.

R_v

R_V, *maximum profile valley depth*, is the distance between the lowest point of the surface and the mean surface, for the entire measured surface.

Uses

The valleys in a surface provide information about how a part might retain a lubricant.

Advantages and Disadvantages

Because R_V is a single extreme height (valley) value, it is not a very repeatable parameter. It may be a true valley or it may be a scratch or atypical hole.

R_t

R_t, *maximum height of the surface*, is the vertical distance between the highest (R_p) and lowest (R_v) points as calculated over the entire dataset:. It is defined by:

$$R_t = R_p + R_v$$

Advantages and Disadvantages

Because R_t is based on two extreme height values, it is not a very repeatable parameter. You may need to make several measurements to arrive at a representative value. R_t is sensitive to high peaks and deep valleys, some of which may be stray particles, flaws, atypical bumps, dents, or scratches.

R_z

R_Z, *average maximum height of the profile*, is the average of the ten highest and ten lowest points in the dataset.

R_Z is calculated using the following:

$$R_z = \frac{1}{10}\left[\sum_{j=1}^{10} H_j - \sum_{j=1}^{10} L_j\right]$$

where H_j are the highest points and L_j are the lowest points found in the dataset.

The following algorithm is used for determining the ten highest points:

1. Tilt, curvature and cylinder are removed from the entire dataset (if these options are selected in the Processed Options dialog box).

2. The highest point in the dataset is found and labeled H_1.
3. An 11 x 11 pixel area is masked around this point.
4. The highest point in the remaining data is found and labeled H_2.
5. Steps 3 and 4 are repeated for H_3 through H_{10}.

A similar algorithm is used to determine the ten lowest points in the dataset.

Uses

R_z is useful for evaluating surface texture on limited-access surfaces such as small valve seats and the floors and walls of grooves, particularly where the typical presence of high peaks or deep valleys is of functional significance.

Advantages and Disadvantages

R_z has the advantage over a peak-to-valley height in that more than two points on the profile contribute to the value. The R_z calculation reduces the effects of odd scratches or non-typical irregularities.

R_{sk}

R_{sk}, *skewness*, measures the asymmetry of the surface about the mean plane. Skewness takes many equally spaced profile heights in a sampling length into account. Skewness is like a mean-cubed roughness. Points farther from the mean surface level when raised to powers of 3 and higher have proportionately more weight than those closer to the mean surface level. Therefore, the Z_j^3 term will be sensitive to points far from the mean plane. The degree of asymmetry can be seen when the surface height data is plotted against the amplitude density to produce an amplitude distribution function (ADF) curve as in Figure 2-3.

R_{sk} is calculated using the following:

$$R_{sk} = \frac{1}{NMR_q^3} \sum_{j=1}^{N} \sum_{i=1}^{M} Z_{ij}^3$$

Uses

If the measured surface is nearly smooth, but with deep scratches or pits, the profile will clearly be asymmetric and will have a definite negative skewness. If different surfaces have the same R_a or R_q values, you can distinguish between these surfaces by looking at their skewness. Surfaces that are smooth but are covered with particulates such as dust or spatters of evaporated material will have a positive skewed distribution function. The mean surface level will be calculated to be slightly above the true surface level. Likewise, a surface containing many pits will have the mean surface level below the true surface level.

Skewness offers a convenient way to illustrate load carrying capacity, porosity, and characteristics of non-conventional machining processes. If you look at the surface after applying a load or a coating, you can see how the peaks and valleys are affected. Figure 2-3 shows how a Gaussian profile would shift if the peaks were compressed under an applied load or if the valleys were filled with a coating.

The sign of the skewness will tell whether the farther points are proportionately above (positive skewness) or below (negative skewness) the mean surface level. Thus the predominance of bumps or peaks on a surface will have a positive skewness, and the predominance of holes or valleys in a surface will have a negative skewness. (See Figure 2-3.)

Negative skew, often specified from -1.6 to -2.0, is used as a criterion for a good bearing surface, indicating the presence of comparatively few spikes which should wear away quickly. Positive skew is sometimes specified for electrical contacts: even a fairly light contact load creates enough pressure on a few protruding summits to deform them to the point of cracking an inelastic and non-conductive oxide film, exposing clean conductive metal. On the other hand, although a surface with positive skew may acquire an adequate bearing face, it is likely to retain lubricant poorly.

Ground and lapped surfaces often have skewness as low as -3; diamond-turned surfaces may have skewness as high as +3. The skewness of most manufactured surfaces is between -3 and +3, but these are not absolute limits. If skewness exceeds ±1.5, you should not use average roughness alone to characterize the surface.

Advantages and Disadvantages

The calculated value of skewness is very sensitive to outliers in the surface data.

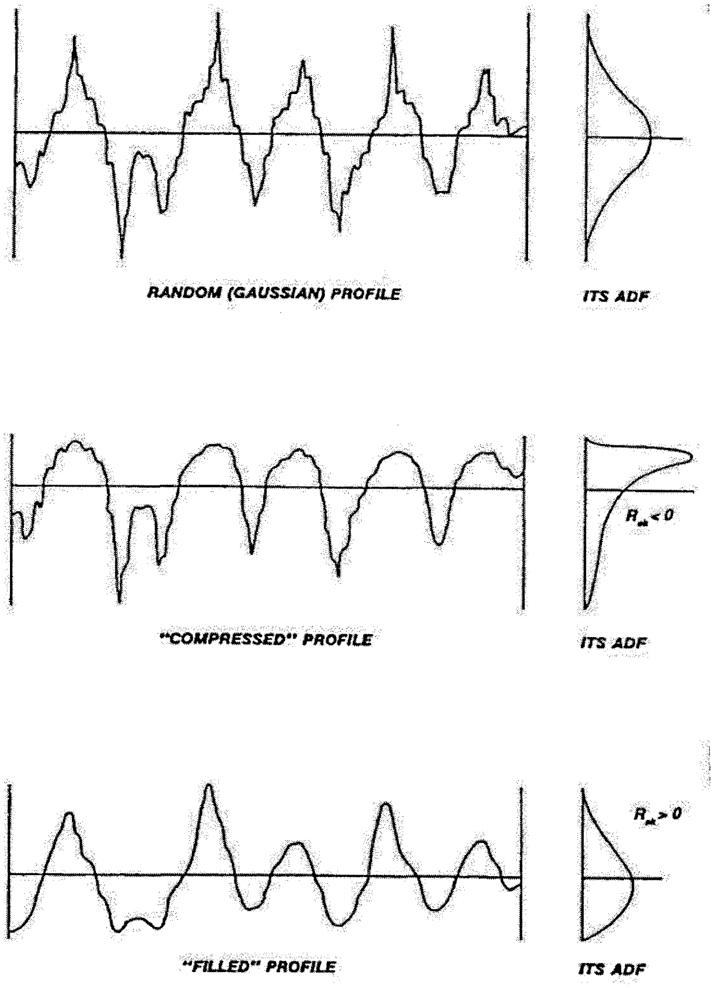


Figure 2-3. Examples of Skewed Profiles

R_{ku}

R_{ku}, *kurtosis*, measures the peakedness of the surface about the mean plane. It provides information about the "spikiness" of a surface, or of the sharpness of the amplitude density function (ADF), which does not necessarily mean the sharpness of individual peaks and valleys.

R_{ku} is calculated using the following:

$$R_{ku} = \frac{1}{NMR_q^4} \sum_{j=1}^{N} \sum_{i=1}^{M} Z_{ij}^4$$

Uses

Kurtosis is a useful evaluation parameter for machined surfaces, sometimes being specified for the control of stress fracture. It is rarely used for optical surfaces.

The kurtosis value is high when a high proportion of the surface falls within a narrow range of heights. If most of the surface is concentrated close to the mean surface level, the kurtosis will be different than if the height distribution contains more bumps and scratches.

Kurtosis is also a measure of the randomness of surface heights. Kurtosis values can range from 0 to 8, with a perfectly Gaussian or random surface having a kurtosis of 3. The farther the value is from 3, the less random (the more repetitive) the surface is. Surfaces with fewer high and low extreme points than a Gaussian surface have a kurtosis value less than 3; those with an appreciable number of high and low extremes have a kurtosis value greater than 3.

For the example profiles in Figure 2-3:

- Random profile (Gaussian ADF curve)$R_{ku} = 3$
- Compressed profile (sharp ADF curve)$R_{ku} > 3$
- Filled profile (smooth ADF curve)$R_{ku} < 3$

Advantages and Disadvantages

The calculated value of kurtosis is very sensitive to outliers in the surface data.

Stylus Parameters

Wyko Vision32 provides a way to measure the surface data as a series of 2D traces in either the X or Y direction, simulating a stylus measurement. Some terms you will need to know include the following:

- The **sample length** is the nominal interval within which a single value of a surface parameter is determined. The sampling length is labeled **l** in Figure 2-4. The sample length is also known as the **long wave cutoff**.
- The **evaluation length** is the length over which the values of surface parameters are evaluated. This length is labeled **L** in Figure 2-1. For meaningful statistics in a stylus instrument, the evaluation length should contain a number of sample lengths. Wyko Vision32 provides a 3D measurement which allows analysis of many parallel traces. In this case, statistical significance can typically be obtained with a single sample length per evaluation length. Evaluation length is also called assessment length.

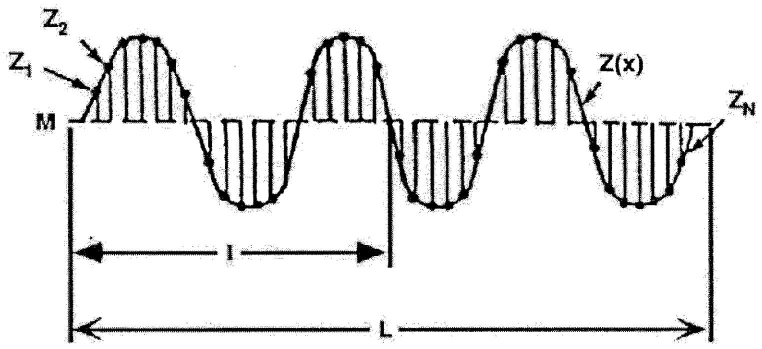


Figure 2-4. Stylus Parameters

R_a (Stylus)

Definition

R_a(stylus) represents the two-dimensional *roughness average*, the arithmetic mean of the absolute values of the surface departures from the mean plane. The digital approximation for the two-dimensional R_a is:

$$R_a = \frac{(|Z_1| + |Z_2| + |Z_3| + \dots + |Z_N|)}{N} = \frac{1}{N}\sum_{i=1}^{N} |Z_i|$$

where N = the number of data points in the sample length
Z_i = the surface height relative to the mean line of the data points in the sample length.

Uses

See *Ra* on page 2-5.

R_q (Stylus)

Definition

R_q(stylus) represents the two dimensional *RMS roughness*. The digital approximation for the two-dimensional R_q is:

$$R_q = \sqrt{\frac{Z_1^2 + Z_2^2 + Z_3^2 + \dots + Z_N^2}{N}} = \frac{1}{N}\sqrt{\sum_{i=1}^{N} Z_i^2}$$

where N = the number of data points in the sample length

Z_i = the surface height relative to the mean line of the datapoints in the sample length.

Uses

See *Rq* on page 2-6.

R_p (Stylus)

See *Rp* on page 2-7.

R_{pi} (Stylus)

R_{pi}, the *profile peak height*, is the peak height along sample length *i*.

R_{pm} (Stylus)

Definition

R_{pm}, *average maximum profile peak height,* is the average of the successive values of R_{pi} calculated over the evaluation length. The calculation of R_{pm} is given by:

$$R_{pm} = \frac{1}{N}\sum_{i=1}^{N} R_{pi}$$

where N = the number of sample lengths in the evaluation length.

Uses

As with the R_p parameter, R_{pm} characterizes a surface based on the upper level, or peaks, of the surface profile. This provides information about friction and wear of a part.

Advantages and Disadvantages

In the R_{pm} calculation, several peak heights are averaged. This makes the value more repeatable than R_p.

☞ Wyko Vision32 analyzes many parallel traces simultaneously, so the values calculated for the mean and the standard deviation for R_p and R_{pm} can indicate system repeatability as well.

R_v (Stylus)

See *Rv* on page 2-8.

R_{vi} (Stylus)

R_{vi}, the *profile valley depth*, is the lowest point along sample length *i*.

R_{vm} (Stylus)

Definition

R_{vm}, *average maximum profile valley depth*, is the average of the successive values of R_{vi} calculated over the evaluation length. The calculation of R_{vm} is given by:

$$R_{vm} = \frac{1}{N}\sum_{i=1}^{N} R_{vi}$$

where N = the number of sample lengths in the evaluation length.

Uses

As with the R_v parameter, R_{vm} characterizes a surface based on the lower level, or valleys, of the surface profile. This indicates how the part will retain a lubricant.

Advantages and Disadvantages

In the R_{vm} calculation, several valley heights are averaged. This makes the value more repeatable than R_v.

☞ Wyko Vision32 analyzes many parallel traces simultaneously, so the values calculated for the mean and the standard deviation for R_p and R_{pm} can indicate system repeatability as well.

R_t (Stylus)

See *Rt* on page 2-8.

R_{ti} (Stylus)

R_{ti}, the *maximum surface height*, is the vertical distance between the highest (R_{pi}) and lowest (R_{vi}) points along sample length *i*.

R_{tm} (Stylus)

Definition

R_{tm}, *average maximum height of the profile*, is the average of the successive values of R_{ti} calculated over the evaluation length. (See Figure 2-5.) This parameter is the same as R_z(DIN)[5] when there are ten sample lengths within an evaluation length. The equation for R_{tm} is given by:

$$R_{tm} = \frac{1}{N}\sum_{i=1}^{N} R_{ti}$$

where N = the number of sample lengths.

☞ When N = 10, R_{tm} is equal to R_z.

Advantages and Disadvantages

Similar to R_{pm} and R_{vm}, the R_{tm} calculation averages several maximum profile heights. This makes the value more repeatable than R_t.

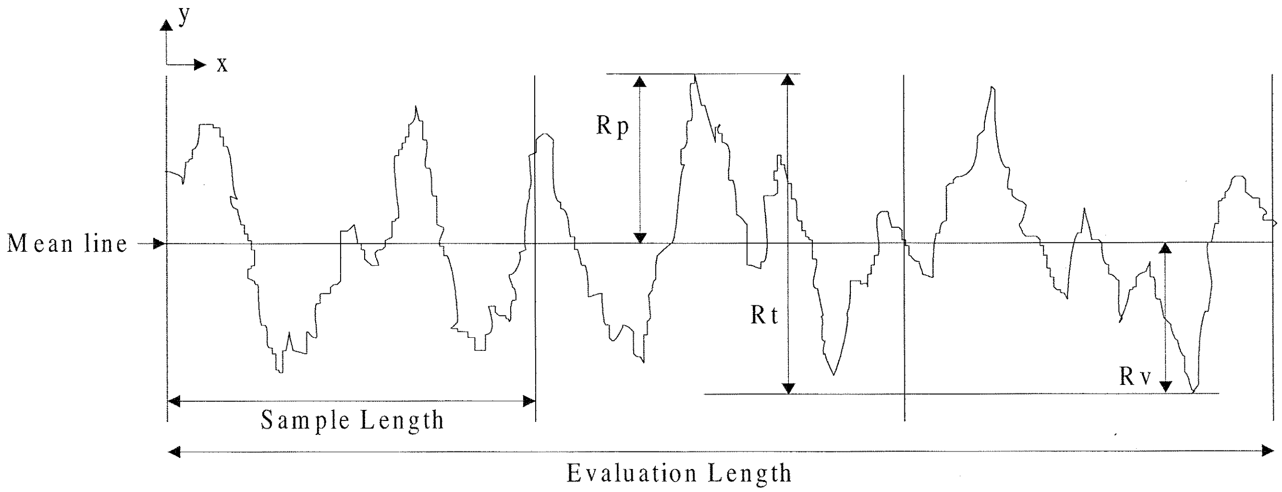


Figure 2-5. R_p, R_v, and R_t

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[5] Ibid.

PC

Definition

PC, *peak count*, is the number of peaks per unit length measured at a specific peak count level which is the vertical distance between the boundary lines. A peak defined for PC is a profile irregularity wherein the profile intersects consecutively a lower and an upper boundary line. The boundary lines are located parallel to and equidistant from the profile mean line and are set by the operator for each application.

In PC, a bandwidth is established symmetrically about the mean line of the roughness profile, and full-wave excursions of the profile through this zone along the nominal profile are counted. (See Figure 2-6.) An important point to remember is that for PC, a peak extending above the selected zone is not counted unless it is first triggered by a valley extending below the zone's lower limit, as indicated by the check marks on Figure 2-4.

PC is expressed in peaks per centimeter or peaks per inch and is calculated as follows:

$$PC = \frac{N}{l}$$

where N = the number of peak counts
l = the sample length.

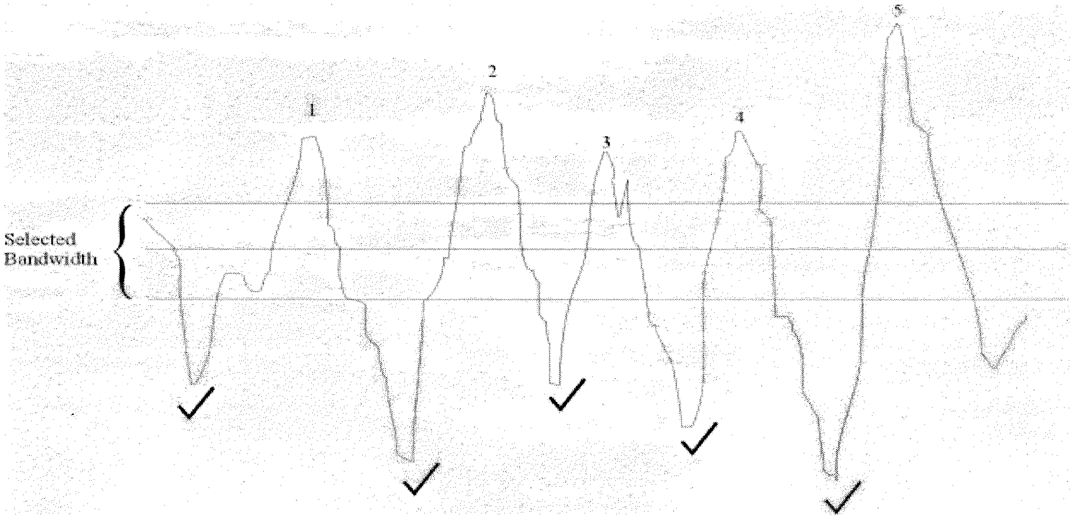


Figure 2-6. Definition of PC

Uses

Although roughness amplitude is very important in most applications, the spacing of the roughness peaks can be equally important. In the manufacture and use of sheet steel, surface texture control is necessary to obtain consistent lubrication when pressing the sheet to avoid scoring and to prevent the texture from showing through the paint on the finished product. Spacing can be particularly important in this situation.

By controlling the roughness peak spacing as well as R_a, it is possible to obtain better bonding of finishes, more uniform finish of plating and painting, and reduced risk of cracking during drawing or forming operations. Peak spacing is also an important factor in the performance of friction surfaces such as brake drums.

Advantages and Disadvantages

PC is sensitive to both spacing and the presence of infrequent high peaks. The parameter R_a misses these features.

S and S_m

Definition

S is the mean spacing between adjacent local peaks, measured over the evaluation length. A local peak is the highest part of the profile measured between two adjacent minima, and is only included if the distance between the peak and its preceding minima is at least 1% of the R_t of the profile. (See Figure 2-7.)

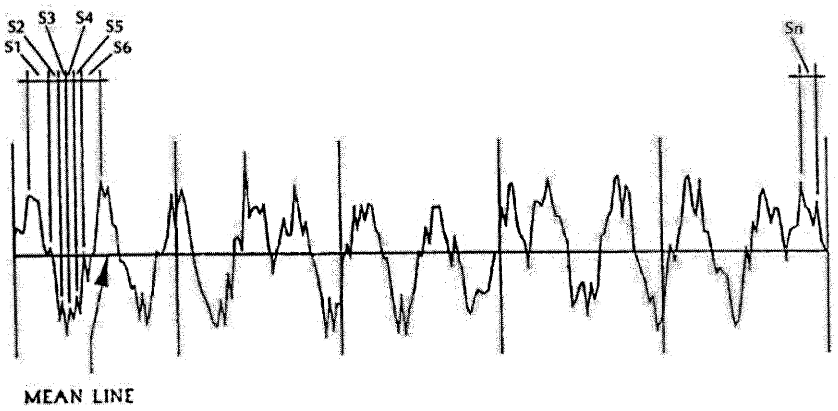


Figure 2-7. Definition of S

S_m is the mean spacing between profile peaks marked where the profile passes through the mean line, measured over the evaluation length. A profile peak is the highest point of the profile between an upwards and a downwards crossing of the profile of the mean line. (See Figure 2-8.) S_m is an ISO-recognized standard parameter.

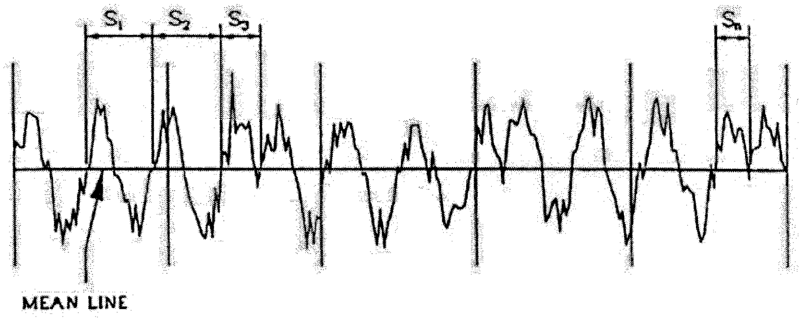


Figure 2-8. Definition of S_m

☞ A peak does not have to cross the mean line for S, but it does for S_m.

Calculation

The equations for S and S_m are identical, and are given by:

$$S\ (or\ S_m) = \frac{1}{N}\sum_{i=1}^{N} S_i$$

where N is the number of peak spacings. Although the equation is the same for both parameters, the value for S_i differs between the two parameters, as shown in Figure 2-7 and Figure 2-8.

Uses

Peak spacing parameters such as S and S_m are important for checking the spacing of regular and irregular peaks and valleys. Spacings or wavelengths are often characteristic of the process that formed the surface. Some useful applications include characterizing the spacing of texture on a hard disk, the effect of abrasives during polishing, or the surface finish on metal parts.

Advantages and Disadvantages

S (mean local peak spacing) provides information about the distance between peaks spaced closely together, while S_m (mean peak spacing) provides information about the distance between peaks spaced farther apart. The height of the peaks is not really a factor in these spacing parameters, since the calculation is based on horizontal, not vertical, distances. However, there is a height criterion for the local peaks in the definition of S (mean local peak spacing)—a local peak is included in the analysis only if the distance between the peak and its preceding minima is at least 1% of the R_t (maximum peak-to-valley) of the profile.

Δ_a and Δ_q

Definition

The slope of the profile is the angle (in terms of gradient) that it, or its tangent in the case of a curved profile, makes with a line parallel to the center line. The mean of the slopes at all points in the profile within the sampling length is known as the *average slope* (Δ_a for the arithmetic mean or Δ_q for the rms value). Average slope is the mean (arithmetic or rms) of the slopes at all the points of a profile within the assessment length.

Calculation

The arithmetic average slope, Δ_a, is given by the following equation:

$$\Delta_a = \frac{1}{N}\sum_{i=1}^{N}|\Delta_i|$$

where N is the number of spacings in the evaluation length and Δ_i is

$$\Delta_i = \frac{1}{60d_0}(Z_{i+3} - 9Z_{i+2} + 45Z_{i+1} - 45Z_{i-1} + 9Z_{i-2} - Z_{i-3})$$

In the equation above, d_o is the sampling interval between the profile points. The value of d_o influences the value of Δ_a.

The RMS average slope, Δ_q, is given by the following:

$$\Delta_q = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\Delta_i)^2}$$

where Δ_i was previously specified. Just as for the average slope Δ_a, the value of d_o influences the value of Δ_q.

Uses

These parameters have been found useful in assessing contact and optical properties as there is a relation to hardness, elasticity, electrical and thermal conductivity, plastic and elastic deformation, reflectivity, friction, adhesion, and others.

Average slope is also used to measure the developed or actual profile length—the length occupied if all peaks and valleys were stretched out in a straight line or, as an analogy, the distance one would have to walk up and down a hill to cross all the peaks and valleys. The steeper the average slope, the longer the actual length of the surface compared with its nominal length. These parameters are employed in painting and plating applications where the length of surface available for keying is important.

Average slope has also been found to be important in assessing three properties of engineering surfaces:

Contact	The parameter can be related to hardness and elasticity and can, therefore, be an indication of the "crushability" of the surface.
Optical	If Δ_a or Δ_q is small, the surface is a good specular reflector, and conversely, the surface is a diffuse scatterer.
Friction	Frictional and adhesion properties vary with the average slope.

Advantages and Disadvantages

These parameters are sensitive to the numerical model used in computing slopes. The calculated value of the slope will generally depend on the separation (d_o) of the data points used for the calculations, the amount of averaging of surface area in each data point, and the amount of instrumental noise included in each height value, Z_i. Large differences in computed values can show between different instruments. For smooth surfaces, of the order of 1-2 Å rms roughness, the calculated rms slope values may be primarily a function of the amplitude of the instrumental noise rather than of the surface topography.

λ_a and λ_q

Definition

λ_a, *arithmetic average wavelength,* and λ_q, *rms average wavelength,* are a measure of the spacings between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies. Both include the spacings of every point, not just the peaks.

Average wavelength is related to the power spectrum and represents an estimate of the weighted mean of the Fourier spectrum.

Calculation

The equation for λ_a is:

$$\lambda_a = 2\pi \frac{R_a}{\Delta_a}$$

and for λ_q:

$$\lambda_q = 2\pi \frac{R_q}{\Delta_q}$$

Note that R_a, R_q, Δ_a, and Δ_q were discussed earlier in this chapter.

Uses

λ_a and λ_q are useful in sheet steel applications and wear tests. They are useful for sheet steel applications because average wavelength is a measure of the openness or closeness of the texture and correlates well with the cosmetic assessment of a surface.

Average wavelength can be particularly useful in applications where the presence of certain harmonics on parts changes with time of usage. Closely spaced irregularities of a surface are normally of a relatively small amplitude, but wear rapidly with the part being used in applications such as rollers or ball bearings, or rotational or reciprocational friction applications. Since the amplitudes of these irregularities are so small, the change in R_a during run-in is small. However, this leaves the lower frequency components of the surface more dominant as the shorter wavelengths disappear, and results in a more pronounced change in average wavelength.

Average wavelength can be used as a measure of directly monitoring the manufacturing process. In good-quality turning, the average wavelength relates directly to the feed marks of the tool. If the machine tool settings are wrong, the value of λ_a or λ_q will change dramatically, even though R_a or a similar height parameter may not change significantly. Similarly, in grinding λ_a and λ_q have a direct relationship to the average grit size; therefore, monitoring average wavelength provides information relating to when the wheel needs dressing to maintain quality.

Advantages and Disadvantages

Because λ_a and λ_q are hybrid parameters, determined from both amplitude and spacing information, they are, for some applications, more useful than a parameter based solely on amplitude or spacing.

Other Surface Parameters

The Wyko profiler systems calculate a variety of other surface parameters during specific analyses (bearing ratio, texture analysis, etc.). For more information about additional surface parameters not included in this chapter, see Chapter 3, "Analysis Options."

❖❖❖

Table 2-1. International Parameters, Symbols, and Their Countries

USA	United Kingdom	Switzerland	Sweden	Spain	Russia	Japan	Italy	Hungary	Germany	France	Finland	Denmark	Canada	Austria	Australia	Wyko Vision32	ISO	
R_a	R_a	R_a	R_a	h_m	R_a	R_a	R_a	R_a	R_a	R_a	R_a	R_a	R_a	R_a	R_a	R_a	R_a	**Arithmetic average roughness**
				h_{rme}				h_q	R_{aq}							R_q		**Root-mean-square roughness**
			R_{max}		R_{max}	R_{max}		R_{max}	R_t	R_t R_{max}	R_{max}	R_{max}		R_t		R_t	R_y	**Maximum peak-to-valley roughness**
	R_z		R_z		R_z	R_z			R_z		R_z	R_z				R_z	R_z	**Ten point height**
				H			R			R						R_{ti}		**Average peak-to-valley roughness**
					S S_m				A_r	A_R						S S_m		**Average spacing of roughness peaks**
			H									R				H		**Swedish height of irregularities**
			K_B		t_p			t_p		$(T_r)_c$				t_{ap}				**Bearing ratio length**
							R_c	R_t	R_p	R_p		R_u						**Leveling depth**
									W	W				W				**Waviness height**

Chapter 3

Analysis Options

Wyko profilers perform several types of data analyses to provide information about the surface. This chapter defines these analyses and discusses how you can use them to learn more about your sample or manufacturing processes.

Histogram

Definition

The Histogram plot shows the distribution of individual surface height values in histogram form, indicating how often various heights occur in the data array. The horizontal axis indicates the individual height values, while the vertical axis shows the number of data points contained within equally spaced intervals (bins).

A Gaussian curve is drawn over the histogram, based on the rms roughness, the number of points in the dataset, and the bin size, which is set by the user. This curve allows you to compare a normal distribution to the actual distribution of the dataset. Figure 3-1 shows a histogram plot of a near Gaussian surface. Figure 3-2 shows a histogram of a skewed surface. The Gaussian curve is drawn over both of these histograms.

Calculation

The largest absolute value of the dataset is used as the peak. The negative of this value is used as the valley. This centers the histogram on a value of zero. The distance between this peak and valley is divided by the number of bins to be plotted. This gives a maximum and minimum value for each bin.

The program examines the first data point in the array and calculates its appropriate bin. This bin is incremented by one, and the bin for the next data point is calculated and incremented. This process continues until all data points have been examined and each bin contains the total number of data points that fall within its limits.

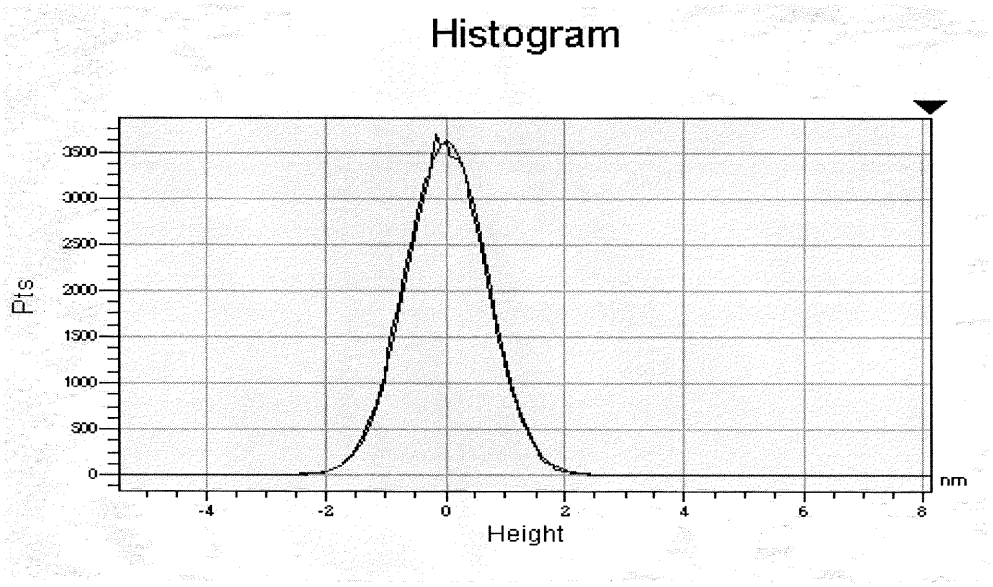


Figure 3-1. Histogram of Near Gaussian Surface

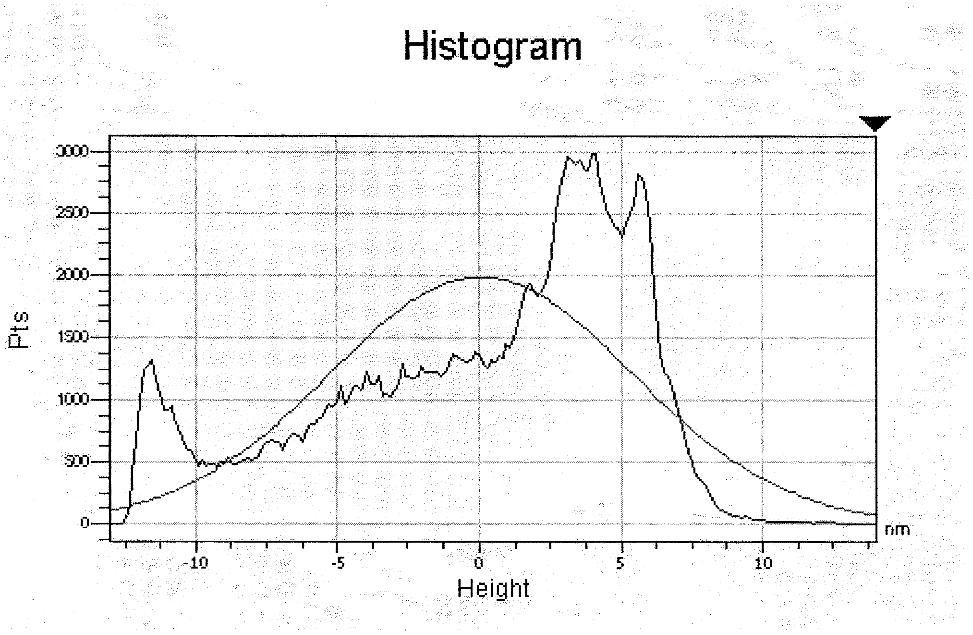


Figure 3-2. Histogram of a Skewed Surface

Uses

By interpreting the histogram, you can determine the amount of noise in the data. A dataset driven entirely by random noise produces a histogram with a Gaussian distribution. However, caution is advised—some surfaces also give a "Gaussian" histogram based on the randomness of the surface texture, not necessarily from noise. Noise spikes are suggested by infrequently occurring heights. Such spikes may be due to contaminating defects such as pits, wear patterns, or other factors.

Measurement Limitations

The histogram gives a visual representation of the relative heights of points in the dataset. It does not, however, give a clear indication of the uniformity across the entire surface.

Bearing Ratio

Definition

Imagine a horizontal slice through the roughness profile surface parallel to the mean plane—it would intercept both workpiece material and air. If this slice were a line drawn parallel to the x-axis, the sum of the horizontal lengths where this slice intercepts material in the two-dimensional XY plane is defined as the *bearing length.* If this slice were a plane drawn parallel to the mean plane, the total three-dimensional area where this slice intercepts material is defined as the *bearing area.*

☞ For measurements with Wyko profilers, the bearing area and 3-D bearing ratio are employed. However, for clarity, 2-D diagrams are used below to explain the concepts.

Figure 3-3 shows a two-dimensional surface profile of an evaluation length L. The profile is bounded by a line labeled 0% which is even with the highest peak (R_p), and by a line labeled 100% which is even with the lowest valley (R_v). A line at a depth p below the highest peak is also shown. The bearing length is the sum of the profile lengths where the line at depth p intercepts the surface. These lengths are labeled b_1, b_2, b_3, …, b_n.

As a three-dimensional extension, if a plane were to intercept the profile surface at this depth p, the area of the surface cut by the plane at depth p, as shown bounded by b_1, b_2, b_3, … b_n, would create individual islands of data. The sum of the area of these islands of data would make up the bearing area.

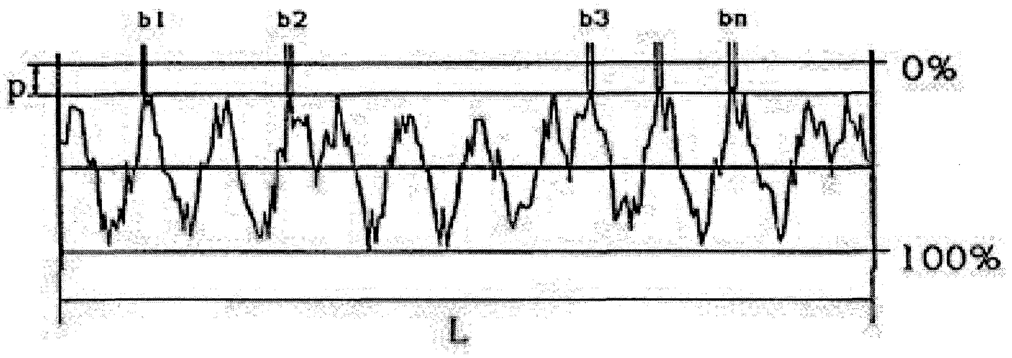


Figure 3-3. Bearing Length

The *bearing area ratio* t_p, also known as the *material ratio*, is the ratio of the bearing area to the total evaluation area.

The *bearing ratio curve*, also known as the *material ratio curve,* is a graphical representation of the t_p parameter in relation to the surface level. As illustrated in Figure 3-4, the bearing ratio curve shows how the bearing ratio varies with level. The bearing ratio curve is the curve generated by running a plane, extending parallel to the mean surface plane, down through the surface, and is defined as the percentage of the plane that intercepts material, versus the depth of the plane into the surface. This curve contains all of the amplitude information of a surface.

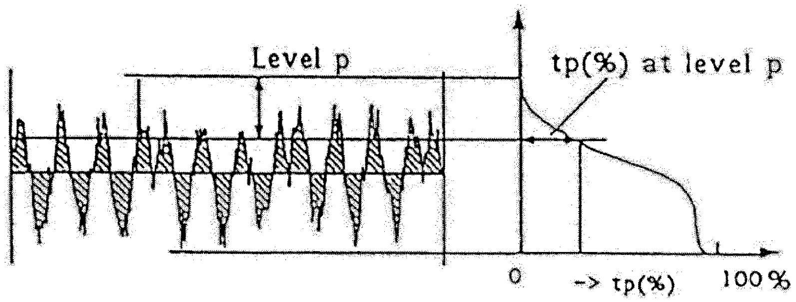


Figure 3-4. Bearing Ratio Curve

Shown in Figure 3-5 is t_{p1}, *the peak threshold bearing ratio value;* t_{p2}, *the valley threshold bearing ratio value*; their corresponding heights H_1 and H_2, respectively, and H_{tp}, *the height between bearing ratios*. In Vision32, you can specify the left (t_{p1}) and right (t_{p2}) bearing ratio percentages used for the calculation of H_{tp}.

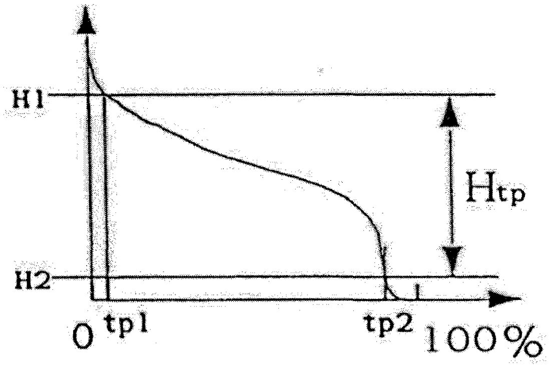


Figure 3-5. Bearing Ratio Curve Showing t_{p1}, t_{p2}, H_1, H_2, and H_{tp}

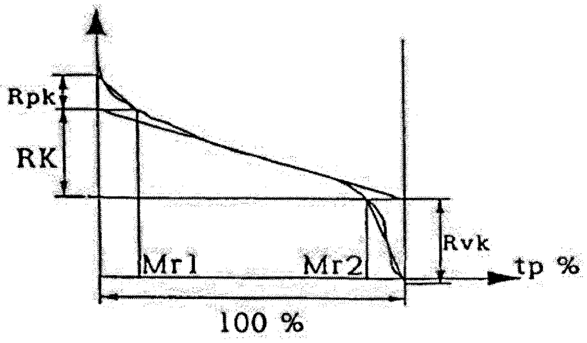


Figure 3-6. Bearing Ratio Curve Showing R_K, R_{pk}, R_{vk}, M_{r1}, and M_{r2}

As illustrated in Figure 3-6, the following definitions apply:

R_K	*Core Roughness Depth*: This is the working part of the surface. It will, after the initial running-in period, carry the load and influence life and performance.
R_{pk}	*Reduced Peak Height*: The top portion of the surface which will be worn away in the running-in period.
R_{vk}	*Reduced Valley Depth*: The lowest part of the surface which has the function of retaining the lubricant.
M_{r1}	*Peak Material Component*: The Bearing Ratio at which R_{pk} and R_K meet. This is the upper limit of the Core Roughness Profile.
M_{r2}	*Valley Material Component*: The Bearing Ratio at which R_{vk} and R_K meet. This is the lower limit of the Core Roughness Profile.

Additionally, there are two secondary parameters which are not shown in the figure, but are associated with the bearing ratio. They are defined as follows:

V_1	*Material Filled Profile Peak Area*: A measure of the amount of material that will be removed in the running-in period.
V_2	*Lubricant Filled Profile Valley Area*: A measure of the area in the profile that can retain lubricant.

Calculation

The bearing ratio should be expressed in percent. The bearing ratio is calculated as follows:

$$t_p = \frac{100}{A} \sum_{i=1}^{n} a_i$$

where a_i = the area of individual islands at depth p
A = the total profile surface evaluation area.

The bearing ratio curve is derived from the bearing ratio at each depth p from the highest peak to the lowest valley. The associated bearing ratio parameters are then derived from the bearing ratio curve.

H_{tp} is determined by selecting t_{p1} and t_{p2}, calculating the corresponding heights (H_1 and H_2), and then subtracting H_2 from H_1: $H_{tp} = H_1 - H_2$. This procedure is illustrated in Figure 3-5.

Swedish Height, *H*, is an additional height calculated as part of the bearing ratio. It is determined by setting $t_{p1} = 5\%$ and $t_{p2} = 90\%$, calculating the corresponding heights, H_1 and H_2, and then subtracting H_2 from H_1: $H = H_1 - H_2$; essentially the same as H_{tp}, only with constant limits at 5 and 90 percent.

To determine the parameters R_{pk}, R_{vk}, R_K, M_{r1}, M_{r2}, V_1, and V_2, the following steps are performed:

The area of minimum slope of the bearing ratio curve within a 40% window is found. This is accomplished by computing the height difference of the curve's profile depth axis for points separated by 40% on the $t_{p\%}$ axis. The bearing ratio curve is first intersected at 0% and 40%, and the H_{tp} is found. The 40% window is then moved to the right and the H_{tp} monitored for each point until the minimum H_{tp} value is found. Refer to Figure 3-7. The smallest height difference (minimum H_{tp}) is at the area of minium slope.

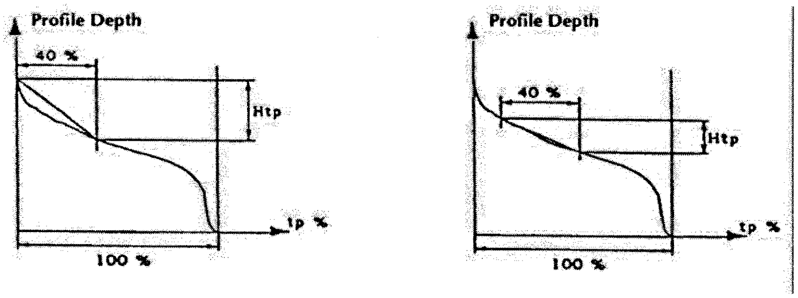
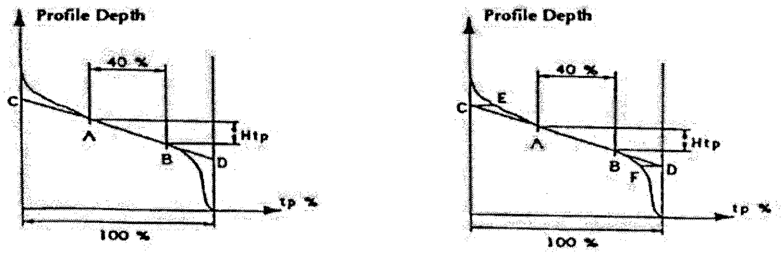


Figure 3-7. Finding Minimum H_{tp} at 40% Separation

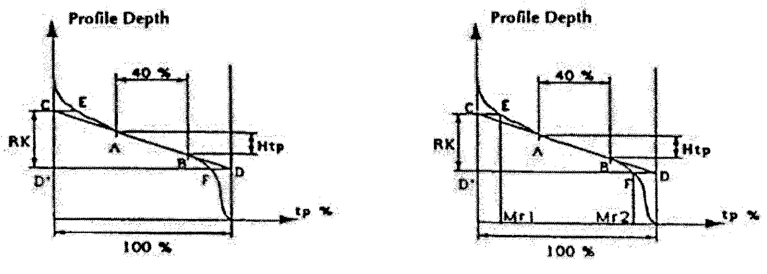
- The points on the bearing ratio curve at minimum H_{tp} in the 40% window are labeled in Figure 3-8 (a) as A and B. The line connecting points A and B is extended to intersect with the ordinates at bearing ratio 0% and 100%, yielding points C and D.
- Lines parallel to the t_p axis through C and D and intersecting with the bearing ratio curve at E and F are now added, yielding lines CE and DF as shown in Figure 3-8 (b).



(a) (b)

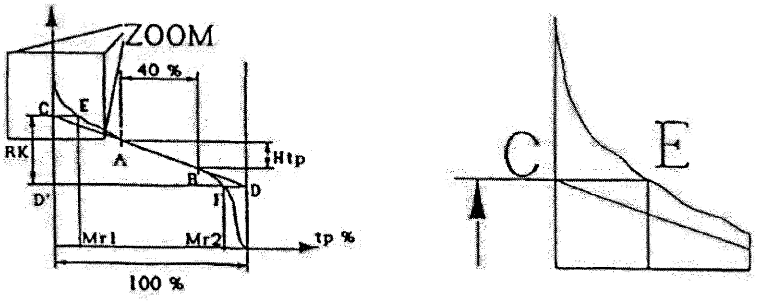
Figure 3-8. Extending Lines at Minimum H_{tp}

- Extending the line DF to intersect with the profile depth axis at $t_p = 0\%$ yields D'. The distance between C and D' is defined as R_K. See Figure 3-9 (a).
- Lines parallel to the profile depth axis through E and F, intersecting with the t_p axis, gives points M_{r1} and M_{r2}. (i.e., distance CE = M_{r1} and distance D'F = M_{r2}), as shown in Figure 3-9 (b).
- To better see what is happening in our calculations for V_1 and R_{pk}, we zoom in on the area around CE, as shown in Figure 3-10.



(a) (b)

Figure 3-9. Derivation of R_K, M_{r1}, and M_{r2}



(a) (b)

Figure 3-10. Zooming in on the Area around R_K and R_{pk}

- *V1*, the Material Filled Profile Peak Volume parameter, is a measure of the volume of material that will be removed in the running-in period. This is a normalized parameter, with units of volume/area = height. It is calculated by:

$$V1 = \frac{\text{Area of hatched region in Figure 3-11a}}{\text{Area of dataset}}$$

The horizontal axis represents a percentage of the total area for a bearing ratio curve of a 3-D measurement. Therefore, the result corresponds to a volume.

This can be expressed by the equation:

$$V1 = \left(\frac{Mr_1 \cdot R_{pk}}{2} \cdot \frac{1}{100}\right)$$

where R_{pk} = the height of the triangle of base MR_1 and an area equal to Area 1. This triangle is labeled Area2 in Figure 3-11 (b). Rpk has units of length; V_1 has units of height.

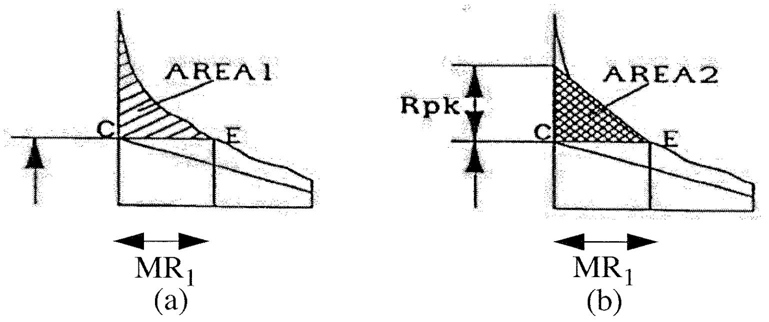


Figure 3-11. Calculating V_1 and R_{pk}

- To better see what is happening in our calculations of V_2 and R_{vk}, we now zoom in on the area around DF, as shown in Figure 3-12.

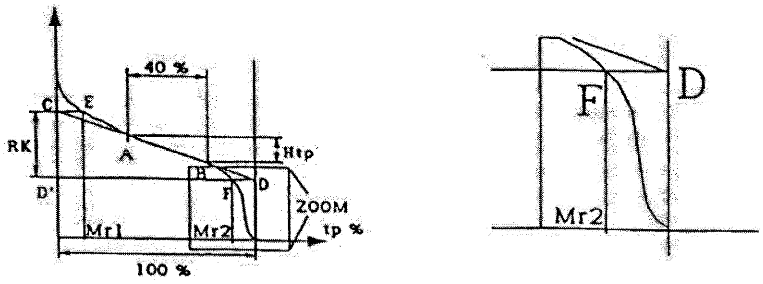


Figure 3-12. Zooming in on the Area around R_{vk}

- *V2*, the *Lubricant Filled Profile Valley Volume* parameter, is a measure of the volume of material that will retain lubricant during operation. This is a normalized parameter, with units of volume/area = length. It is calculated by:

$$V2 = \frac{\text{Area 3 in Figure 3-13a}}{\text{Area of dataset}}$$

This can be expressed by the equation:

$$V_2 = \frac{(100 - Mr_2) \cdot R_{vk}}{200}$$

where R_{pk} is the height of the triangle of base MR_2 with an area equal to Area3. This triangle is labeled Area4 in Figure 3-11 (b). Rv_k has units of length; V_2 has units of height.

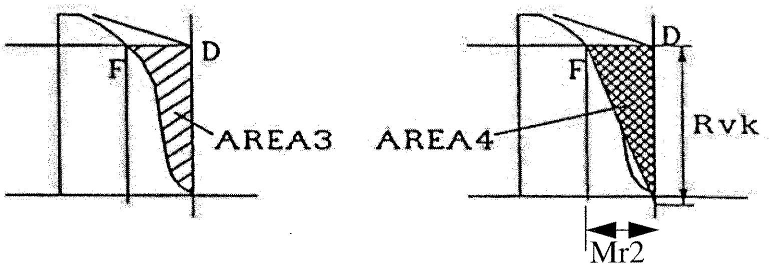


Figure 3-13. Calculating V_2 and R_{vk}

Note that R_{vk} extends below the lowest valley of the profile in this example. R_{vk} can, but does not always, extend below this point. It is also possible that R_{pk} goes higher than the highest profile peak. Adding up $R_{pk} + R_K + R_{vk}$ does *not*, in general, equal R_t.

We can now put these parameters together as shown in Figure 3-14.

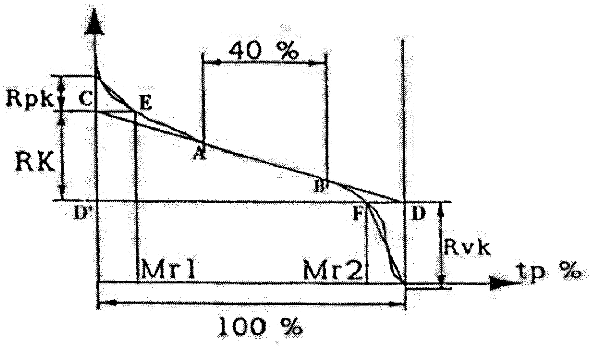


Figure 3-14. Bearing Ratio Curve Parameters

Uses

Bearing ratio is widely considered to be a measure of the suitability of a surface as a bearing surface. The most common use of engineering surfaces is to provide a bearing surface for another component moving relative to it, which results in wear. The bearing ratio simulates the effect of wear.

The bearing ratio is particularly useful if you are concerned with frictional wear on your sample, since it enables you to determine the percentage of surface area that will remain after the sample has been worn to a certain height. The bearing area curve at a profile depth of 50% is especially important. This is known as the *leveling depth* and is used as a criterion for a surface's ability to carry a load or resist wear.

Imagine a lapping plate resting on the highest peak of a surface. As the peaks wear and the bearing area (i.e., the top of the remaining surface) descends down, the size of the bearing surface (the area in contact with the lapping plate) increases. t_p attempts to estimate the available bearing area after the surface has worn down a specified amount. There is good reason to assume that having a high percentage of material near the top of the surface makes a better wear surface than a few skinny peaks. The estimated fractional area is used as a criterion of the quality of the work.

R_K attempts to numerically evaluate the bearing ratio curve of surfaces manufactured with a process resulting in a negative skew. The processes that this parameter relates to in particular are plateau honing, lapping, and all kinds of multiple machining operations which intend to remove peaks but leave larger valleys from a previous process.

Measurement Limitations

The bearing ratio is determined from a comparatively small sample of the surface. It relates to the unloaded surface, whereas in use the surface may undergo elastic deformation. In practice, two contacting surfaces are involved and the surface features of each have a part to play in causing wear. Wear is often accompanied by a physical flow of material, and the geometrical concept of the crests being neatly truncated by a plane drawn through them is probably unrealistic.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
H	Swedish Height
Htp	Bearing Ratio Htp
Mr1	Bearing Ratio Mr1
Mr2	Bearing Ratio Mr2
RK	Bearing Ratio RK
Rpk	Bearing Ratio Rpk
Rvk	Bearing Ratio Rvk
tp1	Bearing Ratio tp1
tp2	Bearing Ratio tp2
V1	Bearing Ratio V1
V2	Bearing Ratio V2

Texture

Definition

The Texture analysis calculates the average number of times the data profile crosses the zero height in the X and Y directions. The numbers is reported as frequencies of crossing per mm.

The Texture analysis displays a contour plot and a bearing ratio plot, with roughness and bearing ratio statistics in addition to the zero-crossing frequency.

Uses

The Texture analysis finds the number of peaks and zero crossings on a surface with random height variations such as those found in the measurement of film, plactics, magnetic tape, and other magnetic media.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
XCrossings	X Crossings
YCrossings	Y Crossings

X and Y Slopes

Definition

Wyko Vision32 displays a contour plot showing the rate of change (steepness) in the X or Y direction at every point in the dataset. The slope of the profile is the angle (in terms of gradient) that it, or its tangent in the case of a curved profile, makes with a line parallel to the reference mean line.

Calculation

X and Y slopes are calculated by comparing the height of a point with the height of the next point—in the X direction for the X slope values and in the Y direction for the Y slope values. The slope calculation is as follows:

$$\text{slope} = \frac{1}{d_o}\left|Z_{j+1} - Z_j\right|$$

where d_o = the lateral spacing of the profile points Z_j.

Uses

X and Y slopes are not normally used in the field as tracking parameters. They are useful, however, for viewing and analyzing such anomalies as disk wear tracks or disk blistering due to a head crash. For example, to examine a surface scratch by eye, you might hold the surface up to the light and tilt it in several directions to let the light reflect off of the scratch. You can simulate this effect by using shading with X and Y slope plots.

Measurement Limitations

You can only see surface textures in the direct X or Y direction. X and Y slopes are only useful for certain types of analyses, and you must have some idea of what you are viewing to make the data meaningful.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
XSlopeRa	XSlope Ra
XSlopeRp	XSlope Rp
XSlopeRq	XSlope Rq
XSlopeRt	XSlope Rt
XSlopeRv	XSlope Rv
YSlopeRa	YSlope Ra
YSlopeRp	YSlope Rp
YSlopeRq	YSlope Rq
YSlopeRt	YSlope Rt
YSlopeRv	YSlope Rv

Intensity

Definition

Intensity data is stored with most datasets. The intensity plot shows the raw intensity from one frame at every point in the dataset.

The intensity plot includes a contour plot and 2D profile plots in the X and Y direction. The profiles show the intensity along the crosshairs on the contour plot.

Uses

The intensity plot is useful for viewing the surface of the sample without interference, as the surface would appear under a non-interferometric microscope of the same magnification.

Measurement Limitations

The intensity plot can only be reconstructed for single datasets. Intensity data is not stored with stitched files, so the intensity contour plot is limited to one field of view.

Power Spectral Density (PSD)

Definition

PSD(*f*), *power spectral density*, is the Fourier decomposition of the measured surface profile into its component spatial frequencies (*f*). The PSD function calculates the power spectral densities for each horizontal (X) or vertical (Y) line in the data, then averages all X or Y profiles.

Basically, the Fourier transform calculates what combination of sine waves makes up a given function. The results are in the form of the amplitude, phase, and frequency of a number of sine waves that, when added together, reproduce the original function. In electronics we analyze signals that are time dependent, while here we analyze profiles that are spatially dependent. Frequency analyzers output the frequency components (Hertz) that make up the signal; we output the spatial frequency components (cycles/mm) that make up the surface profile

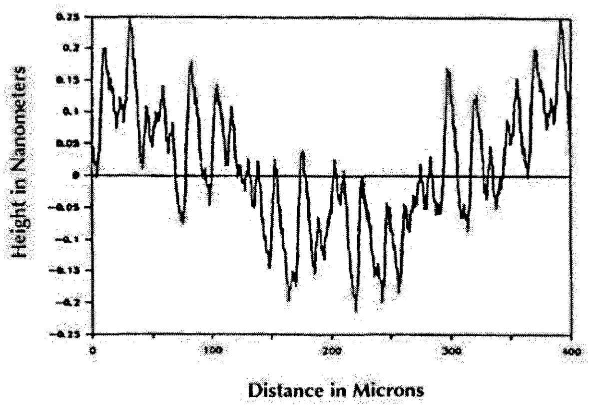


Figure 3-15. Synthesized Surface Profile

Suppose we are given the surface profile pictured in Figure 3-15. The surface appears random in nature with a slight concave upward appearance. The power spectrum of this surface is shown in Figure 3-16. Eight spikes of different heights scattered along the horizontal axis can be seen. The power spectrum shows that the seemingly random surface is the sum of only eight sine waves of different frequency, amplitude, and phase. Each of the eight components is plotted in Figure 3-17. When they are added together, they equal the synthesized profile.

When you calculate the PSD, Wyko Vision32 computes an average lines power spectrum in the X and Y directions and the annular RMS. The output represent the average profile power in X and Y at each spatial frequency and the annular RMS shown on the contour plot.

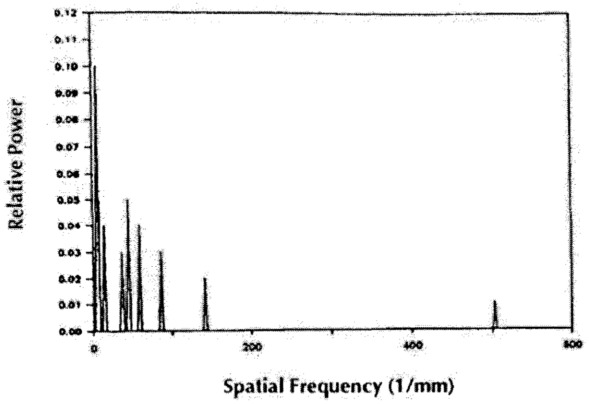


Figure 3-16. Power Spectrum of the Synthesized Surface

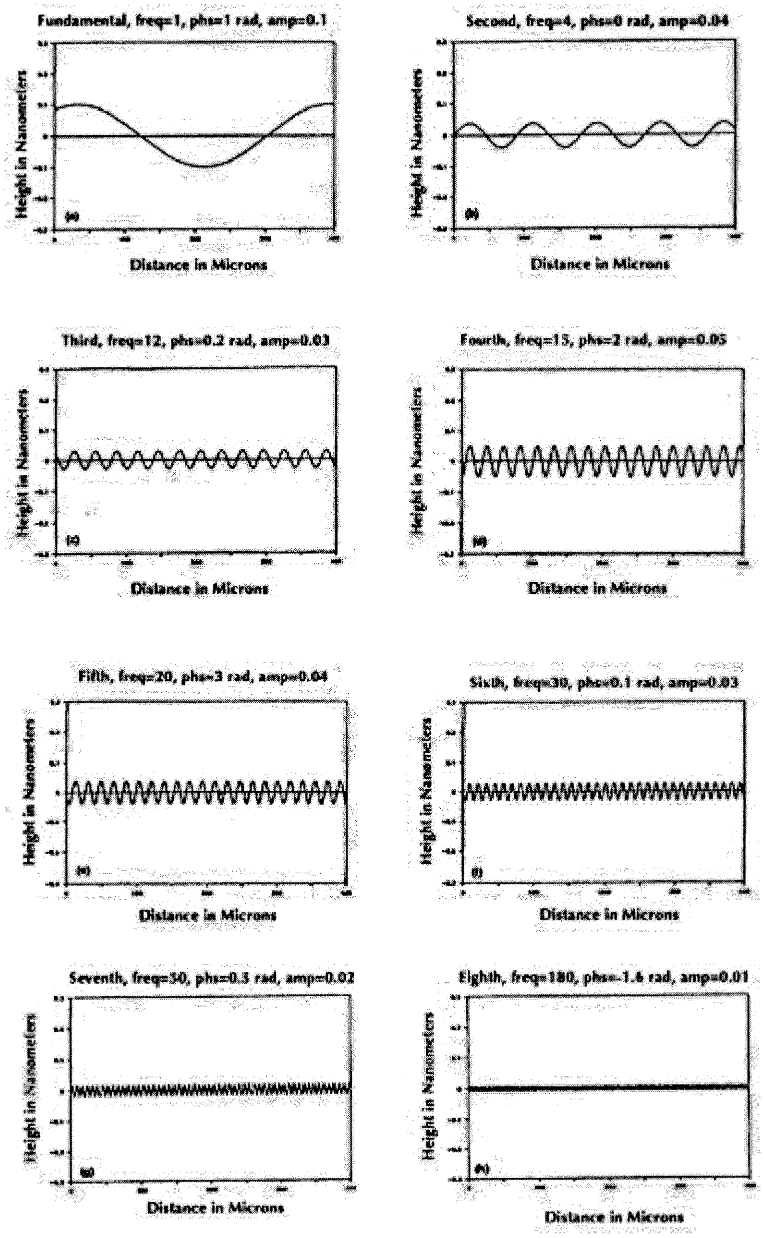


Figure 3-17. Fundamental Through Eighth Component

Calculation

Mathematically, the power spectral density function is the square of the Fourier transform of the original surface profile. For a digitized profile of length L, consisting of N points, the average PSD(*f*) function may be *approximated* by:

$$PSD(f) = \frac{d_o}{N}\left|\sum_{j=1}^{N} Z_j \exp[-i2\pi f(j-1)d_o]\right|^2$$

where $i = \sqrt{-1}$

d_0 = the sampling length

Z_j = the amplitude function

f = the spatial frequency, equal to K/L,

K = an integer that ranges from 1 to N/2.

Uses

There are several things you can learn about a surface from the power spectrum information. The first is the general shape of the function. Most surfaces tend to have power spectrums that fall off monotonically. If the falloff is very steep at the left edge of the plot and less steep thereafter, then the surface is dominated by the longer spatial frequencies and may tend to look wavy. You must make a judgment regarding the difference between waviness and surface roughness.

Power spectrum functions that do not fall off very much over the length of the plot may characterize surfaces that have no waviness, but that have microsurface roughness of a very high spatial frequency. Most surfaces tend to look smoother when examined over smaller and smaller regions. These types of surfaces with a nearly flat power spectrum will have nearly the same roughness, regardless of the spatial frequencies that are measured.

Any deflection in the power spectrum function from a monotonically decreasing function is of interest. Spikes or raised regions that occur anywhere in the data are important. These spikes generally appear in the data taken from periodic surfaces such as diamond-turned surfaces. A spike usually occurs at the spatial frequency associated with the groove spacing remaining after the turning process. If the shape of the groove is not sinusoidal, higher frequency harmonics may be present. Figure 3-18 shows an example of an Average X PSD plot with a spike at a spatial frequency of approximately 3 mm^{-1}. The surface corresponding to this PSD exhibits a repetitive feature every 0.3 mm or so (the inverse of the spatial frequency peak).

Spikes or shoulders in the power spectrum are important and should be examined. They often indicate harmonics of a dominant frequency, which may be the result of a fabrication process. Spikes in the power spectrum usually do not occur naturally in surfaces and are probably a result of some fabrication process. Other examples may include surfaces with depositions of crystals of a certain size, or rolled flexible materials reproducing the characteristics of the roller. In general, you should be suspicious of any spike in the results and should examine them more fully. Figure 3-19 shows an an example of an Average X PSD plot with a shoulder and a more gradual falloff. The surface corresponding to this PSD exhibits more randomly-spaced features than the surface described previously.

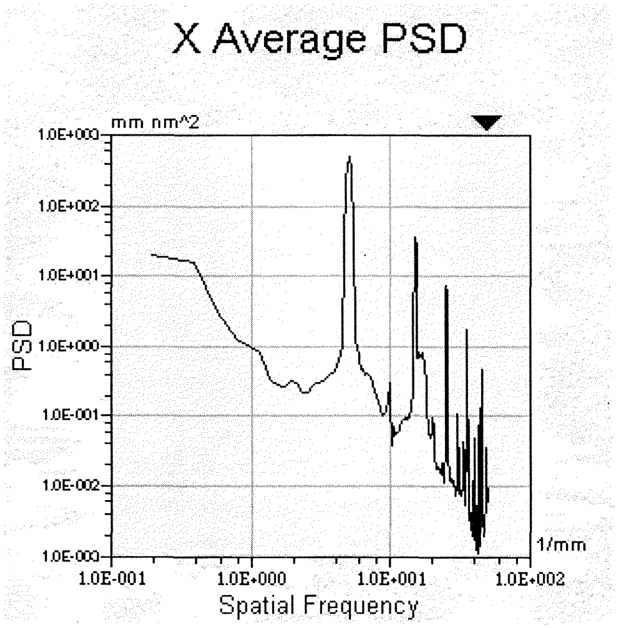


Figure 3-18. Average X PSD Plot of Surface with Repetitive Features

The average lines power spectrum calculation is especially useful for measuring surfaces of an imprecise directional nature. The average lines calculations significantly decrease noise, with random spatial frequencies averaging to zero. This procedure emphasizes nonrandom features, which appear on the plot as obvious shoulders or spikes.

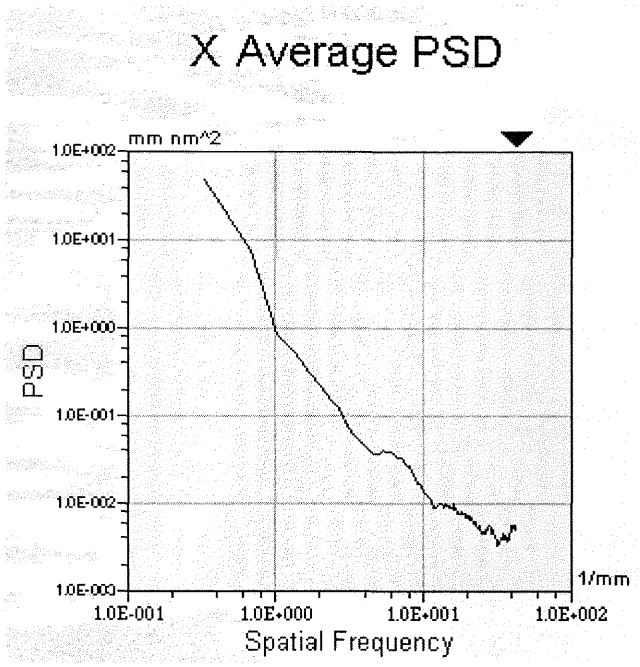


Figure 3-19. Average X PSD Plot of Surface with Random Features

Measurement Limitations

The range of spatial frequencies measured is limited by the objective field of view and spatial sampling. Higher spatial frequencies are smoothed by the instrument transfer function. The power spectrum of a surface may look different, depending on the magnification head used in the measurement. Lower power magnification heads usually show more waviness. By changing to a higher power magnification head, you can perform a simple type of filtering for comparison. The orientation of a surface with nonrandom features also affects the Average X and Y PSD plots.

Fractal Roughness Calculation

The average PSD data is also used to calculate fractal roughness parameters. These parameters provide another way of characterizing surface texture. For randomly polished surfaces, the average PSD is modeled as:

$$PSD(f) = \frac{A}{f^B}$$

where A, B = ISO-standard constants
f = the spatial frequency.

The program uses a linear least-squares fit of the following equation to determine A and B:

$$\log(PSD(f))=\log(A)-B\log(f)$$

The interval of frequencies used in the above equation is defined by the ISO standard as:

$$\frac{1}{D}<f<\frac{1}{C}$$

where 1/D = the program's low frequency cutoff option
1/C = the high frequency cutoff option.

R_f, the fractal roughness, is calculated from the equation below. In nearly all cases, the value of R_f will be between 1 and 2.

$$R_f = \frac{5-B}{2}$$

RMS, a PSD-based roughness that is similar to R_q, is approximated digitally by:

$$RMS = \left[\sum_{(i\cdot\Delta f)\geq\frac{1}{D}}^{(i\cdot\Delta f)\leq\frac{1}{C}} \Delta f\cdot PSD(i)\right]^{\frac{1}{2}}$$

where Δf = the frequency spacing between adjacent points in the PSD array.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
XPSD_A	X Avg PSD A
XPSD_B	X Avg PSD B
XPSD_HCO	X Avg PSD High Cutoff (1/C)
XPSD_LCO	X Avg PSD Low Cutoff (1/D)
XPSD_Rf	X Avg PSD Rf
XPSD_Rms	X Avg PSD RMS
YPSD_A	Y Avg PSD A
YPSD_B	Y Avg PSD B
YPSD_HCO	Y Avg PSD High Cutoff (1/C)
YPSD_LCO	Y Avg PSD Low Cutoff (1/D)
YSPD_Rf	Y Avg PSD Rf
YPSD_Rms	Y Avg PSD RMS

2D PSD

Definition

The 2D PSD calculation calculates the two dimensional PSD between the user-specified high and low frequency cutoffs. Since the center of the contour plot is set as the origin of the graph, the 2D PSD returns the RMS value for an annulus, the inner and outer diameters of which correspond to the low and high frequency cutoffs, respectively. This annulus is displayed on the contour plot with a dark blue outline.

The calculation and the corresponding contour plot are shown on the same display as that of the X and Y Average PSD calculations. By right clicking on the contour plot, you can access the 2D PSD options.

Calculation

See *Calculation* on page 3-17 and *Fractal Roughness Calculation* on page 3-19.

Measurement Limitations

The range of spatial frequencies measured is limited by the objective field of view and spatial sampling. Since the center of the contour plot is set as the origin of the 2D calculation, the range of spatial frequencies is half that of the X and Y Average PSD calculations. Higher spatial frequencies are smoothed by the instrument transfer function. The power spectrum of a surface may look different, depending on the magnification head used in the measurement. Lower power magnification heads usually show more waviness. By changing to a higher power magnification head, you can perform a simple type of filtering for comparison.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
2DPSD_Rms	PSD 2D Annular RMS
2DPSD_HCO	PSD 2D High Cutoff
2DPSD_LCO	PSD 2D Low Cutoff

Cross Hatch

Definition

The cross hatch analysis determines the angle between any two lines or sets of parallel lines in a dataset.

The angle between the lines can be determined automatically or manually. In the automatic method, the PSD is calculated along all radial lines from the center of the dataset. In a plot of PSD versus angle (where the horizontal is set to zero), the PSD will exhibit large spikes when the radial line is perpendicular to the direction of the cross-hatching lines.

Wyko Vision32 requires you to choose one of two situations for the cross hatch angles. **Minimum Separation Angle** prompts you to choose the minimum cross hatch angle allowed between the two sets of lines. Angles below the specification will be ignored. Use **Find 1 positive and 1 negative Angle** if one of the sets of lines makes a positivie angle and one of the sets makes a negative angle with the horizontal. Enter the range of angles allowed for the magnitude of the upper and lower hone angles. Lines at angles outside this range will be ignored.

For manual calculation, position the two cursors along the lines to be measured by clicking and dragging the arrows. The **Manual Angle** is determined from the orientation of the cursors.

The **Upper Hone Angle** and the **Lower Hone Angle**, the angles of each set of lines from the horizontal, are reported. (The Upper Hone Angle is the larger of the two angles.) The **Cross Hatch Angle** is the angle between the upper and lower hone lines.

Uses

One typical application is to determine the angles of grooves in the surface of a honed engine cylinder wall. This analysis can be used on any two sets of periodic lines.

Measurement Limitations

There are limits on the range of angles Wyko Vision32 will allow. For **Minimum Separation**, the minimum angle must be between 2° and 90°. For **Find 1 positive and 1 negative Angle**, the range for the magnitude of the hone angles is limited to 1° — 89°.

The presence of many different sets of lines can skew the calculation. The algorithm works best with two well defined sets of lines or scratches. In addition, if one of the sets of lines is larger and more well-defined than the other set, the PSD may have such a large peak at the corresponding angle that the angle-finding algorithm may be adversely affected.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
XHatchAngle	X-Hatch Angle
XHatchLowerAngle	X-Hatch Lower Angle
XHatchManualAngl	X-Hatch Manual Angle
XHatchUpperAngle	X-Hatch Upper Angle

Autocovariance Function

Definition

ACV(τ), *autocovariance function*, is given by an overlap integral of shifted and unshifted profiles and is also equal to the inverse Fourier transform of the PSD. It is a measure of the correlation properties of the surfaces roughness. ACV is the product of two "copies" of the same surface profile as one is shifted relative to the other. The amount of lateral shift between the two profiles is the *lag length* (τ).

Calculation

In the autocovariance calculation, the program first measures the surface and makes a copy of the surface. Next the program multiplies the surface heights of these duplicate surfaces on a pixel by pixel basis and sums the results. Then the program slides the duplicate surface by one pixel to the right and repeats the calculation. This process continues until the duplicate surface has slid all the way off the original surface.

An analytical definition of ACV for a surface profile of a finite length composed of discrete data points is given by:

$$ACV(\tau_x, \tau_y) = \frac{1}{(AR_q)^2}\left[\sum_{k=0}^{\frac{N}{2}} \sum_{j=0}^{\frac{M}{2}} PSD(f_x, f_y)\exp[i2\pi(f_x\tau_x + f_y\tau_y)]\right]$$

where $\tau_x = j'$, $-N/2<j'<N/2$

$\tau_y = j''d_{0y}$, $-M/2<j''<M/2$

$f_x = K/L_x$

$f_y = J/L_y$

Uses

A high positive value of the ACV indicates that a surface feature will repeat itself for that particular lag length. The value for a lag length of 0, i.e., no lateral shift, is of fundamental importance because it is equal to the square of the rms roughness of the profile.

By examining the autocovariance function, you can learn about the correlation of your surface and the presence of dominant or nondominant spatial frequency components. A random surface generally has low correlation. The auto-covariance function drops quickly toward zero and stays near zero, as seen in Figure 3-20. If the function has additional smaller or higher frequency ripples on the overall shape, there's probably some other nondominant periodic feature on the surface. A surface with periodic features shows higher correlation at periodic distances. Oscillation of the function about zero in a periodic manner indicates the presence of a dominant spatial frequency component, as seen in Figure 3-21.

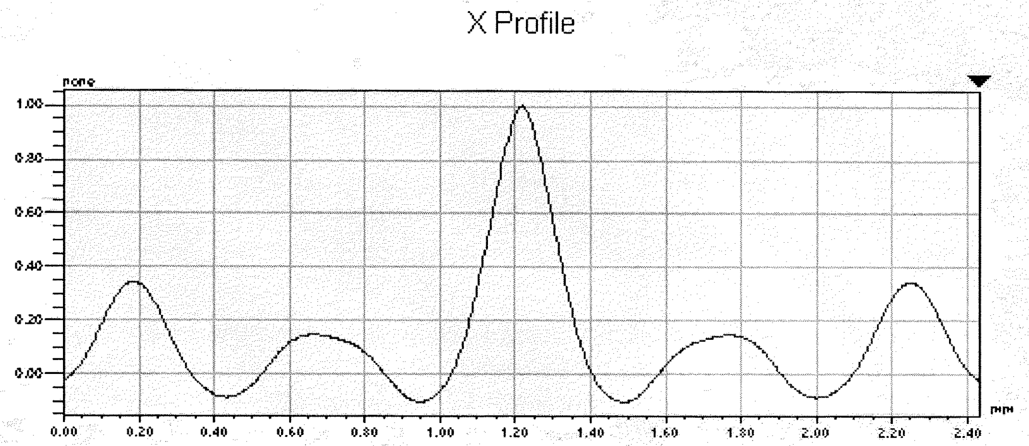


Figure 3-20. Autocovariance Function of Surface with Low Correlation

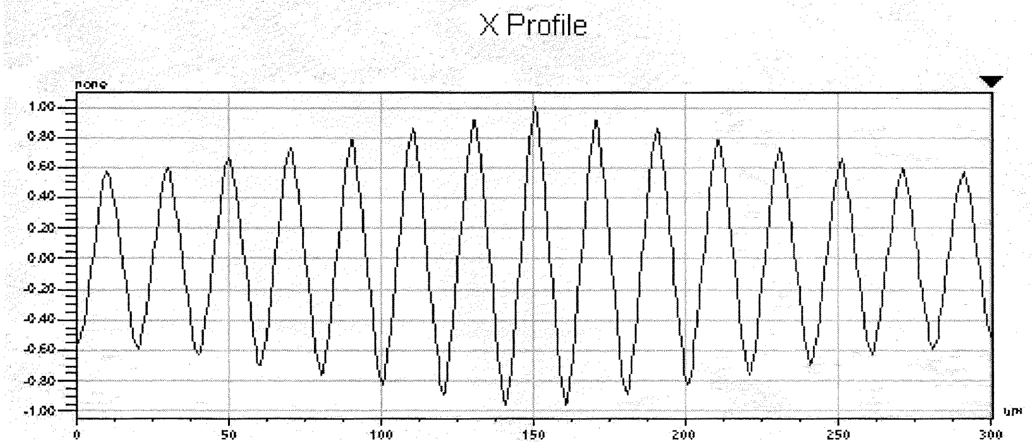


Figure 3-21. Autocovariance Function of Surface with Dominant Spatial Frequency

Measurement Limitations

Because the autocovariance calculation is based on sliding a duplicate surface across the original surface, the autocovariance function is limited by the finite length of the surface profile. As the duplicate surface moves towards the right, fewer and fewer data points are used in the calculation. This, in a sense, is a type of filtering.

Surface Area

Definition

Surface area is the total exposed three-dimensional surface area being analyzed, including peaks and valleys. The lateral surface area is the surface area measured in the lateral direction. An index of the lateral and surface areas is also calculated.

Calculation

To calculate the surface area, four pixels with surface height are used to generate a pixel located in the center with X, Y, and Z dimensions. The four resultant triangular areas are then used to generate approximate cubic volume. This four-pixel window moves through the entire dataset. Bad pixels do not contribute to the calculation.

The lateral surface area is calculated by multiplying the number of valid pixels in the field of view by the XY size of each pixel. The index is calculated by dividing the surface area by the lateral area.

Uses

The surface area index is a measure of the relative flatness of a surface. An index which is very close to unity describes a very flat surface where the lateral (XY) area is very near the total three-dimensional (XYZ) area.

Measurement Limitations

Surface area is dependent on the field of view. However, the surface area index is normalized to give a constant number regardless of the area in the field of view.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
LArea	Lateral Surf Area
SArea	Surface Area
SAreaIndex	SArea Index

Volume

Definition

Volume estimates the volume occupied by the space between a surface and a plane parallel to the reference plane of the surface that intersects the maximum height of the surface. You can visualize this parameter as the minimum volume of water the surface must hold in order to completely “submerge” it. (See Figure 3-22.)

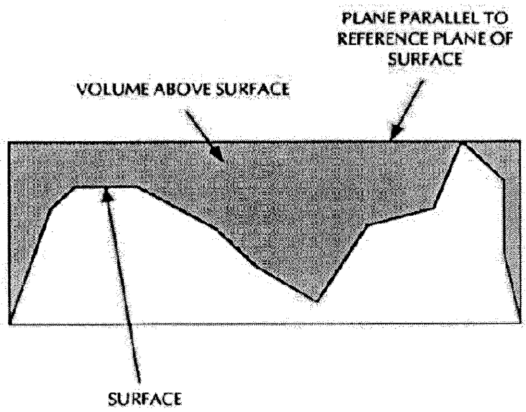


Figure 3-22. Volume

Calculation

The area of the volume above the surface is calculated to find the volume value. By inverting the data before calculating the volume, you can determine the volume of material bounded by the surface. The normalized surface volume, or volume per unit area, is the ratio of the total volume above the surface to the lateral area of the surface. Normalized volume is measured in billions of cubic microns per square inch (BCM) or cubic microns per square millimeter (μ^3/mm^2).

Uses

Of interest is the normalized surface volume. Also of interest is the change in volume above the surface at an arbitrary height below the maximum height of the surface. This function attains its maximum value at R_p, and reaches its minimum value of zero at the minimum value of the surface, R_v. The Volume analysis output is shown as a curve with the relative height of the surface (0 to R_t) versus the volume at that height.

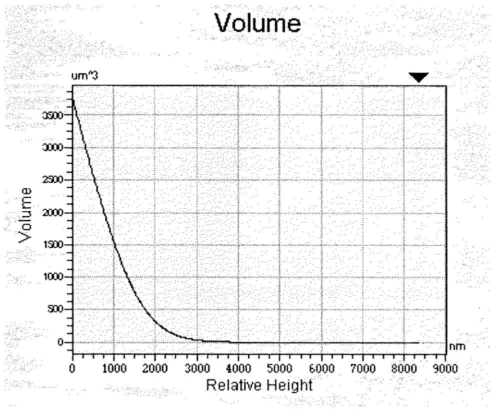


Figure 3-23. Volume Analysis Curve

Measurement Limitations

The spatial frequency content of the surface determines if the normalized surface volume remains constant regardless of the amount of surface measured. Also, if there is any contamination on the surface of the sample, the volume measurement will be skewed.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
Volume	Volume
NegativeVolume	Negative Volume
NetMissingVolume	Net Missing Volume
NormVolume	NormVolume
PositiveVolume	Positive Volume
TotalDisplacedVo	Total Displaced Volume
Vol_opt_String	Volume Options

Line Width

Definition

Line width calculations are performed on features of a surface sample. Horizontal or vertical line widths can be measured.

The line width measurement routine is depicted in Figure 3-24. This routine finds the point of greatest slope on each edge of the feature, then uses the distance between these two points to determine the width of the feature.

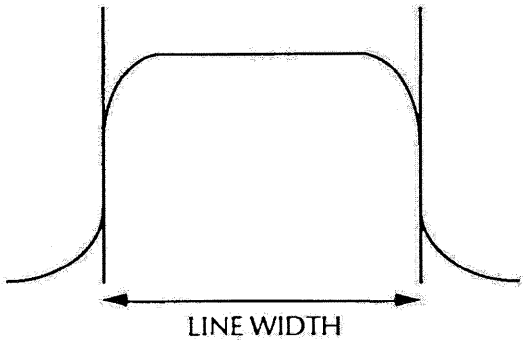


Figure 3-24. Basic Line Width Measurement Routine

This routine defines the calculation of the line width for a single profile. The final line width and line width standard deviation is based on the individual line widths calculated from each profile. (See Figure 3-25.) In this figure, the final line width would be an average with an associated standard deviation.

$$\text{Final Line Width} = \left(\frac{1}{n}\right)(L_1 + L_2 + L_3 + \ldots + L_n)$$

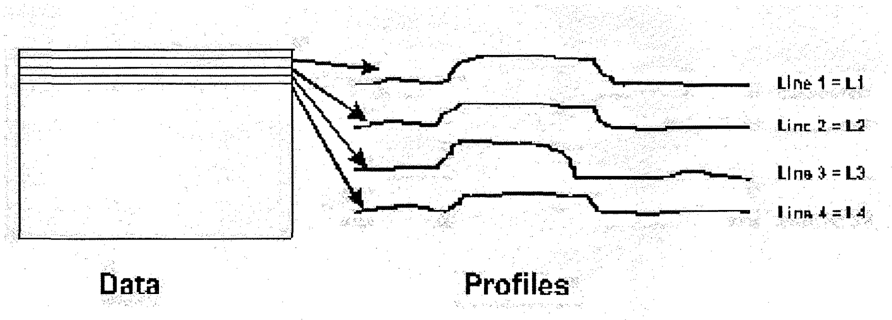


Figure 3-25. Final Line Width with Standard Deviation

Uses

Line width measurements are useful in the semiconductor industry to measure photoresist lines on silicon. They can also be used in the hard drive industry to measure rail widths on thin film magnetic heads.

Measurement Limitations

When line widths are measured across dissimilar materials, phase change effects may occur. In general, highly reflecting line structures in a low-reflectance background will be measured slightly wider than expected, and low reflecting line structures in a high-reflectance background will be measured slightly narrower than expected. These effects of the reflectivity variations are apparent for line widths approaching 2 µm or less. Chapter 4 describes how phase changes between dissimilar materials can affect measurements.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
LineN	Line Width Count
LineStDev	Line Width StDev
LineWidth	Line Width

Step Height

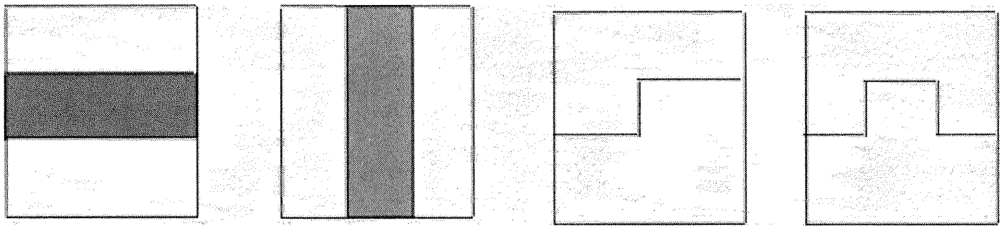
The step height calculation allows you to measure both regular and irregular steps. The differences between these types of steps are outlined below.

Regular Step

Definition

A step is a surface structure characterized by a large height change that occurs over a short distance. An ideal step has infinite slope between adjacent pixels.

The step height value is based on the average of a series of single profile step height calculations. Single- or double-sided step height calculations can be performed, and step orientation can be in the horizontal or vertical direction. Step heights are assumed to have a vertical orientation in Wyko Vision32. (See Figure 3-26.) In general, lines are scanned in the horizontal direction, perpendicular to the step transition.



Horizontal

Vertical

Single-Sided (profile)

Double-Sided (profile)

Figure 3-26. Profile of Regular Steps

First, the edge(s) of the step must be determined. This is done by searching for the maximum slope(s) of the profile. For a single-sided step, a single edge (largest absolute slope magnitude) is found. For a double-sided step, two edges (largest positive slope magnitude and largest negative slope magnitude) are found. These points are assumed to be the center of the step transition. Figure 3-27 shows the step profile and a plot of the slope values. The left edge is marked at the largest positive slope magnitude and the right edge is marked at the largest negative slope magnitude. For single-sided steps, only the largest absolute slope magnitude would be marked.

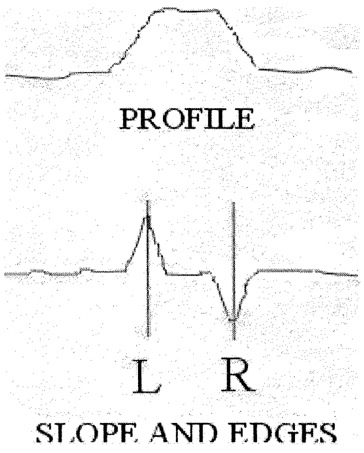


Figure 3-27. Edge Determination

For single-sided step measurements, tilt or curvature is fit to either the left or right side of the step, according to selected parameters. For double-sided step measurements, tilt or curvature is fit to either the base or step, according to selected parameters. These fits are then removed from the entire trace.

The transition zone around each edge is determined. This is done by searching for the position in the slope data to the left and right of each edge where the slope passes the zero level. The transition zones are then removed from the step profile. (See Figure 3-28.).

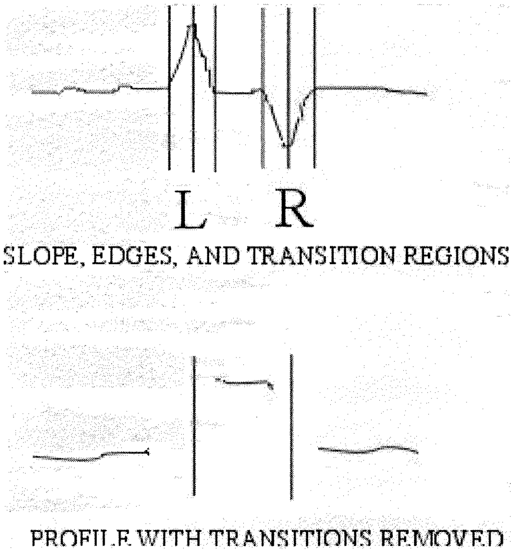
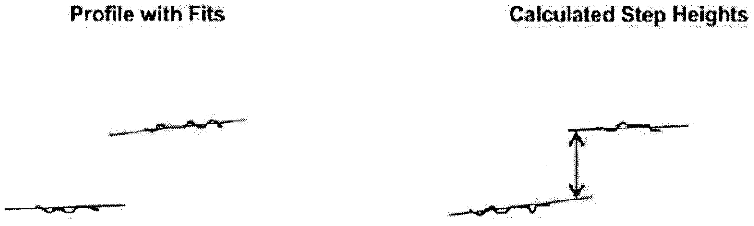


Figure 3-28. Transition Zone Determination

After the edges and transition points have been found, lines are then fit to areas of data defined by the edges and transition points. For a single-sided step, two lines are fit—one to the bottom (left or right) region and one to the top region. (See Figure 3-29.) With the resulting data for single-step height calculations, tilt is fit to either the left or right side only, and the height (H_S) is projected at the center of the step transition. H_S is the single-sided step height.


Profile with Fits

Calculated Step Heights

Figure 3-29. Line Fitting for Single-Sided Step Heights

When Wyko Vision32 performs double-sided step height calculations, it calculates both the left and right single-sided step height values, and an average double-sided step height value. The single-sided step height values are calculated as previously explained. The average double-sided step height is calculated by determining a best fit line at the top and at the bottom of the calculated step heights, and then measuring the height (H_S). (See Figure 3-30.)

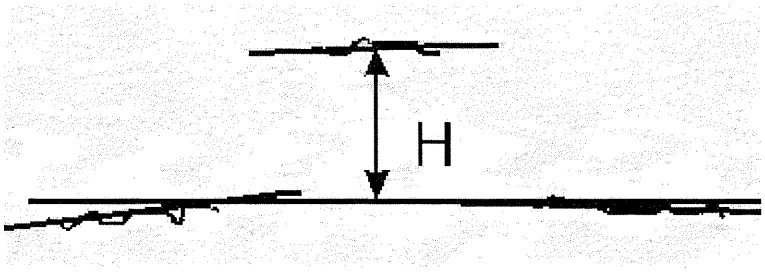


Figure 3-30. Average Double-Sided Step Height Calculation

This procedure defines the calculation of the step height for a single profile. The final step height and step height standard deviation are based on the individual step heights calculated from each profile. (See Figure 3-31.) In this figure, the final step height would be (S1 + S2 + S3 + S4 + ... + Sn)/n, with an associated standard deviation.

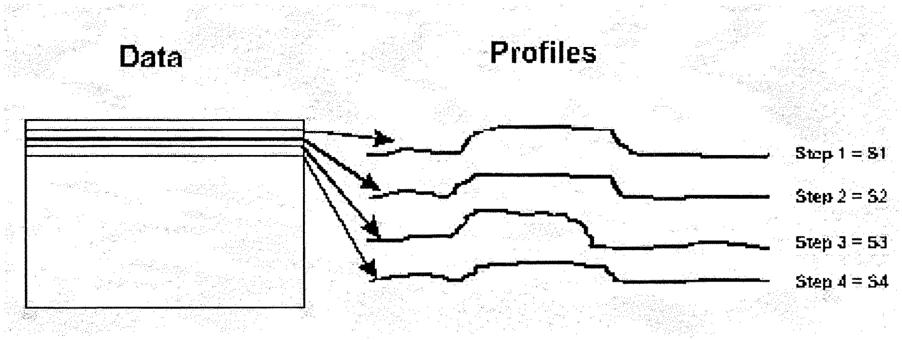


Figure 3-31. Final Step Height with Standard Deviation

Irregular Step Definition

An irregular step refers to a surface structure characterized by several steps within the field of view, where the steps have varying widths and varying distances between them. All steps in the field of view must be bi-level and approximately the same height. Figure 3-32 shows an irregular step with levels L1 and L2. An example of an irregular step surface is a surface with several line patterns that are the same height.

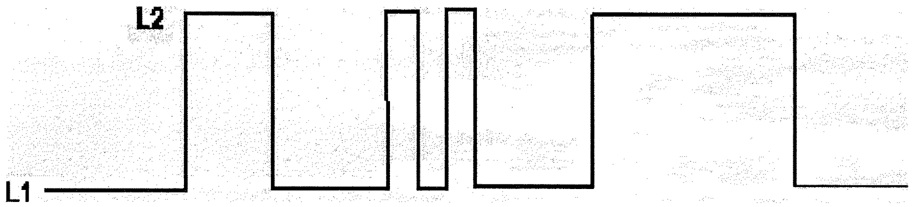


Figure 3-32. Profile of Irregular Steps

First, *you must apply a terms mask to the data to fit tilt correctly. Fitting tilt correctly is critical to the irregular step height calculation.* Once the terms mask is applied, the program uses a histogram of heights to determine the average heights of the step levels L1 and L2. Each of these levels is represented by a distribution on the histogram, as seen in Figure 3-37. Weighted L1 and L2 heights are then calculated by two different methods, which are described in the next sections.

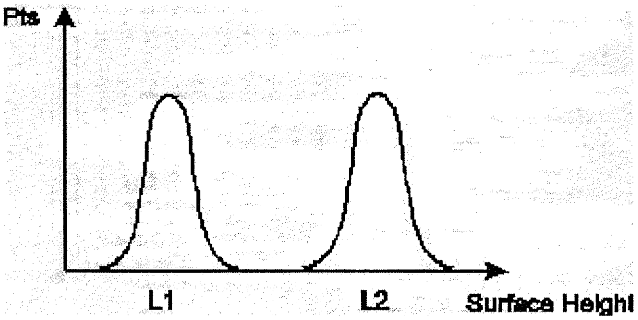


Figure 3-33. Histogram of Heights Showing Distributions for Two Levels

Once the weighted L1 and L2 values are determined for each method, the step height for each method is calculated as the difference between the two levels (Step = L2 - L1). The average, final step height is then based on the step heights for both methods as follows:

$$\text{StepAvg (StepAvg)} = \frac{\text{Step method1 (70pcStepH)} + \text{Step method2 (2sigStepH)}}{2}$$

where the terms outside the parenthesis are the long (extended) database names; the terms inside the parenthesis are the short (block) database names.

70% Method for Irregular Step Height Calculation (Method 1)

1. The user applies a terms mask to fit tilt to a step.
2. The program uses a histogram to determine the binomial peaks.

3. Data points within 70% of the peak for each distribution are retained to calculate new average heights for levels L1 and L2. (See Figure 3-34.)

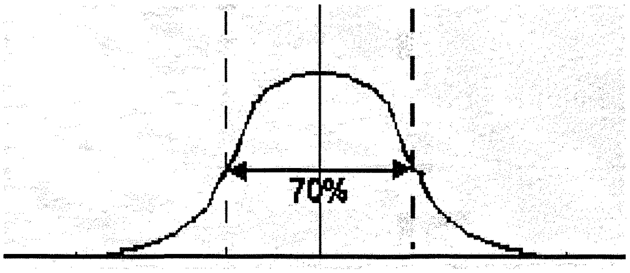


Figure 3-34. 70% of Data Retained

Standard Deviation (Sigma) Method for Irregular Step Height Calculation (Method 2)

1. The user applies a terms mask to fit tilt to a step.
2. The program uses a histogram to determine the binomial peaks.
3. The program calculates the minima between the two peaks; this minima serves to separate the data into two distributions for histograms that do not show a clear separation between distributions
4. The program calculates the standard deviation, sigma (σ), for each distribution.
5. Data within 2 sigma (2σ) of the peak for each distribution are retained to calculate new average heights for levels L1 and L2. (See Figure 3-35.)

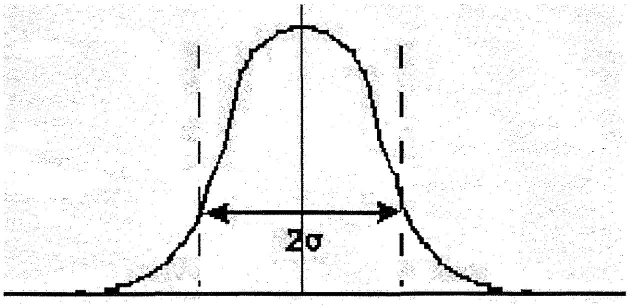


Figure 3-35. 2 Sigma (2σ) of Data Retained

The step height calculation for irregular steps is based on the conditions listed below. *If these conditions are not met, the step height is not calculated.*

Condition for Peak Separation:

$$\text{Separation} > \frac{\text{\# Bins in entire histogram}}{5}$$

Conditions for Peak Heights:

- Calculate the number of points in the peak bin for each distribution.
- Determine the maximum and minimum bin sizes.
- If max bin size > 20X min bin size, then the step height is not calculated.

Uses

Step height analysis is used in the magnetic head industry to measure the formation of heads. Step height standards are also used with the Wyko surface profilers to calibrate VSI measurements.

Measurement Limitations

For accurate measurements of both single- and double-sided step calculations, steps must be oriented vertically, and each step region must be defined by a minimum of three pixels. For single-sided step measurements, the step transition region must be centered in the field of view. For double-sided step measurements, both step regions must be visible in the field of view.

When measuring samples with dissimilar material boundaries, a sample in which the step is a different material from the substrate, the step height can be skewed by several nanometers. This may or may not be a significant amount, depending on the magnitude of the step height.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
StepAvg	StepAvg
StepLAvg	StepLAvg
StepLStDev	StepLStDev
StepN	StepN
StepRAvg	StepRAvg
StepRStdev	StepRStdev
StepStdev	StepStdev
CenterWidth	Step C-Width
CenterWidthStdev	Step C-Width StDev
LeftWidth	Step L-Width
LeftWidthStdev	Setp L-Width StDev
RightWidth	Step R-Width
RightWidthStdev	Step R-Width StDev
StepRLDelta	StepRLDelta
StepBStdev	StepBStdev

StepBAvg	StepBAvg
StepTAvg	StepTAvg
StepTStdev	StepTStdev
StepTBDelta	StepTBDelta
StepType	Step Type
EdgeOrientation	Step Edge Orientation
70pcStepH	Step method1
70pcHP1	Step method1 Peak 1
70pcHP2	Step method1 Peak 2
70pcPIP1	Step method1 Pixels 1
70pcPIP2	Step method1 Pixels 2
70pcPCPIP1	Step method1 %Pixels 1
70pcPCPIP2	Step method1 %Pixels 2
2sigStepH	Step method2
2sigHP1	Step method2 Peak 1
2sigHP2	Step method2 Peak 2
2sigPIP1	Step method2 Pixels1
2sigPIP2	Step method2 Pixels 2
2sigPCPIP1	Step method2 %Pixels 1
2sigPCPIP2	Step method2 %Pixels 2

Stylus Analysis

Definition

Stylus analysis provides a way to measure surface data as a series of 2D traces in either the X or Y direction. The cutoff filters, analysis options, and results options available in the software are comparable to those used with stylus instruments. Stylus analysis includes the calculation of several surface parameters, such as amplitude and spacing parameters, hybrid parameters, and bearing ratio parameters.

Stylus analysis calculations depend on surface parameters you select to be included in the results, digital filter parameters, and the sample length. In stylus analysis, the data is filtered in a way that separates the waviness from the roughness. You can turn filtering on or off and make filtering adjustments by entering your own cutoff values or by allowing the program to automatically select appropriate values.

Surface Parameters Calculated

Roughness:	R_a, R_q, R_{sk}, R_{ku}, R_t, R_p, R_v, R_z, R_{max}, R_{pm}, R_{vm}, S, S_m
Waviness:	Δ_a, Δ_q, λ_a, λ_q
Bearing/PC:	H_{tp}, R_k, R_{pk}, R_{vk}, M_{r1}, M_{r2}, PC

For a detailed discussion of these parameters, see Chapter 2, *Surface Parameters*.

Wavelength Cutoff Options

Long Wave Cutoff

The **Long Wave Cutoff** (also called **Sample Length**) sets the filter to attenuate the long wavelengths (waviness) in the surface profile. This cutoff should be short enough to exclude irrelevant long wavelengths, yet long enough to ensure that enough texture has been included in the evaluation to provide meaningful results. Standard long wave cutoff values are 0.08 mm, 0.25 mm, 0.8 mm, 2.5 mm, 8 mm, or any power of ten times 8 or 25. The long wave cutoff and the number of sample lengths are not completely independent parameters. Their product is limited by the size of the field of view. See the discussion about the long wave cutoff later in *Measurement Limitations* on page 3-40.

Short Wave Cutoff

The **Short Wave Cutoff** sets the filter to attenuate the short wavelengths in the surface profile. It removes high-frequency components, such as noise, that don't contribute to the overall roughness. Standard short wave cutoff values are 0.25 μm, 0.8 μm, 2.5 μm, and 8 μm. The short wave cutoff is related to the stylus diameter.

Types of Filters

The **Filter Types** for separating the long and short wavelengths are **Gaussian**, **Recursive 2RC**, and extended (**EXT**) Gaussian and Recursive 2RC. Both filter types attenuate (dampen) spatial frequency components by applying a transmission factor to the amplitude.

☞ If you do not want to remove waviness, or if you are not interested in stylus-type filtering, select **No Filtering**.

Gaussian Filter

The **Gaussian** filter does not introduce phase distortion, so it is the recommended filter unless you are comparing the results to stylus data taken with a 2RC filter. It is essentially a high bandpass filter that removes waviness. The Gaussian filter masks a minimum of one sample length on each side of the trace.

Recursive 2RC Filter

The **Recursive 2RC** filter mimics the effect of passing the signal through an analog 2RC electronic circuit. It is essentially a high bandpass filter that removes waviness. This filter may introduce phase distortion, thus altering the appearance of surfaces with abrupt features. The 2RC filter masks a minimum of one sample length on each side of the trace.

EXT Filters

The **Recursive 2RC (EXT)** and **Gaussian (EXT)** filters are extended filters that do not mask any sample lengths on either side of the data. This allows for more sample lengths per trace. Because the edges are not masked, data near the edges of the trace may contain artifacts.

Transmission Functions of 2RC and Gaussian Filters

The transmission functions for the 2RC and Gaussian filters are shown in Figure 3-36. The Gaussian transmits 50% at the specified cutoff frequency; the 2RC transmits 75%. In other words, at a specified cutoff wavelength, the amplitude will be 50% or 75% of its original value, depending on the filter selected.

For example, if you want to remove long wavelengths and specify a long wave cutoff of 1 mm with a Gaussian filter, the 1 mm wavelength will be attenuated by 50%. Wavelengths greater than 1 mm will be more severely attenuated according to the shape of the Gaussian curve. Wavelengths less than 1 mm will be less severely attenuated.

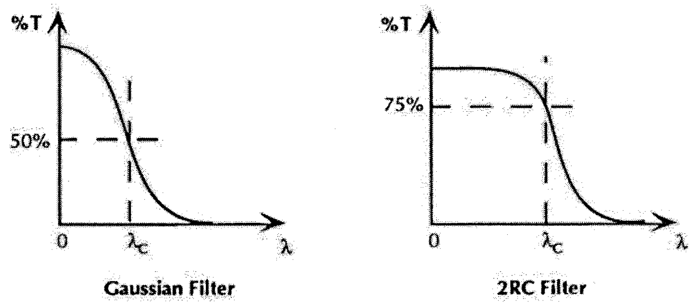


Figure 3-36. Transmission Functions of the Gaussian and 2RC Filters

Number of Sample Lengths

The standard digital filters (2RC and Gaussian) used in the stylus analysis algorithm introduce edge effects near the edges of the dataset. These effects appear within one sample length from each edge. Therefore, the first and last sample lengths are masked during the calculation when standard filters are used. Typically, five sample lengths are used with a traversing length of seven. However, you can use the entire dataset by either not using filters or by using the extended 2RC (EXT) and Gaussian (EXT) filters. If you are not using a filter, select a value of one sample length.

The number of sample lengths and the long wave cutoff are not completely independent parameters. Their product is limited by the size of the field of view. See the section entitled *Measurement Limitations* on page 3-40.

☞ Note that the sample length (not the same as the number of sample lengths) is identical to the long wave cutoff.

Uses

Stylus analysis is useful in two different ways, depending on whether you use specific cutoff filters and analysis options. You can use stylus analysis as follows:

1. When you use values for stylus analysis parameters that are comparable to those used for stylus instruments, you are, in a sense, simulating a measurement made with a stylus instrument. This provides a way of correlating your Wyko surface profiler results to those you would obtain from stylus measurements. Typically, choose a long wave cutoff frequency of 0.8 mm for this application.
2. If you want to calculate standardized surface parameters without stylus filtering, then use the stylus analysis algorithm without using a cutoff filter. In other words, select **No Filtering** as the filter type. This provides 2D analyses, with the average of all statistics calculated for all of the profiles. The results can help you quantify the properties of your test surface based on multiple 2D profiles. Choose "1" for the number of sample lengths for this application.

☞ If you select **No Filtering** for analyzing a surface with a large amount of tilt, cylinder, or other inherent qualities that could distort the data, make sure you remove terms before you calculate surface parameters. You can remove terms through the Processed Options dialog box, which you access by selecting **Analysis » Processed » Options**.

Measurement Limitations

Some of the measurement parameters for stylus analysis depend on other parameters and the value of the Long Wave Cutoff. You may specify the long wave cutoff value or choose **Auto Select** to have Wyko Vision32 select the cutoff for you. The long wave cutoff is related to the field of view, spatial frequencies of the surface, filtering, and the number of sample lengths; the short wave cutoff is related to the lateral resolution (spacing between adjacent pixels) of the objective. Guidelines for these parameters are provided in the next sections.

☞ If **Auto Select** is on, you are limited to cutoff values that are any power of ten times 8 or 25. Otherwise, you can use any cutoff length.

The stylus analysis program can calculate profile data in which small regions of the data array are incomplete (bad pixels). If the array has large regions of incomplete data, the program interpolates across the bad pixels. This may cause unreliable results.

☞ Other digital filtering techniques available through the Processed Options dialog box must be off so you don't filter the data twice.

Long Wave Cutoff

As mentioned earlier, the long wave cutoff depends on the field of view and the apparent spatial frequencies of the surface. The length of a scan produced by a stylus instrument is much longer than the field of view of the Wyko surface profiler magnification objectives. To obtain meaningful results that can be correlated with stylus instrument data, use the following guidelines when setting the long wave cutoff filter:

- Generally, a cutoff of 0.8 mm provides the best results for a field of view (in the X direction) greater than 0.8 mm and less than 8 mm.
- For a larger field of view, use a longer cutoff. For example, if you use the 1.5X objective with an MMD of 0.5X, the field of view is 8.2 mm. For this case, use a cutoff of 2.5 mm to dampen the waviness.
- For a smaller field of view (magnifications of 10X or larger), use a smaller cutoff that is the longest assessment length below 0.8 mm. For example, if you use the 20X objective with an MMD of 1.0X, the field of view is 0.3 mm. For this case, use a cutoff of 0.25 mm.

The long wave cutoff also depends on filtering, sample lengths, and whether **Auto Select** is on or off, as summarized in Table 3-1 and Table 3-2.

Table 3-1. Long Wave Cutoff Related to Filtering

Filter	Effect
ON	LW cutoff limited to 1/3 the width of the data array
OFF	LW cutoff limited to entire width of the data array

For example, if **Auto Select** is on and you are calculating X profiles for an array that is 2.4 mm (in X), the longest allowable long wave cutoff is 0.8 mm. If you enter a value that is too long for the data, the program automatically selects an appropriate value.

Table 3-2. Long Wave Cutoff Related to Sample Lengths

LW Cutoff Auto Select	Sample Length Auto Select	Effect
ON	OFF	Program selects largest LW standard cutoff for user-specified number of sample lengths
ON	ON	Program selects largest LW standard cutoff for 3 sample lengths
OFF	ON	Program selects largest number of sample lengths for user-specified LW cutoff

Short Wave Cutoff

When you use **Auto Select** for the short wave cutoff value, the program selects the smallest standard short wave cutoff the dataset can accommodate. If you enter your own cutoff, use a standard value that is at least 2 times the spacing between adjacent pixels. Otherwise, the filter will have no effect. The Gaussian filter is always used for the short wave cutoff. Note that the short wave cutoff is independent of the long wave cutoff and the number of sample lengths.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
SX_lng_cut	Stylus X Long Cutoff Freq
SX_sht_cut	Stylus X Short Cutoff Freq
SX_Pc_ht	Stylus X Pc Height
SX_Flt_Long	Stylus X Filter Type (Long)
SX_Flt_Shrt	Stylus X Filter Type (Short)
SX_asm_1	Stylus X Assessment Length
SX_Del_a	Stylus X Delta_a
SX_Del_a_H	Stylus X Delta_a High
SX_Del_a_L	Stylus X Delta_a Low

SX_D_a_RMS	Stylus X Delta_a RMS
SX_Del_q	Stylus X Delta_q
SX_Del_q_H	Stylus X Delta_q High
SX_Del_q_L	Stylus X Delta_q Low
SX_D_q_RMS	Stylus X Delta_q RMS
SX_Htp	Stylus X Htp
SX_Htp_H	Stylus X Htp High
SX_Htp_L	Stylus X Htp Low
SX_Htp_RMS	Stylus X Htp RMS
SX_Lam_a	Stylus X Lambda_a
SX_Lam_a_H	Stylus X Lambda_a High
SX_Lam_a_L	Stylus X Lambda _a Low
SX_Lam_a_RMS	Stylus X Lambda_a RMS
SX_Lam_q	Stylus X Lambda_q
SX_Lam_q_H	Stylus X Lambda_q High
SX_Lam_q_L	Stylus X Lambda_q Low
SX_Lam_q_RMS	Stylus X Lambda_q RMS
SX_Mr1	Stylus X Mr1
SX_Mr1_H	Stylus X Mr1 High
SX_Mr1_L	Stylus X Mr1 Low
SX_Mr1_RMS	Stylus X Mr1 RMS
SX_Mr2	Stylus X Mr2
SX_Mr2_H	Stylus X Mr2 High
SX_Mr2_L	Stylus X Mr2 Low
SX_Mr2_RMS	Stylus X Mr2 RMS
SX_num_1	Stylus X Num Sample Length
SX_lines	Stylus X Num Valid Lines
SX_Pc	Stylus X Pc
SX_Pc_H	Stylus X Pc High
SX_Pc_L	Stylus X Pc Low
SX_Pc_RMS	Stylus X Pc RMS
SX_Ra	Stylus X Ra
SX_Ra_H	Stylus X Ra High
SX_Ra_L	Stylus X Ra Low
SX_Ra_RMS	Stylus X Ra RMS
SX_Rk	Stylus X Rk
SX_Rk_H	Stylus X Rk High
SX_Rk_L	Stylus X Rk Low

SX_Rk_RMS	Stylus X Rk RMS
SX_Rku	Stylus X Rku
SX_Rku_H	Stylus X Rku High
SX_Rku_L	Stylus X Rku Low
SX_Rku_RMS	Stylus X Rku RMS
SX_Rmax	Stylus X Rmax
SX_Rmax_H	Stylus X Rmax High
SX_Rmax_L	Stylus X Rmax Low
SX_Rmax_RMS	Stylus X Rmax RMS
SX_Rp	Stylus X Rp
SX_Rp_H	Stylus X Rp High
SX_Rp_L	Stylus X Rp Low
SX_Rp_RMS	Stylus X Rp RMS
SX_Rpk	Stylus X Rpk
SX_Rpk_H	Stylus X Rpk High
SX_Rpk_L	Stylus X Rpk Low
SX_Rpk_RMS	Stylus X Rpk RMS
SX_Rpm	Stylus X Rpm
SX_Rpm_H	Stylus X Rpm High
SX_Rpm_L	Stylus X Rpm Low
SX_Rpm_RMS	Stylus X Rpm RMS
SX_Rq	Stylus X Rq
SX_Rq_H	Stylus X Rq High
SX_Rq_L	Stylus X Rq Low
SX_Rq_RMS	Stylus X Rq RMS
SX_Rsk	Stylus X Rsk
SX_Rsk_H	Stylus X Rsk High
SX_Rsk_L	Stylus X Rsk Low
SX_Rsk_RMS	Stylus X Rsk RMS
SX_Rt	Stylus X Rt
SX_Rt_H	Stylus X Rt High
SX_Rt_L	Stylus X Rt Low
SX_Rt_RMS	Stylus X Rt RMS
SX_Rv	Stylus X Rv
SX_Rv_H	Stylus X Rv High
SX_Rv_L	Stylus X Rv Low
SX_Rv_RMS	Stylus X Rv RMS
SX_Rvk	Stylus X Rvk

SX_Rvk_H	Stylus X Rvk High
SX_Rvk_L	Stylus X Rvk Low
SX_Rvk_RMS	Stylus X Rvk RMS
SX_Rvm	Stylus X Rvm
SX_Rvm_H	Stylus X Rvm High
SX_Rvm_L	Stylus X Rvm Low
SX_Rvm_RMS	Stylus X Rvm RMS
SX_Rz	Stylus X Rz
SX_Rz_H	Stylus X Rz High
SX_Rz_L	Stylus X Rz Low
SX_Rz_RMS	Stylus X Rz RMS
SX_S	Stylus X S
SX_S_H	Stylus X S High
SX_S_L	Stylus X S Low
SX_S_RMS	Stylus X S RMS
SX_Sm	Stylus X Sm
SX_Sm_H	Stylus X Sm High
SX_Sm_L	Stylus X Sm Low
SX_Sm_RMS	Stylus X Sm RMS
SX_BRB	Stylus X BR Bins
SX_BRP	Stylus X BR Peak Offset
SX_BRV	Stylus X BR Valley Offset
SY_lng_cut	Stylus Y Long Cutoff Freq
SY_sht_cut	Stylus Y Short Cutoff Freq
SY_Pc_ht	Stylus Y Pc Height
SY_Flt_Long	Stylus Y Filter Type (Long)
SY_Flt_Shrt	Stylus Y Filter Type (Short)
SY_asm_1	Stylus Y Assessment Length
SY_Del_a	Stylus Y Delta_a
SY_Del_a_H	Stylus Y Delta_a High
SY_Del_a_L	Stylus Y Delta_a Low
SY_D_a_RMS	Stylus Y Delta_a RMS
SY_Del_q	Stylus Y Delta_q
SY_Del_q_H	Stylus Y Delta_q High
SY_Del_q_L	Stylus Y Delta_q Low
SY_D_q_RMS	Stylus Y Delta_q RMS
SY_Htp	Stylus Y Htp
SY_Htp_H	Stylus Y Htp High

SY_Htp_L	Stylus Y Htp Low
SY_Htp_RMS	Stylus Y Htp RMS
SY_Lam_a	Stylus Y Lambda_a
SY_Lam_a_H	Stylus Y Lambda_a High
SY_Lam_a_L	Stylus Y Lambda_a Low
SY_Lam_a_RMS	Stylus Y Lambda_a RMS
SY_Lam_q	Stylus Y Lambda_q
SY_Lam_q_H	Stylus Y Lambda_q High
SY_Lam_q_L	Stylus Y Lambda_q Low
SY_Lam_q_RMS	Stylus Y Lambda_q RMS
SY_Mr1	Stylus Y Mr1
SY_Mr1_H	Stylus Y Mr1 High
SY_Mr1_L	Stylus Y Mr1 Low
SY_Mr1_RMS	Stylus Y Mr1 RMS
SY_Mr2	Stylus Y Mr2
SY_Mr2_H	Stylus Y Mr2 High
SY_Mr2_L	Stylus Y Mr2 Low
SY_Mr2_RMS	Stylus Y Mr2 RMS
SY_num_1	Stylus Y Num Sample Lengths
SY_lines	Stylus Y Num Valid Lines
SY_Pc	Stylus Y Pc
SY_Pc_H	Stylus Y Pc High
SY_Pc_L	Stylus Y Pc Low
SY_Pc_RMS	Stylus Y Pc RMS
SY_Ra	Stylus Y Ra
SY_Ra_H	Stylus Y Ra High
SY_Ra_L	Stylus Y Ra Low
SY_Ra_RMS	Stylus Y Ra RMS
SY_Rk	Stylus Y Rk
SY_Rk_H	Stylus Y Rk High
SY_Rk_L	Stylus Y Rk Low
SY_Rk_RMS	Stylus Y Rk RMS
SY_Rku	Stylus Y Rku
SY_Rku_H	Stylus Y Rku High
SY_Rku_L	Stylus Y Rku Low
SY_Rku_RMS	Stylus Y Rku RMS
SY_Rmax	Stylus Y Rmax
SY_Rmax_H	Stylus Y Rmax High

SY_Rmax_L	Stylus Y Rmax Low
SY_Rmax_RMS	Stylus Y Rmax RMS
SY_Rp	Stylus Y Rp
SY_Rp_H	Stylus Y Rp High
SY_Rp_L	Stylus Y Rp Low
SY_Rp_RMS	Stylus Y Rp RMS
SY_Rpk	Stylus Y Rpk
SY_Rpk_H	Stylus Y Rpk High
SY_Rpk_L	Stylus Y Rpk Low
SY_Rpk_RMS	Stylus Y Rpk RMS
SY_Rpm	Stylus Y Rpm
SY_Rpm_H	Stylus Y Rpm High
SY_Rpm_L	Stylus Y Rpm Low
SY_Rpm_RMS	Stylus Y Rpm RMS
SY_Rq	Stylus Y Rq
SY_Rq_H	Stylus Y Rq High
SY_Rq_L	Stylus Y Rq Low
SY_Rq_RMS	Stylus Y Rq RMS
SY_Rsk	Stylus Y Rsk
SY_Rsk_H	Stylus Y Rsk High
SY_Rsk_L	Stylus Y Rsk Low
SY_Rsk_RMS	Stylus Y Rsk RMS
SY_Rt	Stylus Y Rt
SY_Rt_H	Stylus Y Rt High
SY_Rt_L	Stylus Y Rt Low
SY_Rt_RMS	Stylus Y Rt RMS
SY_Rv	Stylus Y Rv
SY_Rv_H	Stylus Y Rv High
SY_Rv_L	Stylus Y Rv Low
SY_Rv_RMS	Stylus Y Rv RMS
SY_Rvk	Stylus Y Rvk
SY_Rvk_H	Stylus Y Rvk High
SY_Rvk_L	Stylus Y Rvk Low
SY_Rvk_RMS	Stylus Y Rvk RMS
SY_Rvm	Stylus Y Rvm
SY_Rvm_H	Stylus Y Rvm High
SY_Rvm_L	Stylus Y Rvm Low
SY_Rvm_RMS	Stylus Y Rvm RMS

SY_Rz	Stylus Y Rz
SY_Rz_H	Stylus Y Rz High
SY_Rz_L	Stylus Y Rz Low
SY_Rz_RMS	Stylus Y Rz RMS
SY_S	Stylus Y S
SY_S_H	Stylus Y S High
SY_S_L	Stylus Y S Low
SY_S_RMS	Stylus Y S RMS
SY_Sm	Stylus Y Sm
SY_Sm_H	Stylus Y Sm High
SY_Sm_L	Stylus Y Sm Low
SY_Sm_RMS	Stylus Y Sm RMS
SY_BRB	Stylus Y BR Bins
SY_BRP	Stylus Y BR Peak Offset
SY_BRV	Stylus Y BR Valley Offset

Digital High/Low Pass

Definition

The digital high/low pass analysis applies both a digital high and low pass filter to the dataset. In the digital filtering algorithms, an FFT (Fast Fourier Transform) mathematically removes data which have a spatial frequency below or above a user-specified cutoff frequency. High pass filters suppress waviness and general surface shape, emphasizing the surface roughness and microstructure. Low pass filters suppress roughness, leaving the waviness and general form of the surface. This analysis performs the same function as selecting digital filters in the **Processed Options** dialog box. (For more information, see *Digital Filtering* on page 4-8)

Uses

The digital high/low pass analysis is a quick and easy way to see how various low and high pass filters affect the data. Once the cutoffs are defined, the analysis displays the unfiltered data, the data with a low pass filter applied, and the data with a high pass filter applied as contour plots, allowing you to view the affects of each filter simulatneously.

☞ The digital filters available in the Processed Options dialog will filter the data before any analysis is applied. If a digital filter is selected for use while the Digital High/Low Pass analysis is used, the data will be filtered twice.

Measurement Limitations

This analysis is a visual analysis only. Filters applied in the Digital High/Low Pass analysis will not apply to other analyses. If filters are needed in other analyses, use the Digital High/Low Pass analysis to determine the appropriate filter and cutoff, then apply the filter to the entire dataset using the filters available in Processed Options.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
RCut	Roughness Cutoff Freq
RRa	Roughness Ra
RRp	Roughness Rp
RRq	Roughness Rq
RRt	Roughness Rt
RRv	Roughness Rv
WCut	Waviness Cutoff Freq
WRa	Waviness Ra
WRp	Waviness Rp
WRq	Waviness Rq
WRt	Waviness Rt
WRv	Waviness Rv

Multiple Region Analysis

Definition

Multiple region analysis calculates surface statistics for separated regions of data on your sample. These regions can be features higher than the background surface, such as peaks or bumps, or they can be features lower than the background surface, such as valleys or indents.

Calculation

The software program identifies multiple regions on the sample in one of four ways—by separation, by height, by designated levels, or by threshold.

When you select the **Separation** method for finding regions, the program searches for individual regions that are completely separated from others. Each region must be completely surrounded by invalid pixels for this method. In other words, the background must be either unresolvable or intentionally masked from the analysis, and the regions must be isolated, resolvable features.

When you select the **Height** method for finding regions, the program uses a histogram of height distributions to determine which histogram peak corresponds to the background and which histogram peak corresponds to other features, such as a bump or an indent. The background height will show up as one peak on the histogram, while regions higher or lower than the background material will show up as a different peak. The program assumes the highest peak corresponds to the background unless you specify otherwise with the **Regions have greater area than background** check box. Once the program determines the surface's height distribution, it can identify the separate regions.

Figure 3-37 shows the histogram of a sample that contains one height level of isolated regions. The tall peak corresponds to the background; the short peak corresponds to the regions. For this sample, you would set the **Number of Levels** option to 2. If there were two height levels of isolated islands, the histogram would show three peaks and you would set the **Number of Levels** option to 3.

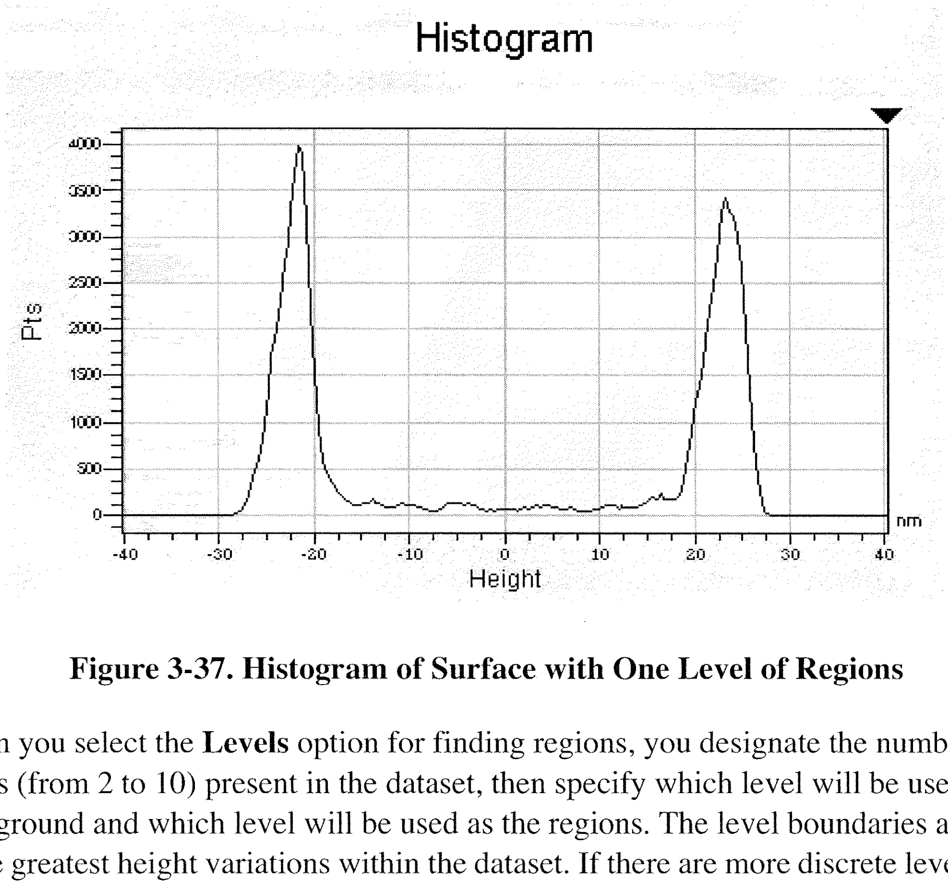


Figure 3-37. Histogram of Surface with One Level of Regions

When you select the **Levels** option for finding regions, you designate the number of discrete levels (from 2 to 10) present in the dataset, then specify which level will be used as the background and which level will be used as the regions. The level boundaries are determined at the greatest height variations within the dataset. If there are more discrete levels in a dataset than are specified in the **Number of Levels**, the closest levels will be lumped together.

When you select the **Threshold** method for finding regions, the program uses a height threshold to define the cutoff between the background and the desired regions on the surface. Set the **Region Level** to **Peaks** to find non-background regions higher than the threshold. Set the **Region Level** to **Valleys** to find non-background regions lower than the threshold value. This method is best for surfaces in which the edges of the regions gradually blend into the background surface without producing clean boundaries between features. A histogram of this type of surface does not show two distinct peaks, so Wyko Vision32 cannot distinguish the background from the regions. The threshold value specifies which data are considered background and which data are considered regions—data that are higher than the background data by the specified threshold are identified as high regions.

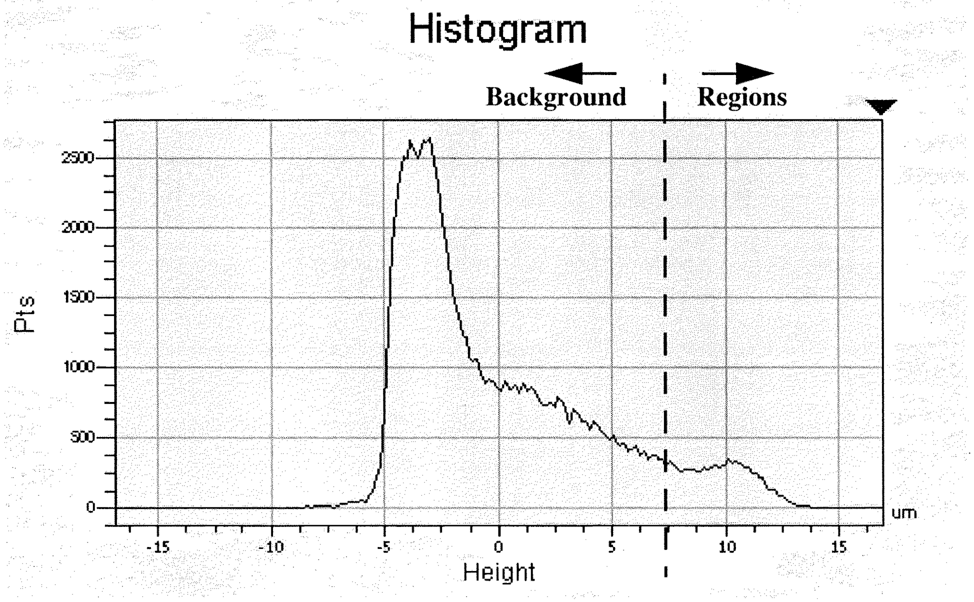


Figure 3-38. Threshold on Histogram of Surface Lacking Background/Regions Separation

On the histogram, the threshold is the distance from the top of the peak. Data with heights to the right of the threshold are considered high regions; data with heights to the left of the threshold are considered background. Figure 3-38 shows a histogram of a surface lacking a clean boundary between the background and the high regions, and how a threshold cutoff serves to create the separation needed to identify the regions. In Figure 3-38 the threshold is arbitrarily set at 8 µm. When setting your own threshold, you may need to try a few different values to determine the optimum cutoff between the background and the regions.

As the program identifies regions, it also uses the minimum region size you specify to evaluate whether the region should be considered for analysis. You can specify the minimum cutoff size in terms of number of pixels, area, or percentage of total pixels. Any region with a size below this value would not be included in multiple region analysis. The program identifies regions as high points (peaks or bumps) or low points (valleys or indents) based on whether you have selected the **Find Peaks** option or the **Find Valleys** option.

Parameters Calculated

Multiple region analysis calculates several parameters for each region. You can select which ones will be displayed on the multiple region output display by selecting the **Statistics** button and then checking the desired parameters. The statistical parameters in the Individual Parameters Displayed box are calculated for each individual region. The calculations for each region are independent of the other regions or the background. Parameters included in the Relative Parameters Displayed box are calculated relative to the reference region.

The reference region, which is initially the largest region, is indicated on the plot by the presence of an asterisk (*). You can change the reference region by positioning the mouse over the region you want as the new reference, then pressing the SHIFT key and clicking the right mouse button at the same time.

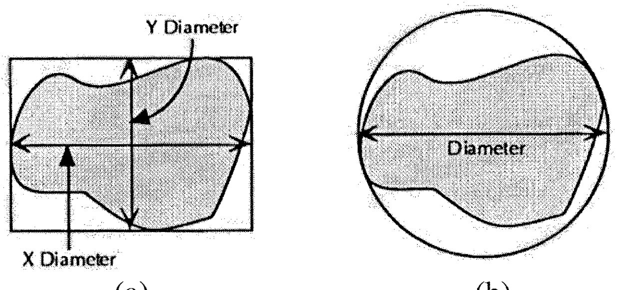
☞ You can write the region statistics to a comma-separated-variable (csv) file, which can then be imported into a spreadsheet program. On the Parameter Output File section of the Multiple Region Statistics dialog box, click the **On** check box and enter a filename with a `.csv` extension.

Besides selecting specific parameters to be calculated, you can remove terms such as mean, tilt, and curvature from each individual region. *Mean* performs a zero mean, *tilt* removes tilt, and *curvature and tilt* removes both curvature and tilt. For more information about terms removal,see Chapter 3, *Analysis Options*, and your system's online help.

For multiple region statistics, the following definitions apply:

R_t, R_p, R_v	These standard surface parameters are discussed fully in Chapter 2, "Surface Parameters."
R_a, R_q	These standard surface parameters are discussed fully in Chapter 2.
R_{sk}, R_{ku}	These standard surface parameters are discussed fully in Chapter 2.
Mean	When regions are identified by height, this is the mean region height above the background. When regions are identified by separation, this is the mean height of the dataset.
Data Points	The number of valid data points in the region.

X Diameter, Y Diameter	When a box is drawn to encompass the region (island), the *X Diameter* is the width of the box and the *Y Diameter* is the height of the box. (See Figure 3-39 (a).)



(a) (b)

Figure 3-39. Definition of Diameter Parameters for Multiple Region Analysis

XY Diameter	The average of the *X Diameter* and *Y Diameter* parameters: $XYDiameter = \frac{XDiameter + YDiameter}{2}$
Diameter	When a circle is drawn to encompass the region (island), this is the diameter of the circle. (See Figure 3-39 (b).) (Also known as Island Diameter.)
Area	The number of pixels in the region (island) multiplied by the area of one pixel: Area = Number of Pixels X Area of Pixel
A Diameter	The diameter of a circle of an area equivalent to the area of the island. Note that the area for this calculation is not the same as the Area parameter described above. (Also called Area Diameter.)
Volume	The area multiplied by the mean height: Volume = Island Area X Mean Height
X Sag, Y Sag	The maximum curvature height in either the X or the Y direction. Sag sign conventions are shown in Figure 3-40. Tilt is removed in the calculation of sag.

Figure 3-40. Sag Sign Conventions

X Tilt,	The amount of tilt in either the X or the Y direction.

Y Tilt	Tilt sign conventions are shown in Figure 3-41. Tilt is calculated relative to either the background or the mean height, depending on whether you select **None** or **Mean**, respectively, for terms removal.

Figure 3-41. Tilt Sign Conventions

Full Diameter	For regions with steep sides, the full region may not be resolved completely, resulting in a partial region that is smaller than it should be. When you select this option, bad pixels along the sides of the region are restored to obtain the full region. Once the full region is restored, the **Full Diameter** calculation is identical to that of the **Diameter** parameter.
Full X Diameter, Full Y Diameter	For regions with steep sides, the full region may not be resolved completely, resulting in a partial region that is smaller than it should be. When you select this option, bad pixels along the sides of the region are restored to obtain the full region. Once the full region is restored, the **Full X Diameter** and **Full Y Diameter** calculations are identical to those of the **X Diameter** and **Y Diameter** parameters.
X Center, Y Center	The center points of the region in the X and Y directions, relative to the lower left corner of the region.
Line Width	Line width of a line-shaped region, calculated by averaging the individual line width traces along the region.
Line Width Std Dev	Standard deviation of the line width calculation.
Rp%	The average roughness of a specified percentage of the highest data points (peaks) in the region. The percentage amount is specified with the **R% Percent** option.
Rv%	The average roughness of a specified percentage of the lowest data points (valleys) in the region. The percentage amount is specified with the **R% Percent** option.
Rt%	Rt% = Rp% - Rv%
Incline	The incline of a specific island relative to the reference island, as shown in Figure 3-46.

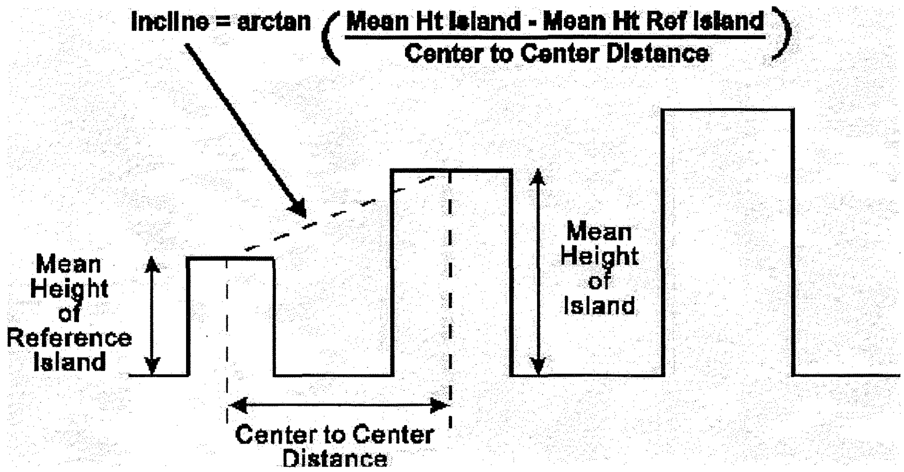


Figure 3-42. Incline Parameter

Uses

Multiple region analysis is useful in the optical industry for analyzing samples with multiple optical components on the same surface, such as blocked parts. It is also useful for analyzing solder bumps or traces on circuit boards. Multiple region analysis is not limited to these applications—you can use it for analyzing any surface with isolated regions of data.

Measurement Limitations

By examining a histogram of your surface's heights, you can see how many histogram peaks are present and how well defined they are. If there is one tall peak (the background) and only one or two other smaller peaks (the regions), the analysis will provide meaningful information. If there are multiple peaks or no clear peaks on the histogram, the analysis results may not be meaningful. This applies to surfaces in which the multiple regions are the same height as other general surface features.

In the analysis, the regions must be distinguished from the background. If the edges of the regions gradually blend into the background, the distinction between the regions and the background is not as clear. There are two methods you can use that will create a physical separation to help distinguish the regions from the background:

1. Use an analysis or detector mask to outline the regions and mask the background from the analysis. The height threshold mask, a special type of analysis mask, might be especially useful in multiple region analysis to block or pass data points based on their heights. You create a height threshold mask by pressing the **Hist** button on the Mask Editor, and then editing the surface height histogram that appears in the Histogram dialog box.

2. Use the **Threshold** method for finding regions. This method specifies a cutoff between the regions and the background. For more information, see *Calculation* on page 3-48

Sometimes the program may not identify every isolated region on the surface. If this happens, you can outline one region at a time to be added to the analysis. To outline new regions from the multiple region output display, single-click the left mouse button to draw the sides of a polygon around the region, then double-click to complete the polygon.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
MRAlgorithm	MultiReg Algorithm
MRAvgADiam	MultiReg Avg A Diam
MRAvgArea	MultiReg Avg Area
MRAvgHeight	MultiReg Avg Height
MRAvgVolume	MultiReg Avg Volume
MRAvgXDiam	MultiReg Avg X Diam
MRAvgXYDiam	MultiReg Avg XY Diam
MRAvgYDiam	MultiReg Avg Y Diam
MRBackRa	MultiReg Background Ra
MRBackRq	MultiReg Background Rq
MRIslands	MultiReg Islands
MRMaxADiam	MultiReg Max A Diam
MRMaxADRgn	MultiReg Max AD Rgn
MRMaxADXLoc	MultiReg Max AD X Loc
MRMaxADYLoc	MultiReg Max AD Y Loc
MRMaxArea	MultiReg Max Area
MRMaxAreaRgn	MultiReg Max Area Rgn
MRMaxAreaXLoc	MultiReg Max Area X Loc
MRMaxAreaYLoc	MultiReg Max Area Y Loc
MRMaxHeight	MultiReg Max Height
MRMaxHtRgn	MultiReg Max Ht Rgn
MRMaxHtXLoc	MultiReg Max Ht X Loc
MRMaxHtYLoc	MultiReg Max Ht X Loc
MRMaxVol	MultiReg Max Vol
MRMaxVolRgn	MultiReg Max Vol Rgn
MRMaxVolXLoc	MultiReg Max Vol X Loc
MRMaxVolYLoc	MultiReg Max Vol Y Loc
MRMaxXDiam	MultiReg Max X Diam

MRMaxXDRgn	MultiReg Max XD Rgn
MRMaxXDXLoc	MultiReg Max XD X Loc
MRMaxXDYLoc	MultiReg Max XD Y Loc
MRMaxXYDiam	MultiReg Max XY Diam
MRMaxXYDRgn	MultiReg Max XYD Rgn
MRMaxXYDXLoc	MultiReg Max XYD X Loc
MRMaxXYDYLoc	MultiReg Max XYD Y Loc
MRMaxYDiam	MultiReg Max Y Diam
MRMaxYDRgn	MultiReg Max YD Rgn
MRMaxYDXLoc	MultiReg Max YD X Loc
MRMaxYDYLoc	MultiReg Max YD Y Loc
MRMinADiam	MultiReg Min A Diam
MRMinADRgn	MultiReg Min AD Rgn
MRMinADXLoc	MultiReg Min AD X Loc
MRMinADYLoc	MultiReg Min AD Y Loc
MRMinArea	MultiReg Min Area
MRMinAreaRgn	MultiReg Min Area Rgn
MRMinAreaXLoc	MultiReg Min Area X Loc
MRMinAreaYLoc	MultiReg Min Area Y Loc
MRMinHeight	MultiReg Min Height
MRMinHtRgn	MultiReg Min Ht Rgn
MRMinHtXLoc	MultiReg Min Ht X Loc
MRMinHtYLoc	MultiReg Min Ht Y Loc
MRMinIslSize	MultiReg Min Island Size
MRMinVol	MultiReg Min Vol
MRMinVolRgn	MultiReg Min Vol Rgn
MRMinVolXLoc	MutiReg Min Vol X Loc
MRMinVolYLoc	MultiReg Min Vol Y Loc
MRMinXDiam	MultiReg Min X Diam
MRMinXDRgn	MultiReg Min XD Rgn
MRMinXDXLoc	MultiReg Min XD X Loc
MRMinXDYLoc	MultiReg Min XD Y Loc
MRMinXYDiam	MultiReg Min XY Diam
MRMinXYDRgn	MultiReg. Min XYD Regn
MRMinXYDXLoc	MultiReg Min XYD X Loc
MRMinXYDYLoc	MultiReg Min XYD Y Loc
MRMinYDiam	MultiReg Min Y Diam
MRMinYDRgn	MultiReg Min YD Rgn

MRMinYDXLoc	MultiReg Min YD X Loc
MRMinYDYLoc	MultiReg Min YD Y Loc
MRStdADiam	MultiReg Std A Diam
MRStdArea	MultiReg Std Area
MRStdHeight	MultiReg Std Height
MRStdVolume	MultiReg Std Volume
MRStdXDiam	MultiReg Std X Diam
MRStdXYDiam	MultiReg Std XY Diam
MRStdYDiam	MultiReg Std Y Diam
MRAvgRpP	MultiReg Avg Rp Percent
MRAvgRvP	MultiReg Avg Rv Percent
MRAvgRtP	MultiReg Avg Rt Percent
MRStdRpP	MultiReg Std Rp Percent
MRStdRvP	MultiReg Std Rv Percent
MRStdRtP	MultiReg Std Rt Percent

Feature Statistics

Definition

The feature statistics analysis calculates the height of a single feature relative to a substrate. The analysis uses an operator-defined template to find and orient the feature and the substrate.

☞ If more than one discrete island of data on the template is defined as a "feature", the reported feature height will be an average of the heights of all pixels in the "feature" islands.

Uses

Feature statistics allows you to quickly determine and record feature heights, which is convenient during automated measurements. Since the feature and substrate are defined with a template, the analysis works well for samples that may have slight geometrical or positional differences.

Measurement Limitations

The feature statistics analysis only calculates one number: the feature height. If more than one discrete island of data is designated as a "feature" region, the heights will be averaged, possibly masking height differences between the islands.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
FHeight	Feature Height

⁂

Chapter 4

Processing Data

This chapter describes how some of the software features of the Wyko surface profiler systems can affect data to which analyses have been applied, or *processed data.* It also discusses anomalies that might appear in the processed data.

Reference Subtraction

For greater accuracy in your measurements, you can generate a reference surface of the interferometer's internal optical system and subtract that reference from your measurements. (See *Accuracy* on page 1-9.) This is especially important in PSI mode when you are measuring random, smooth surfaces.

For smooth-surface measurements, the surface roughness of the internal reference surface can be a limiting factor in obtaining an accurate measurement. The measured value has contributions from both the internal reference and the test surfaces:

measured value = test surface + reference surface

For test and reference surfaces of random roughness, the rms of this measurement is a combination of the two rms values:

$$rms_{meas} = \sqrt{rms_{test}^2 + rms_{ref}^2}$$

Because the terms are squared in the above equation, the contribution of the reference surface will affect the measured value.

Generally, if the roughness of your test surface is at least 2 times greater than the roughness of the optical reference surface, the error introduced by the reference surface will not significantly affect the measurement. For a quick estimate of your system's optical reference surface, see Table 4-1. It lists the approximate roughness contribution of the optical system for various objectives.

Table 4-1. R_q Values of Optical Reference Surfaces

Objective	Optical Reference Surface Values, R_q
1.5X	< 30 Å (< 3.0 nm)
2.5X, 5X	< 25 Å (< 2.5 nm)
10X, 20X, 50X	< 10 Å (< 1.0 nm)

You can evaluate your own system's optical reference surface by averaging several measurements in the same location on a supersmooth surface. The corresponding R_q value indicates the rms roughness of the optical reference surface. Compare this value to the value of your test surface to determine if the optical reference surface contribution is significant. If so, it is best to subtract the reference surface.

Wyko® Vision32™ includes an algorithm for generating a reference surface from a mirror. Once this is done, you can subtract the file from your measurements. Your operator's guide and online help describe how to do these procedures.

Data Restore

During a measurement, data may not be recorded for a given pixel for one of several reasons:

- The surface is too steep to be measured,
- The surface is not reflective at that location, or
- The pixel was discarded because it did not reach the modulation threshold.

The Wyko Vision32 software includes a patented algorithm[1] that can restore these data points. The **Data Restore** algorithm identifies missing data points in a two-dimensional array and interpolates between valid data points to fill in the missing data.

Data Restore is a powerful option which can result in invalid data if used incorrectly. To ensure accurate interpolation of missing data points, use the **Data Restore** option only when 95% or more of the data points are valid. Do not use **Data Restore** when using detector masks, as the algorithm will attempt to fill in the masked area as well.

See your setup guide for specific instructions regarding the use of **Data Restore**.

Terms Removal

Wyko Vision32 provides options for the removal of characteristics that are either inherent in a sample or that occur due to the manner in which the measurement was taken. When you remove terms, you are able to remove the general shape of the surface, leaving its microstructure. This eliminates shapes that distort or distract from the true surface features.

The program removes terms with a least-squares fitting technique for linear and quadratic terms on a point-by-point basis.

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[1] U.S. Patent #5,717,782

☞ Any terms removed from the data are listed under the "Terms Removed" section on the output display.

Tilt

Typically, you select **Tilt Only** to remove the amount of tilt introduced in a measurement if the fringes were not perfectly nulled. Even if you have nulled the fringes, i.e. minimized the angle of the sample relative to the reference optics, there is still some residual tilt present in the system. In most cases, tilt should be removed to make slanted samples appear flat.

Curvature and Tilt

Select **Curvature and Tilt** to remove tilt and any natural curvature in the sample. Removing curvature causes a spherical sample, such as a ball bearing, to appear flat. This allows you to observe the surface features instead of the dominant spherical shape. When you remove curvature, the radius of curvature (Rcrv) value is noted on the output display.

Cylinder and Tilt

Select **Cylinder and Tilt** to remove tilt and extreme curvature associated with cylindrical objects. Removing cylinder causes a cylindrical object, such as a rod, to appear flat. This allows you to observe the surface features instead of the dominant cylindrical shape.

How Removing Terms Can Improve or Distort Data

Removing terms can sometimes cause the analyzed data to misrepresent the sample surface that you are measuring. For example, removing only tilt for a measurement of a thin material, such as a polymer film, may produce a set of data characterized by a saddle shape since Wyko Vision32 will attempt to flatten a spherical distortion with a linear correction. Subtracting curvature and cylinder in addition to tilt serves to flatten the data. Removing terms over a surface that is not continuous, has sloped regions, or has an asymmetrical structure such as a large hole can distort the data. In these types of surfaces, it may be best to not remove terms at all, or to use a terms mask over one region of the data set. (See *Terms Mask* on page 4-12.) You may also have a case in which removing the wrong terms causes distortions in the data. Figures 4-1 and 4-2 show how removing terms or removing the wrong ones can either improve the analysis results or cause distortions.

Figure 4-1 shows a set of data for an inverted, somewhat spherical surface. Figure 4-1 (a) shows the profile with no terms removed; Figure 4-1 (b) shows the profile with tilt removed; and Figure 4-1 (c) shows the profile with curvature and tilt removed. For this sample, Figure 4-1 (c) is the correct profile, based on removal of curvature and tilt. This example shows how removal of terms can improve analysis results.

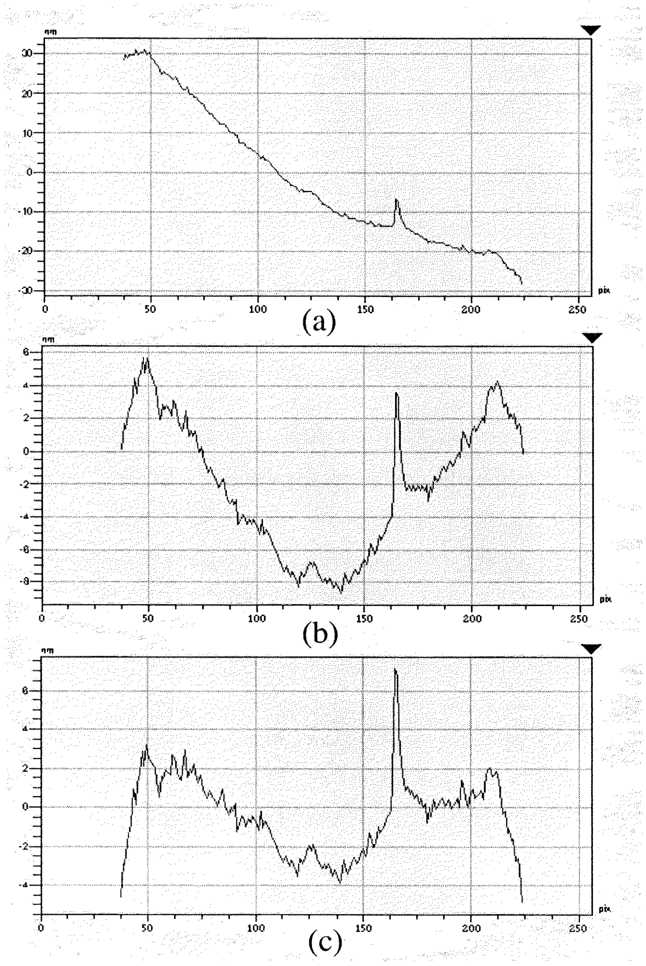
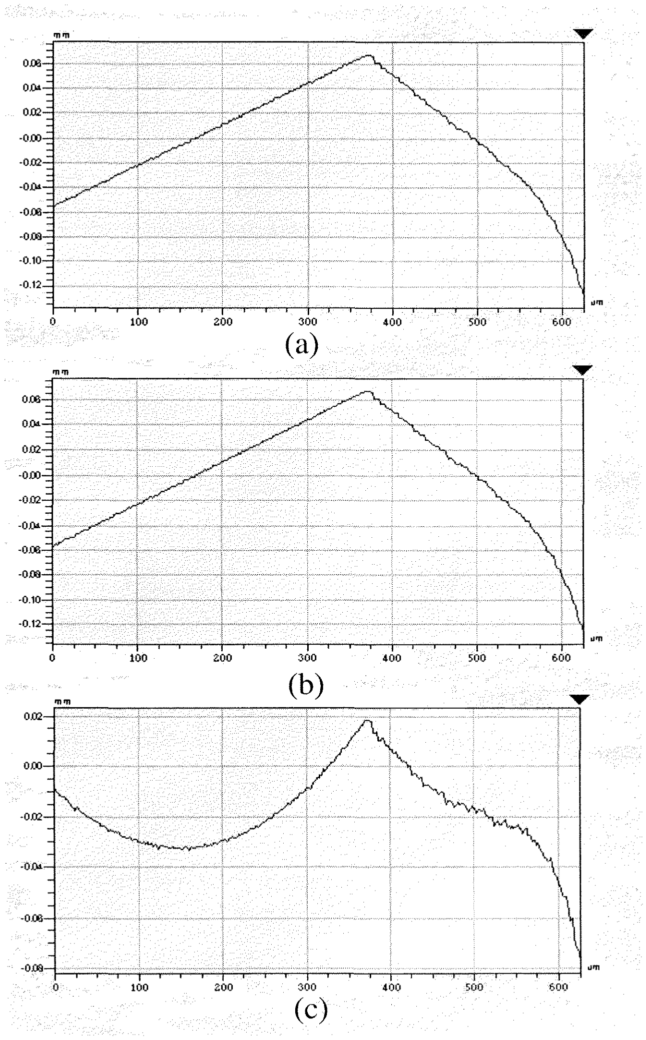


Figure 4-1. Profile of Spherical Surface Showing Improvement with Terms Removal

Figure 4-2 shows a set of data for a ramped surface. Figure 4-2 (a) shows the profile with no terms removed; Figure 4-2 (b) shows the profile with tilt removed; and Figure 4-2 (c) shows the profile with cylinder and tilt removed. For this sample, Figure 4-2 (a) or (b) are correct profiles. The distortions Figure 4-2 (c) illustrate how removal of terms can actually misrepresent the actual surface.



(a)

(b)

(c)

Figure 4-2. Profile of Surface with a Step Showing Distortion with Terms Removal

Averaging

Wyko surface profilers allow you to average several readings from the same location to obtain a final, single measurement. When you average raw data, the system repeatedly takes data from the same location on the sample and averages the data point-by-point before calculating the profile.

In most cases, averaging helps reduce the effects of electronic noise and improves the repeatability of your measurements at the expense of total measurement time. Be aware that averaging can degrade measurement quality if long-term drifts or vibrations are present.

In deciding when to average and how many measurements to use, consider the sample, its reflectance, the noise level in nonaveraged observations, the stability of the instrument setup, and the desired level of repeatability. Generally, two to four measurements is sufficient for averaging.

☞ There are two types of averaging: averaging raw data and averaging stored data. Raw data averaging records data a user-specified number of times in the same location during a measurement, then averages the raw data. Stored data averaging uses processed data from stored data sets.

Filters

The Wyko Vision32 includes two types of filtering algorithms: data smoothing and digital filtering. In the smoothing algorithms, data within a window is smoothed as the window moves from one point to another across the entire data set. In the digital filtering algorithms, data below or above a user-specified frequency is eliminated from the analysis. Using these types of filters to manipulate the processed data enables you to examine waviness or microroughness characteristics in a sample's surface.

Smoothing

The smoothing filter options are **Low Pass**, **Median**, and **High Pass**. Each of the smoothing algorithms looks at an array of height data within a window. The program adjusts the height value of the center point according to the height values of the neighboring data points in the window (array), moves the window to the next location, and repeats the calculation. This is done for the entire data set. The method used to determine the center point depends on the type of smoothing selected.

Low Pass

For a low pass smoothing filter, the height values in the window are averaged, and the average is stored as the new center height. The average is based only on valid data points. (The denominator in the equation below is always the number of valid data points.) The window then moves to the next location to perform the same calculation.

The array and center height calculation for a 3x3 window are:

$$\begin{matrix} Z_1 & Z_2 & Z_3 \\ Z_4 & Z_c & Z_6 \\ Z_7 & Z_8 & Z_9 \end{matrix}$$

$$Z_{c_{new}} = \frac{Z_1 + Z_2 + Z_3 + Z_4 + Z_c + Z_6 + Z_7 + Z_8 + Z_9}{9}$$

Using a low pass filter can provide information about waviness, the more widely-spaced irregularities on your sample's surface. A low pass filter can be helpful if you want to examine the general characteristics of a surface that are not associated with a machining tool.

Median

For a median smoothing filter, the height values in the window are sorted in ascending order, and the median of this bubble sort is stored as the new center height. The median is the value of the middle point when the points are sorted from smallest to largest. If there is an even number of valid data points, the median is the second number of the two middle points. The window then moves to the next location to perform the same calculation.

For the 3x3 window shown below, the number **12** is the median value when the numbers are sorted in ascending order.

$$\begin{matrix} 11 & 12 & 10 \\ 13 & 17 & 11 \\ 17 & 10 & 15 \end{matrix}$$

sorted: 10,10,11,11,**12**,13,15,17,17

$$Z_{c_{new}} = 12$$

A median filter is particularly effective for preserving edges and steps in the data.

High Pass

For a high pass smoothing filter, a weighted average of the height values in the window is subtracted from the center height, and this value is stored as the new center height. The average is based only on valid data points. (The denominator in the equation below is always one less than the number of valid data points.) The window then moves to the next location to perform the same calculation.

The array and calculation for a 3x3 window are:

$$\begin{matrix} Z_1 & Z_2 & Z_3 \\ Z_4 & Z_c & Z_6 \\ Z_7 & Z_8 & Z_9 \end{matrix}$$

$$Z_{c_{new}} = Z_c - \frac{Z_1 + Z_2 + Z_3 + Z_4 + Z_c + Z_6 + Z_7 + Z_8 + Z_9}{8}$$

Using a high pass filter can provide information about roughness, the closely-spaced irregularities on your sample's surface. A high pass filter can be helpful if you want to examine the microroughness of a surface or frequent features left from a machining tool, such as a grinding or polishing wheel.

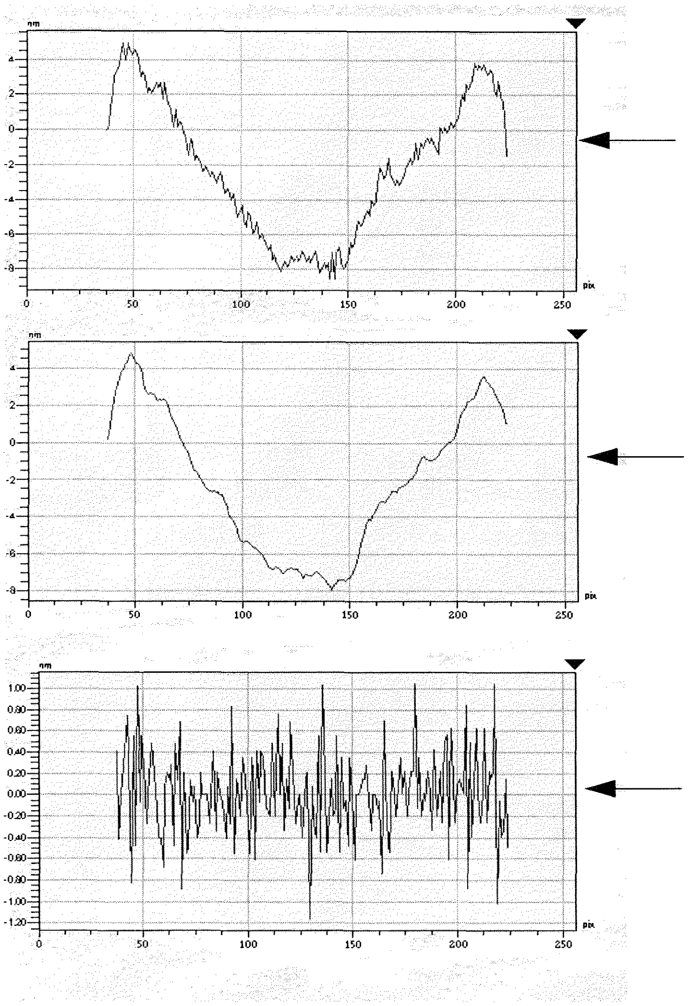
Digital Filtering

In the digital filtering algorithms, an FFT (Fast Fourier Transform) mathematically removes data which have a spatial frequency below or above a user-specified cutoff frequency. By using the PSD (Power Spectral Density) plots to examine the frequency components in your sample's surface, you can determine an appropriate cutoff frequency. The digital filters are described below.

☞ FFT calculations require an array size that is some power of 2, such as 2^8, or 256. When Digital Filtering is selected, the array size is increased to the next power of 2, and the extra pixels are filled in with zeroes. These extra data points are discarded before the resultant data is displayed.

Digital Low Pass

For a digital low pass filter, data with spatial frequencies *above* the cutoff frequency are eliminated from the analysis. In other words, low-frequency data is passed. When you apply a low pass filter to eliminate the high spatial frequency components, the waviness of a surface becomes more visible. The frequently-occurring repetitive patterns, such as those from a machining tool, are removed from the profile, leaving the general shape of the surface. Figure 4-3 shows a sample profile before and after a low pass filter is applied.



No filter applied (Microroughness and surface form together)

Low pass filter applied (only surface form)

High pass filter applied (only microroughness left)

Figure 4-3. Profile with Low and High Pass Filters Applied

Digital High Pass

For a digital high pass filter, data with spatial frequencies *below* the cutoff frequency are eliminated from the analysis. In other words, high-frequency data is passed. When you apply a high pass filter to eliminate the low spatial frequency components, the microroughness of a surface becomes more visible. The general shape of the surface is removed, leaving the residual microroughness or any repetitive features. This is helpful if you are interested in how a machining process affects the sample's surface. Figure 4-3 shows a sample profile before and after a high pass filter is applied.

☞ If you are using stylus analysis filters to filter the data, make sure all non-stylus filters, such as those described above, are turned off. Otherwise, you will be filtering the data twice.

Band Pass

The Band Pass filter eliminates frequencies above the **High Cutoff** and below the **Low Cutoff**, leaving only the frequencies between the two cutoff values.

Notch Filter

The Notch filter passes frequencies above the **High Cutoff** and below the **Low Cutoff**.

Digital Filter Type (window)

Wyko Vision32 allows you to select which type of smoothing window to use during the Digital Filtering operation.

Rectangle	No smoothing window is applied to the data before Fourier transformation. Thus, edge discontinuities may cause artifacts to appear near the edges of the filtered data.
Exponential	The data is multiplied by a two-dimensional smoothing window that falls off in an exponential factor before Fourier transformation. The data falls smoothly to zero near the edges and filtering artifacts are reduced.
Butterworth	The data is multiplied by a two-dimensional Butterworth smoothing window before Fourier transformation. The data falls smoothly to zero near the edges and filtering artifacts are reduced.

Advanced Digital Filtering Options

Near Field Windowing

To suppress artifacts caused by applying digital filters to edge regions of data, "near field envelopes" can be applied in the time domain before the data is transformed to Fourier space. These envelops are general cosine filters of the form

$$A - B\cos(\pi F_s K) + C\cos(2\pi F_s K)$$

where $F_S = (n-1)^{-1}$

$K = 0...n-1$ = the coordinates of each point in the dataset.

Select the filter to use. **Hanning**, **Hamming**, and **Blackmann** are specific cases of the cosine filter; the **General Cosine Filter** option allows you to choose your own coefficients.

The coefficients for the chosen filter are displayed in the boxes labelled **Coeff A**, **B**, and **C** in the dialog. See your setup guide for specific instructions on the use of Advanced Digital Filtering Options.

Far Field Filtering

You can also select the shape of the "far field" digital filter to apply in the Fourier domain to minimize filtering artifacts.

Select the shape of the far field filter: **Rectangular**, **Butterworth**, or **Exponential**. (See *Digital Filter Type (window)* on page 4-10 for more information on these filters.)

- For the Butterworth filter, you may select the **Filter Order**.
- For the **Exponential** filter, you may set the **Std Deviation**.

As the filters are applied, Wyko Vision32 transforms the data back to the time domain and divides out the near field envelopes, accurately reproducing the filtered data.

Masks

Masks are overlays that you create to block or emphasize selected features of a data set. You can also use masks to fit a plane over a specified region, such as the top surface of a step.

Detector Mask

A detector mask blocks designated areas of the data during a measurement. When you use a detector mask, pixels that are in the masked region are ignored by the detector. This permanently eliminates masked data points from the raw data. The only way to recover these data points is to turn off the detector mask and make another measurement of the same surface. A detector mask is useful for blocking regions of data that are not pertinent to the analysis, such as a part of a fixture, or a feature on the sample that should not be included in the analysis. You can also use a detector mask to create well-defined boundaries between regions for special analyses such as multiple region analysis.

Analysis Mask

An analysis mask blocks designated areas of data during an analysis. It does not permanently affect the raw data—it is only effective when it is applied to the data When you use an analysis mask, maked pixels are not included in the calculation of surface statistics like R_a and R_q.

You can use an analysis mask to eliminate regions in the surface map that are not of interest. In a sense, an analysis mask provides a filtering capability—you can remove specific points or regions of the data, reanalyze the data, and see a "filtered" data set. This is especially useful if you want to see the effects of eliminating irregularities in the surface.

For example, a contaminant such as dust may show up on a surface plot as a large spike. The rest of the surface may look flat in comparison to the spike because the height scale will be large to accommodate the tall spike. If you use an analysis mask to remove the spike(s) from the analysis, you will be able to see the true surface, not one that is skewed by a feature that is not representative of the surface.

Terms Mask

A terms mask allows you to define an area over which you want the program to perform a tilt, curvature, or cylinder terms fit. The fit that is performed on the masked area is then applied to the entire data set.

You can use a terms mask when you want to fit terms to a surface that has an abrupt change, such as a step. As described in the section entitled "Terms Removal," removing terms (such as tilt) over an entire surface of this type can cause distortions. (See Figure 4-4.) If you were to select tilt for terms removal based on the entire surface (A), the resulting dataset would resemble a sawtooth (B). This sawtooth occurs because the plane that best represents the data must take into account both planes forming the step. This "best fit" plane is approximately the average of the two plane surfaces; subtracting it produces the sawtooth. If you define a terms mask that covers only one side of the step (C), the terms fit will then be based on the best fit plane over the flat part of the sample only, resulting in a more accurate step (D).

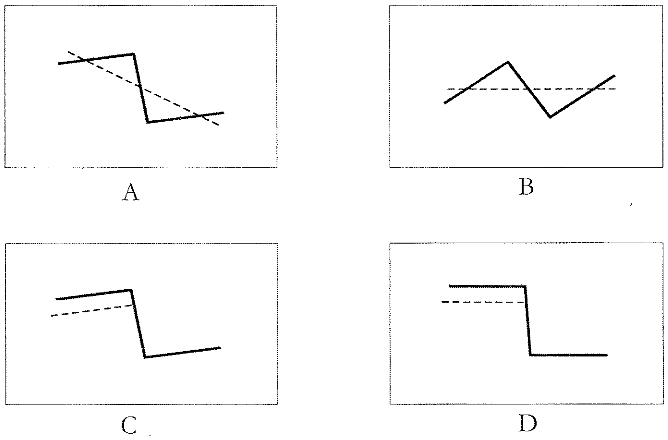


Figure 4-4. Removing Tilt from a Step Height Measurement

In Figure 4-2 (a) earlier in this chapter, defining a terms mask over a flat segment of the ramp and removing tilt only will also provide the correct profile.

Analysis and terms masks can be defined geometrically by masking areas on the dataset, or by height threshold, called the *height threshold analysis mask*. You create this mask on a special version of a masking histogram, which shows the surface height distribution. From this histogram, you can mask spikes, pass data above or below a threshold height, or pass or block data between two threshold heights. This is a very useful mask for eliminating features that may not be part of the surface, such as contaminants. To access the height threshold mask, press the **Hist** button on the Mask Editor dialog box.

Integration Errors

Integration errors occur when the height difference between two adjacent pixels is too abrupt for the system to resolve. In PSI mode, you may sometimes see integration errors in your processed data. Integration errors are evident as lines of abrupt discontinuity in the processed data. Do not confuse them with step features in your sample's surface.

As mentioned in Chapter 1, the maximum resolvable height difference between adjacent points in PSI mode is approximately 160 nm ($\lambda_0/4$ for a nominal center wavelength of 640nm). If you use PSI mode to measure surfaces with height changes greater than this between adjacent pixels, the program cannot properly integrate the phase data to reconstruct the measured wavefront. At the point of the steep difference, erroneous data is substituted, resulting in a line of discontinuity. Figure 4-5 shows a three-dimensional plot of a surface in which phase ambiguities could not be resolved. The abrupt changes in surface height are integration errors.

To avoid integration errors:

- Use VSI mode if the height changes are too abrupt for PSI to resolve. (PSI should not be used for surfaces with discontinuities greater than $\lambda/4$, or approximately 160nm.)
- Increase the modulation threshold. This may drop some data points from the analysis, but it should also eliminate the low signal-to-noise points that are causing the integration errors. See your setup guide for information on the use of the modulation threshold.

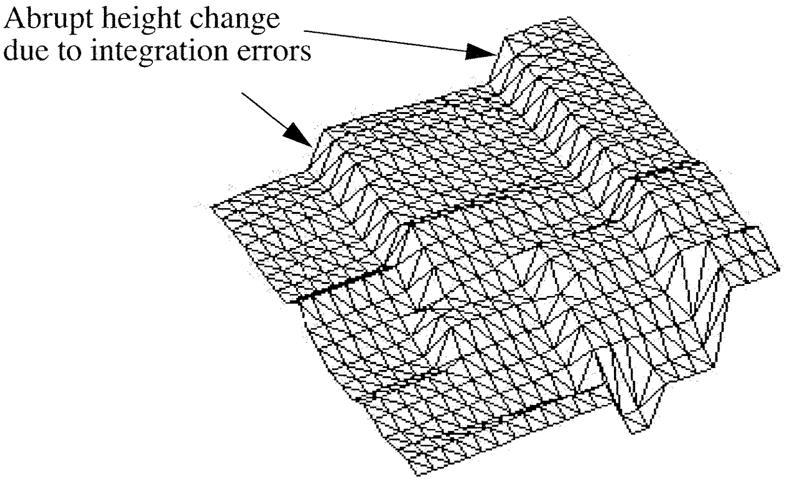


Figure 4-5. Surface with Integration Errors

Phase Change Effects

What is a Phase Change?

When you illuminate a material, the reflected light exhibits a phase change from the incident light. If your sample has features in which adjacent regions or layers are dissimilar materials, the phase change upon reflection may vary, causing phase change effects.

Phase change effects occur in both PSI and VSI because the system cannot distinguish between the phase contributions from optically dissimilar materials. The phase change is dependent on the optical constants of the film and substrate, and also on the film thickness.

How Do Phase Changes Affect Measurements?

The main types of samples affected by phase changes include the following:

- opaque islands of dissimilar materials
- transparent island(s) on an opaque substrate
- transparent continuous film on an opaque substrate

As mentioned earlier, the measured phase is a function of the optical constants of the film and the substrate materials. Unless an adjustment is made for these values, measurements across boundaries of dissimilar materials may be inaccurate.

In some cases, you may see a visible step or island, but the height will not be correct. In other cases, a certain surface feature may be completely obscured by the contribution from the material interaction, and you will not even see the feature. In extreme cases, as the material interaction becomes larger, certain surface features may even appear inverted.

The measurement "bias", or offset, is the difference between the true value and the measured value. It can be insignificant, or quite important, depending on the required measurement accuracy and the materials under consideration.

If you are examining relative height differences between similar samples, the bias should not present a problem. You will still be able to make comparative judgments between samples. However, if you require absolute height values, you need to determine the bias. Once you determine the bias, you subtract it from the measured height to come up with the true height.

The methods in which you can determine the bias to apply to the measured surface heights are listed below.

- Measure the sample and store the data. Then deposit a thin metallic film over the surface, remeasure the sample in the same location, and store the data. The difference between the two data sets provides an approximate bias.
- Measure the complex indices of refraction (n and k values) using an ellipsometer and calculate the bias from theoretical equations that account for these optical constants.
- Calibrate the offsets with an atomic force microscope (AFM).

☞ Determining a bias and subtracting it from measurements is valid for surfaces with well-defined separations between dissimilar materials, such as steps. It becomes much more complicated when the surface has "pockets" of dissimilar materials throughout the surface.

When measuring samples with dissimilar material boundaries, keep the following in mind:

- For a **step** in which the step is a different material from the substrate, the step height can be skewed by several nanometers. This may or may not be a significant amount, depending on the magnitude of the step height.
- For a **continuous opaque film** on a substrate, there will be no measurement bias.
- For a **continuous transparent film** on a substrate, you can measure the film directly *if* the film thickness is greater than the objective's depth of focus for PSI measurements. This prevents the objective from seeing through the film into the substrate. For VSI measurements of a transparent film, the film thickness should be at least 3 or 4 µm.

During the VSI scan, stop the scan after the objective has scanned downward through the film approximately 2-3 µm. This stops the scan well before the substrate layer is reached.

Additional References

Walter Hahn, "Dissimilar Materials Analysis for SiO2 Films on Silicon and Carbon Coated Magnetic Disks," Wyko Corporation, October, 1991.

Walter Hahn, "Phase Correction for Dissimilar Substrates and Conformal Films," Wyko Corporation Application Note 91-09, 1991.

Eric Marcellin-Dibon, "The Effects of Reflection from Diverse Materials on Phase," Final Project in conjunction with Optical Sciences Center, University of Arizona, Tucson, and Wyko Corporation, July 1989.

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Appendix A

Exporting Data and Graphics from Wyko® Vision32™

Data files and graphics from Wyko Vision32 can be exported into other applications for further analysis and data manipulation. Graphics and screen captures can be copied from Wyko Vision32 and pasted into other Windows™ applications via the Clipboard.

OPD Data Array Format

Wyko Vision32 analyzes and stores data in OPD (optical path difference) format, a proprietary binary format developed for use with Wyko interferometers and profilers. This is the default format for saving files.

OPD Format Header Information

Important information on measurement parameter settings is listed in the ASCII file in front of the measured output data. This ASCII "header" information is listed in the following format:

blockname   blocktype   size   attribute   parameter value

- The **blockname** field specifies the name utilized for a particular parameter.
- The **blocktype** field specifies the block type: Array 3D or Array 2D. Array 2D blocks include byte, float (32 bit floating point), double (64 bit floating point), string (multiple bytes), short (16 bit integer), long (32 bit integer).
- The **size** field specifies the number of elements.
- The **attribute** field is used by Wyko OPD analysis programs.
- The **parameter value** field is the assigned value for the parameter.

Table A-1. Sample OPD Output Converted to ASCII

```
Directory           Directory                        250    FFFF
Mult                Short_Array_2D                     1    0001
   15
RAW_DATA            Array_3D                           1    0001
          368          238             2
  22564     22570     22568     22562     22561     22574     22570     22569     22599     22576
  22549     22551     22540     22524     22608     22569     22554     22542     22537     22534
  22718     22704     22698     22705      BAD      22581     22591     22561     22544     22530
   BAD       BAD       BAD      22572     22556     22565     22585     22544     22545     22566
  22571     22573     22570     22555     22582     22602     22576     22570     22571     22556
Time                Byte_Array_2D               8    0008
   15:19:36
Date                Byte_Array_2D               8    0008
   08/13/95
Wavelength          Float_Array_2D              1    0010
   240
Magnification       Float_Array_2D              1    0010
   1.65
ObjectiveLabel      Byte_Array_2D              60    0010
   1.650
Wedge               Float_Array_2D              1    0010
   1
Mod_threshold       Float_Array_2D              1    0010
   1.2
SCAN_SLOPE          Short_Array_2D              1    0010
   566
SubtractRef         Byte_Array_2D              10    0010
   No
Pixel_size          Float_Array_2D              1    0008
   0.010303
Terms_String        Byte_Array_2D              40    0008
   None
Data_Restore        Byte_Array_2D              10    0008
   Yes
Data_Invert         Byte_Array_2D              10    0008
   No
Filt_Type           Byte_Array_2D              40    0008
   Low Pass
Vol_opt_String      Byte_Array_2D              40    0008
   Normal
UserNote1           Byte_Array_2D             100    0008
   Sample 1
UserNote2           Byte_Array_2D             100    0008

Pupil               Float_Array_2D              1    0008
   100
Use_XYR_cent        Short_Array_2D              1    0010
   0
Use_XYR_spac        Short_Array_2D              1    0008
   1
Pupil_diam          Float_Array_2D              1    0008
   0
XYR_x_spac          Float_Array_2D              1    0008
   0.010303
Aspect              Float_Array_2D              1    0001
   1.16
Title               Byte_Array_2D              20    0001
   Dataset
Note                Byte_Array_2D              60    0001
```

For example, as shown in Table B-1, a wavelength parameter assigned a value of 240 nm would be listed as follows:

- Wavelength Float_Array_2D 1 0010
  240

OPD Data

After the various header fields are the actual measured output data, or the OPD Data. The data is preceded by a line that looks like this:

```
RAW DATA  Array_3D     1        0001

    368          238     2
```

This line tells us that the array size (in pixels) is 368x238. Thus, there are 368 columns of pixels in the X direction, and 238 rows of pixels in the Y direction. The last integer may be 1, 2, or 4. A value of 1 or 2 indicates the OPD data is in integer format. A value of 4 indicates the OPD data is in floating point format.

The data are measured and stored in the .opd file by column, starting from the bottom leftmost pixel, moving down and to the right. As shown in Figure A-1, the first column would consist of pixels from (0, 0) to (0, max Y). The second column would consist of pixels from (1, 0) to (1, max Y), etc., up to the final column which would consist of the pixels from (max X, 0) to (max X, max Y). For the example shown in Table Table A-1., where the array size is 368x238, we have 368 columns, and 238 rows of data. Therefore, max X would be equal to 367 and max Y would be equal to 237, since we start at (0,0).

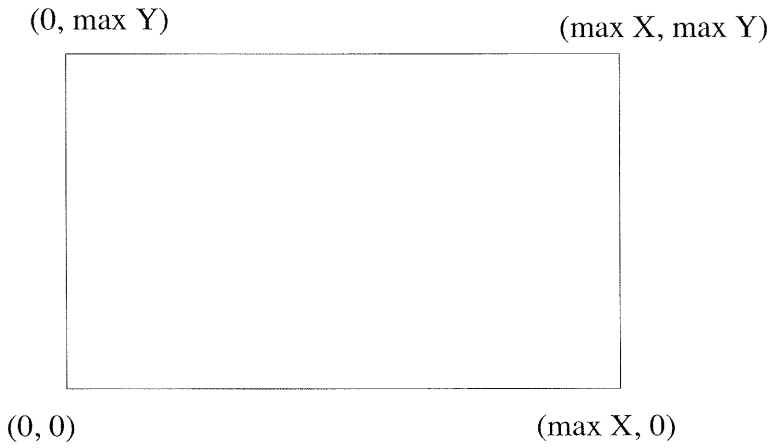

Figure A-1. Measured OPD Data Orientation

When the .opd file is converted to ASCII format, the columns of measured pixel data points are listed in the ASCII output file in wrap-around format (as if you were reading a book), in rows of ten, as shown in Table C-2. Thus, for our example of a 368x238 array, the first 238 data points listed in the ASCII file are the first column of pixels, (0, 0) to (0, 237). The second 238 data points stored are the second column of pixels, (1, 0) to (1, 237), etc., for a total of 87,584 data points. Thus, for this example, the first 24 rows of data in the ASCII file are the first column of measured data.

Table A-2. Sample Pixel Placement of Stored Data Array in ASCII Format

(0,0)	(0,1)	(0,2)	(0,3)	(0,4)	(0,5)	(0,6)	(0,7)	(0,8)	(0,9)
(0,10)	(0,11)	(0,12)	(0,13)	(0,14)	(0,15)	(0,16)	(0,17)	(0,18)	(0,19)
.									
.									
.									
(0,230)	(0,231)	(0,232)	(0,233)	(0,234)	(0,235)	(0,236)	(0,237)		
(1,0)	(1,1)	(1,2)	(1,3)	(1,4)	(1,5)	(1,6)	(1,7)	(1,8)	(1,9)
.									
.									
.									
(367,0)	(367,1)	(367,2)	(367,3)	(367,4)	(367,5)	(367,6)	(367,7)	(367,8)	(367,9)
(367,10)	(367,11)	(367,12)	(367,13)	(367,14)	(367,15)	(367,16)	(367,17)	(367,18)	(367,19)
.									
.									
.									
(367,230)	(367,231)	(367,232)	(367,233)	(367,234)	(367,235)	(367,236)	(367,237)		

Converting Integer and Floating Point Data

To convert OPD integer data from units of height to waves, divide the integer number by the **Mult** value, which is found in the header information.

To convert OPD integer data to surface height in nanometers (nm), divide the integer number by the **Mult** value and multiply it by the **Wavelength** value. Both values are found in the header information.

Floating point data is stored in waves. To convert waves to surface height (nm), multiply the floating point number by the **Wavelength** value, which is found in the header information.

Converting OPD and ASCII Data Formats

Wyko Vision32 will automatically save or read ASCII-formatted data (in the correct format). The format of the ASCII data must be the same as shown in Table Table A-1..

To save a dataset in ASCII format:

1. Select **File » Save Dataset As**.
2. Enter the name of the dataset.
3. From the **Save as type** pull-down menu, select **ASCII Datasets (*.asc)**.
4. Click **OK** to save the dataset.

To open an ASCII dataset:

1. Select **File » Open Stored Dataset**.
2. From the **Files of type** pull-down menu, select **ASCII files (*.asc)**.
3. Enter the pathname of the file, or select it with the mouse, and click **Open**.

Importing and Exporting Using SDF format

Wyko Vision32 allows the user to import and export data in the SDF (universal Surface Data File) format as defined by Stout et al[1].

To save a file in SDF format:

1. Select **File » Save Dataset As**.

☞ You can also access the Save As dialog box by right-clicking on the contour plot of the dataset you wish to save and selecting **Save to disk**.

2. Select **SDF Datasets (*.sdf)** from the **Save as type** pull-down menu.
3. Under the **SDF Format Options**, select the formatting style you wish to use.
   a. Select **Binary** or **ASCII**.
   b. Select the base data type: **Uint** (unsigned integer), **Uchar** (unsigned character), or **Float** (floating point).

☞ SDF files may be defined using Uint, Uchar, Float, ULongInt (unsigned long), Char (signed character), Integer (signed integer), LongInt (signed long), or Double (double). Although Wyko Vision32 will only save an SDF file using Uint, Uchar, or Float, files defined with all base data types can be opened.

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[1] Stout, Sullivan, Dong, Mainsah, Luo, Mathia, Zahouani, "The Development of Methods For The Characterisation of Roughness in Three Dimensions," Commission of the European Communities, 1993.

To open an SDF file:

1. Select **File** » **Open Stored Dataset**.
2. Select **SDF Datasets (*.sdf)** from the **Files of type** pull-down menu.
3. Click **OK**.

SDF Data Array Format

SDF files are divided into three sections:

1. Header
2. Data area
3. Trailer

SDF files can be stored in either ASCII or binary format. For ease of reading, only examples of the ASCII format will be shown.

Table A-3. Sample of an ASCII Representation of an SDF file

```
aBCR-1.0
ManufacID        =  Wyko
CreateDate       =  070619991907                     ; June 7, 1999 @ 7:09 pm
ModDate          =  090619991339                     ; June 9, 1999 @ 1:39 pm
NumPoints        =  368
NumProfiles      =  240
XScale           =  1.64E-006
YScale           =  1.41E-006
ZScale           =  6.5064E-006
Zresolution      =  -1
Compression      =  0
DataType         =  Float
CheckType        =  0
*                                                    ; End of header
352      245        5453     3214     2321     2456     235      452      765
987      125        764      98       987      454      312      243      545
.........................
...........
123      564        432                        ; data point 88,320
*                                                    ; End of Data Area
*                                                    ; End of trailer
```

Header

The header contains all the formating information for the file:

1. The Version number is the first line in the file. The version number specifies the data type (ASCII or binary) of the file as well as the format (BCR or ISO). Some examples:

aBCR-1.0	ASCII "BCR Format, version 1.0"
bISO-1.0	Binary "ISO Format, version1.0"

   When the file is saved, the version number will be dependent on whether you selected Binary or ASCII format.
2. The Manufacturer's ID provides the source of data. For Wyko systems, this value is "Wyko".
3. The original creation date and time is a 12 character field and stores the date and time the measurement was completed in the format DDMMYYYYHHMM. Separator characters are not stored, but zero padding of fields is required. For example, a measurement completed at 2:39 pm on June 9, 1999 would be signified with 090619991439.
4. The last modification date and time is a field similar to (3), but this field stores the last time the file was modified.
5. The number of points per profile is equivalent to the number of pixels in the X direction. This value will change depending on the resolution chosen for the measurement.
6. The number of profiles is equivalent to the number of pixels in the Y direction. This value will change depending on the resolution chosen for the measurement.
7. The X scale is the sampling rate (in meters) for the dataset.
8. The Y scale is the sampling rate (in meters) (in (7)) multiplied by the aspect ratio of the camera. For information on the aspect ratio for your system, see the setup guide for your system.
9. The Z scale is the wavelength of the filter used for the measurement in meters.
10. The Z resolution factor is unknown, so it is set to -1 by definition.
11. Wyko Vision32 does not use compression.
12. Wyko Vision32 does not use a Checksum.

☞ The version number (#1 in the above list) MUST be the first line in the file. Items #2 - #11 may follow in any order.

Table A-4. Header Information

Information	ASCII Record Name
Version Number	
Manufacturer's ID	ManufacID
Creation Date and Time	CreateDate
Last Modification Date and Time	ModDate
Number of Points per Profile	NumPoints
Number of Profiles	NumProfiles
X Scale	Xscale
Y Scale	Yscale
Z Scale	Zscale
Z Resolution	Zresolution
Compression Type	Compression
Data Type	DataType
Checksum	CheckType

Data Area

The number of points per profile and the number of profiles give you the size of the array in pixels. If the number of points is 368, and the number of profiles is 240, the array size is 368 X 240.

The data is measured and stored in the .sdf file by row, starting with the bottom leftmost pixel and moving across. As shown in Figure A-1, the first row would consist of the pixels from (0, 0) to (max X, 0). The second row would consist of pixels from (0, 1) to (max X, 1), etc., up to the final row, which would consist of pixels from (0, max Y) to (max X, max Y).

When the .sdf file is stored in ASCII format, the rows of measured pixel data points are listed in the ASCII output file in wrap-around format (as if you were reading a book), in rows of ten, similar to the data shown in Table C-2 for .opd data. Thus, for our example of a 368x240 array, the first 368 data points listed in the ASCII file are the first row of pixels, (0, 0) to (367, 0). The second 368 data points stored are the second column of pixels, (0, 1) to (367, 1), etc.

Trailer

Wyko Vision32 does not store any information in the trailer.

Exporting Graphics Via the Clipboard

Because Wyko Vision32 is a Windows NT™ application and is connected to the Clipboard, you can use the Clipboard to transport analysis screens in graphic format between Wyko Vision32 and another Windows™ application, just as you would within and between any Windows™ applications.

Analysis output screens can be copied via the Clipboard in two ways: using the **Edit » Copy** and **Paste** commands, and using the Print Screen key.

Exporting Graphics Using Edit » Copy and Paste Commands

1. Select (highlight) the analysis screen you would like to copy. The analysis screen can be from a new measurement or from a stored dataset. It does not matter, as long as the screen you wish to copy is the selected (highlighted) screen.
2. Select **Edit » Copy To Clipboard**.
3. Switch to your other application. If the other application is not open, start the other application.
4. Position the cursor where you want to insert the screen graphic.
5. From your application select **Edit » Paste**, or Ctrl+V.

☞ Copying data to the Clipboard is only available for .opd datasets.

☞ Most Windows NT™ applications work in this manner. Depending on the application you are working with, your exact method of copying and pasting may be slightly different.

Exporting Graphics Using the Print Screen Key

1. Press Alt+Print Screen, to copy the entire *display* to the Clipboard.
2. Switch to your other application. If the other application is not open, start the other application.
3. Position the cursor where you want to insert the screen graphic.
4. From your application select **Edit » Paste**, or Ctrl+V.

☞ Most Windows™ applications work in this manner. Depending on the application you are working with, your exact method of copying and pasting may be slightly different.

Saving Data to a TIFF File

Wyko Vision32 allows you to save the current image of the data as a TIFF (tagged image format) file. You can save raw data, intensity data, and the mask if it was saved with the data set. Saving data in TIFF format is useful for examining data without the effects of tilt or other terms applied to the data.

☞ Wyko Vision32 saves only your data set, not the entire measurement display.

To save data as a TIFF file:

1. Right-click on the contour plot of the desired dataset.
2. Select **Save as TIFF...**
3. Enter the filename you wish to use and click **OK**.

   The data will be saved with a .tif extension.

❖ ❖ ❖

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Glossary

2RC Filter

A stylus analysis filter that transmits 75% of the amplitude at the cutoff frequency.

A Diameter

Island Area Diameter. Area diameter of an island in multiple region analysis. It is back-calculated from the equation for the area of a circle. The area is set to be the number of valid data points (assuming a unit area per data point).

Aberration

The deviation of a wavefront from a perfect reference surface, usually a sphere or a plane.

Accuracy

The measure of how close a measurement compares to that of a known value.

Amplitude Distribution Function (ADF) Curve

A plot of profile height data versus the amplitude density.

Analysis Mask

A mask that blocks designated areas of the data array. An analysis mask can be used to view or analyze only specified portions of the raw data set. Unlike a detector mask, an analysis mask doesn't permanently affect the raw data.

Area

Island Area. The area of an island in multiple region analysis, defined as the number of pixels in an island times the area of a pixel.

Array Size

The number of pixels in the detector array located inside the interferometer's video camera.

Autocovariance Function

A measure of the correlation properties of the surface roughness.

Average Roughness

See R_a.

Average Slope (Δ_a, Δ_q)

The mean of the slopes at all points in the profile within the sampling length. Δ_a is the arithmetic average slope; Δ_q is the rms average slope.

Average Wavelength (λ_a, λ_q)

The average wavelength or a measure of the spacings between local peaks and valleys. λ_a is the arithmetic average wavelength; λ_q is the rms average wavelength.

Bearing Area

The area of the surface cut by a plane at the depth specified for the bearing length.

Bearing Length

The length of the bearing surface at a specified depth below the highest peak.

Bearing Ratio (t_p)

The ratio of the bearing length to the sampling length.

Bidirectional Reflectance Distribution Function (BRDF)

The amount of power scattered at various angles when light impinges on a surface.

Coherence Length

The distance between two arms of an interferometric system for which the phase remains correlated. A measure of the range of heights over which the instrument will be able to obtain measurable interference fringes.

Curvature

The second derivative of the surface data, or the rate of change of the slope data. Also a detrending shape that distracts from the surface features of a sample. Removing curvature causes spherical samples to appear flat. Curvature is inherent to the sample.

Cylinder

A detrending shape that distracts from the surface features of a sample. Removing cylinder causes cylindrical samples to appear flat. Cylinder is inherent to the sample.

Data Parameters

User-specified parameters associated with a set of data, such as terms removed, resolution, and modulation threshold.

Data Points

The number of points used in the analysis and depicted on the plots. This number depends on the resolution and the data reduction operations performed.

Delta a, Delta q (Δ_a, Δ_q)

Average Slope. The mean of the slopes at all points in the profile within the sampling length. Δ_a is the arithmetic average slope; Δ_q is the rms average slope.

Detector
Device used to record the fringe pattern in the interferometer system.

Detector Mask
A mask that blocks designated areas of the data array immediately after new data are taken. The area marked off by a detector mask is permanently marked as invalid.

Diameter
Island Diameter. The diameter of the circle needed to encompass an island in multiple region analysis.

Digital Filtering
Filtering algorithms that pass data above or below a specified spatial frequency. Used to examine microroughness and waviness components of a surface.

Dissimilar Materials Analysis
A type of software analysis that corrects for phase change errors across boundaries of dissimilar materials.

Dynamic Range
The vertical range of heights that an instrument can accurately measure. Also called Range.

Evaluation Length/Area
The length or area over which surface parameters are evaluated. An evaluation length is comprised of several sampling lengths.

Fast Fourier Transform (FFT)
A method of calculating the combination of sine waves that makes up a given function.

Filtered Data
Data that has been smoothed or digitally filtered; data from which terms have been removed and/or a reference file has been subtracted. *See also* Digital Filtering; Smoothing.

Form
The general shape of a surface, such as curvature of a ball bearing. The deviation from the nominal surface.

Fractal Roughness
A roughness parameter calculated from power spectral density data.

Fringe
A dark or light band in the intensity pattern formed by the interference of two or more beams of light.

Gaussian Curve

A curve showing a normal, or random, distribution.

Gaussian Filter

A stylus analysis filter that transmits 50% of the amplitude at the cutoff frequency.

Height Cutoff

Determines which summits to use for the statistics and for the plots. All summits with a height above this cutoff are used in calculations. The user has the choice between this type of cutoff and the percentage cutoff. *See also* Percentage Cutoff.

Height Threshold

The height difference a peak needs to be above each of its four nearest neighbors to be considered a summit.

Height Threshold Mask

A type of analysis mask that passes or blocks data points based on a user-specified height threshold.

Histogram

A plot that shows the distribution of individual surface parameters.

H_{tp}

The height between bearing ratios H_1 and H_2, where H_1 and H_2 are the corresponding heights at tp_1 and tp_2, respectively.

Incline

Relative Incline. The incline of a specific island relative to the reference island in multiple region analysis.

Integration

The process of wavefront or surface reconstruction from the analysis of phase-shifted interferograms.

Integration Error

Incorrect surface reconstruction due to factors such as noise, tight fringe spacing, and high sampling frequency.

Integration Time

The length of time that the detector takes to collect intensity data for a measurement. Note that this is different from Integration as defined above.

Intensity

The amount of light energy per unit area.

Intensity Display

A display that shows the image and intensity. This display serves as a guide for setting system intensity.

Interference

Physical phenomenon that takes place when two beams of light reinforce or neutralize each other, resulting in dark and light bands called fringes.

Interferogram

The pattern of dark and light fringes produced by two overlapping wavefronts.

Interferometer

An instrument that employs the interference of light waves to measure the accuracy of an optical surface or wavefront. *See also* Phase Shifting Interferometer.

Invalid Pixel

A data element that's not included in the analysis because it represents a saturated detector element, has been selected by the operator to be excluded, or whose modulation value falls below the set threshold value.

Island

An area of data that is completely separated from any other area. No two pixels are touching between one island and another.

Lambda a, Lambda q (λ_a, λ_q)

Average Wavelength. The average wavelength or a measure of the spacings between local peaks and valleys. λ_a is the arithmetic average wavelength; λ_q is the rms average wavelength.

Long Wave Cutoff

The cutoff wavelength used in stylus analysis for separating waviness from the surface profile.

Mask

An overlay that's applied to the data to block certain regions so that you can view, analyze, or process just those portions that you specify. The program includes detector, analysis, and terms masks. A special height threshold mask is a type of analysis mask.

Masked Data

Data in which an overlay is applied to block or pass user-specified regions of the wavefront during analysis.

Mean

Mean Height. In multiple region analysis, this is the mean island height above the background when islands are identified by height, or the mean height of the data set when islands are identified by separation.

Mean Line/Surface

A straight line or surface running centrally through the peaks and valleys that divides the profile equally above and below the line.

Mean Summit Height

The height of the summit point relative to the mean plane.

Modulation

The amount of intensity variation that occurs during phase shifting divided by the mean intensity.

Modulation Threshold

The value that specifies the lowest acceptable modulation for valid data. Data points with modulation below the threshold are identified as bad data.

M_{r1}

Peak Material Component. The bearing ratio at which R_{pk} and R_K meet.

M_{r2}

Valley Material Component. The bearing ratio at which R_{vk} and R_K meet.

Multiple Magnification Detector (MMD)

A device in the optical path that changes the magnification factor of the magnification objective in use.

Multiple Region Analysis

A type of software analysis that calculates surface parameters for individual regions (islands) of data.

Noise

The statistical variation of a measured value that decreases repeatability; data that provide no information about the sample being measured.

Numerical Aperture (NA)

The sine of half the angular aperture, used as a measure of the optical power of an objective.

Optical Path Difference (OPD)

The difference between the optical path lengths of the test and reference beams of the interferometer. The program uses the OPD to determine surface height or wavefront deviations.

Peak

A point which is higher than its two neighbors in a given profile. Peaks only exist along a single line profile and are a two-dimensional quantity.

Peak Count (PC)

The number of peaks per unit length measured at a specific peak count level, which is the vertical distance between the boundary lines.

Peak-to-Valley (P-V) Value

The height difference between adjacent peaks and valleys. These are the peaks and valleys between adjacent zero crossings. They are not the global peaks and valleys. *See also* Zero Crossings.

Percentage Cutoff

Specifies the cutoff for determining which summits to use for the statistics and for the plots. When the height difference between the lowest and highest summit is calculated, any peaks higher than the percentage cutoff of this difference are considered summits. The user has the choice between this type of cutoff and the height cutoff. *See also* Height Cutoff.

Phase

The fractional part of a cycle through which a periodic wave of light has advanced at any instant measured from a defined starting point.

Phase Calculation

The process of converting several detector measurements of fringe intensity to a phase at each pixel. The output of this calculation is then integrated to produce the raw phase data.

Phase Change

A change in the phase of light when it is reflected from a surface. Phase change effects can occur between boundaries of dissimilar materials, causing incorrect reconstruction of the surface.

Phase Data

Data describing the wavefront phase at the entrance pupil of the interferometer. Measurement is based on the difference between the paths of the test and the reference beams of the interferometer. *See also* OPD.

Phase Shifting Interferometer

A digital interferometer that alters the optical path length of the test and reference beams in a series of shifts. This optical path change causes a shift in the interferogram. The moving fringes are recorded by the detector, producing a series of interferograms that are transferred to the system's computer. Computerized calculations then combine the interferograms to determine the optical path difference (OPD), and subsequently, surface heights.

Piezoelectric Transducer (PZT)

A translator device in the phase shifter inside the interferometer. It contains crystals that expand in response to a computer-controlled voltage. The PZT moves the mirror in the path of the test beam to produce a series of shifts in the interference pattern.

Power Spectral Density (PSD)

The Fourier decomposition of the measured surface into its component spatial frequencies. The PSD plot shows power vs. spatial frequency.

Precision

A measure of the capability of a system to produce consistent results. The precision of an interferometer can be determined by taking two measurements, subtracting them, and looking at the rms of the wavefront error.

Profile

A two-dimensional slice of a surface.

Profile Height Function

A function representing the height deviations between the measured profile and the mean line or surface.

PSI

Phase Shifting Interferometer. A digital interferometer that alters the optical path length of the test and reference beams in a series of shifts. This optical path change causes a shift in the interferogram. The moving fringes are recorded by the detector, producing a series of interferograms that are transferred to the system's computer. Computerized calculations then combine the interferograms to determine the optical path difference (OPD), and subsequently, surface heights.

PZT Calibration Data

Data acquired during the automatic PZT calibration process. This value is used to calculate the calibration number for a ideal phase shift.

PZT Step

A value that controls the degree of fringe shift that is produced by the PZT translator. The factory-set PZT calibration number produces a fringe shift of 90 degrees. A software routine lets you automatically calibrate the PZT.

R_a

Roughness Average. The arithmetic average height calculated over the entire measured array.

Raw Data

Integrated phase data with no terms removed or reference subtracted. Raw data can be input from new data that have just been taken, or they can be copied and loaded from a file that has been stored to disk.

Rcrv

Notation on output displays for the radius of curvature value.

Reference File

A file generated by measuring the variations in smoothness and shape of the reference surface inside the interferometer. When the reference file is subtracted from the sample surface or wavefront, errors associated with minute reference surface irregularities are removed from the measurement results.

Reference Mean Line/Surface

A straight line or surface running centrally through the peaks and valleys that divides the profile equally above and below the line.

Refractive Index

The ratio of the velocity of light in a vacuum to the velocity of light in a refractive sample.

Repeatability

A measure of the capability of a system to produce consistent results. The repeatability of an interferometer can be determined by taking two measurements, subtracting them, and looking at the rms of the wavefront error.

Resolution

The smallest vertical or lateral distance that the instrument can accurately measure. Also refers to the number of pixels sampled by the detector.

R_K

Core Roughness Depth. The working portion of the surface that will carry the load after the run-in period.

R_{ku}

Kurtosis. A measure of the sharpness of the profile about the mean line.

R_{max}

The maximum roughness depth measured over the evaluation length. It is the largest of the successive R_{ti} values. R_{max} is also called R_{ymax} in ISO documents.

Root Mean Square Roughness

See R_q.

Roughness

A measure of the closely-spaced irregularities or texture of a surface. *See also* R_a; R_q.

R_p

Maximum Profile Peak Height. The distance between the mean line and the highest point over the evaluation length.

R_{pi}

The distance between the mean line and the highest point over the sampling length.

R_{pk}

Reduced Peak Height. The top portion of the surface that will be worn away during the run-in period.

R_{pm}

Average Maximum Profile Peak Height. The average of successive R_{pi} values over the evaluation length.

R_q

Root Mean Square Roughness. The root mean square average height calculated over the entire measured array.

R_{sk}

Skewness. A measure of the asymmetry of the profile about the mean line.

R_t

Maximum Profile Height. The distance between the highest and lowest points over the evaluation length.

R_{ti}

The distance between the highest and lowest points over the sampling length.

R_{tm}

Average Maximum Profile Height. The average of successive values of R_{ti} over the evaluation length.

R_v

Maximum Profile Valley Depth. The distance between the mean line and the lowest valley over the evaluation length.

R_{vi}

The distance between the mean line and the lowest valley over the sampling length.

R_{vm}

Reduced Valley Depth. The lowest portion of the surface that will retain lubricant.

R_{vm}

Average Maximum Profile Valley Depth. The average of successive R_{ti} values over the evaluation length.

R_z

Ten-Point Height. The average of the five greatest peak-to-valley separations.

S

Mean Local Peak Spacing. The mean spacing between adjacent local peaks measured over the evaluation length. *See also* S_m.

Sampling Length/Area

The interval or area within which a single value of a surface parameter is determined. Several sampling lengths comprise an evaluation length. The *Number of Sample Lengths* is a stylus analysis parameter.

Short Wave Cutoff

The cutoff wavelength used in stylus analysis for separating roughness from the surface profile.

Signal-to-Noise Ratio

The ratio of the power in a given signal to the power of the noise present in the absence of a signal.

Slope

The first derivative of the surface data, or the rate of change of the sample surface. Slope plots show the steepness of the surface or wavefront. The program calculates X slopes by comparing the height of one point with the height of the next point, in the X direction. It calculates Y slopes similarly for points in the Y direction.

S_m

Mean Peak Spacing. The mean spacing between profile peaks at the mean line measured over the evaluation length. *See also* S.

Smoothing

Filtering algorithms that modify the data to display it in a smoother form.

Stylus Analysis

A type of software analysis that uses stylus filtering to generate surface statistics that can be correlated to stylus instrument data.

Summit

A data point which is higher than its four nearest neighbors by a user-specified height and exists on a three-dimensional surface.

Summit Base

The point at which, by moving outward from a summit, the slope goes to zero or reverses.

Summit Count Threshold

A count of the number of summits with a radius of curvature exceeding the radius count threshold.

Summit Curvature

A measure of the sharpness of a peak found using a summit and one of its nearest neighbors.

Summit Cutoff

The distance below the maximum data value where a summit can occur.

Summit Density

The number of summits found divided by the area of the valid pixels searched.

Summit Diameter

Twice the summit XY radius.

Summit Mean Height

The height of the summit point relative to the mean plane.

Summit Radius of Curvature

The inverse of the summit curvature found using a summit and one of its nearest neighbors. *See also* Summit Curvature.

Summit Slope

The slope of a line connecting a summit and a valley along a profile in one direction.

Summit Threshold

The minimum distance a point must rise above its four nearest neighbors to be considered a summit.

Summit XY Radius

The distance from the summit point to the summit base.

Surface

A three-dimensional measurement of test sample heights.

Surface Area

The total, exposed area on the surface, including peaks and valleys.

Swedish Height (H)

A height calculated as part of the bearing ratio.

Terms Mask

A mask that performs a terms fit to one region of the surface, then adjusts the rest of the surface accordingly.

Tilt

A detrending alignment resulting from a slope or slant. Removing tilt compensates for residual tilt, causing slanted surfaces to appear flat. Tilt is inherent in the interferometer configuration.

t_p

See Bearing Ratio.

Transition Zone

The region of a step between the base and the top where the slope is not zero.

V_1

Material Filled Peak Area. A measure of the material removed during the run-in period.

V_2

Lubricant Filled Profile Valley Area. A measure of the area that can retain lubricant.

Valley

A point that is lower than its two neighbors in a given profile. Valleys only exist along a single line profile and are a two-dimensional quantity. Note that a valley must be lower than the surrounding points in *both* X and Y. A local valley is defined as any point that is lower than its nearest neighbors in *either* X or Y.

Vertical Scanning Interferometer

A digital interferometer that vertically scans through focus. The fringe modulation corresponding to each plane of focus is recorded by the detector and transferred to the system's computer. Computerized calculations demodulate the peak interference signals to determine the optical path difference (OPD), and subsequently, surface heights.

Volume

The volume the surface would hold if it were covered just to the surface of the highest peak. Also the volume of an island in multiple region analysis, defined as the island area times the mean height.

Volume, normalized

The ratio of the volume to the lateral area, measured in billions of cubic microns per square inch (BCM).

VSI

Vertical Scanning Interferometer. A digital interferometer that vertically scans through focus. The fringe modulation corresponding to each plane of focus is recorded by the detector and transferred to the system's computer. Computerized calculations demodulate the peak interference signals to determine the optical path difference (OPD), and subsequently, surface heights.

Wavefront

A light wave radiating from a point source.

Wavelength

A control value that specifies the wavelength of the light source used by the system to produce the test and reference beams.

Waviness

A measure of the widely-spaced irregularities or general feature of a surface.

Window

An array size that specifies the number of pixels used in the data smoothing algorithms.

X Crossing

A measure of the number of times data crosses zero when it is scanned in the X direction.

X Diameter

Island X Diameter. The width of the box needed to encompass an island in multiple region analysis.

X PSD

The PSD function for the horizontal lines of data. *See also* Power Spectral Density.

X Sag

The maximum curvature in the X direction for an island in multiple region analysis.

X Slope

The rate of change of the surface in the X direction. *See also* Slope.

X Tilt

The amount of tilt in the X direction for an island in multiple region analysis.

XY Diameter

Island Average Diameter. The average value of X Diameter and Y Diameter.

Y Crossing

A measure of the number of times data crosses zero when it is scanned in the Y direction.

Y Diameter

Island Y Diameter. The height of the box needed to encompass an island in multiple region analysis.

Y PSD

The PSD function for the vertical lines of data. *See also* Power Spectral Density.

Y Sag

The maximum curvature in the Y direction for an island in multiple region analysis.

Y Slope

The rate of change of the surface in the Y direction. *See also* Slope.

Y Tilt

The amount of tilt in the Y direction for an island in multiple region analysis.

Zero Crossing

A point where a profile crosses the zero height plane, which is usually also the mean plane.

Zero Order Fringe

The interference fringe exhibiting the peak modulation or intensity. It is the highest-contrast fringe.

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