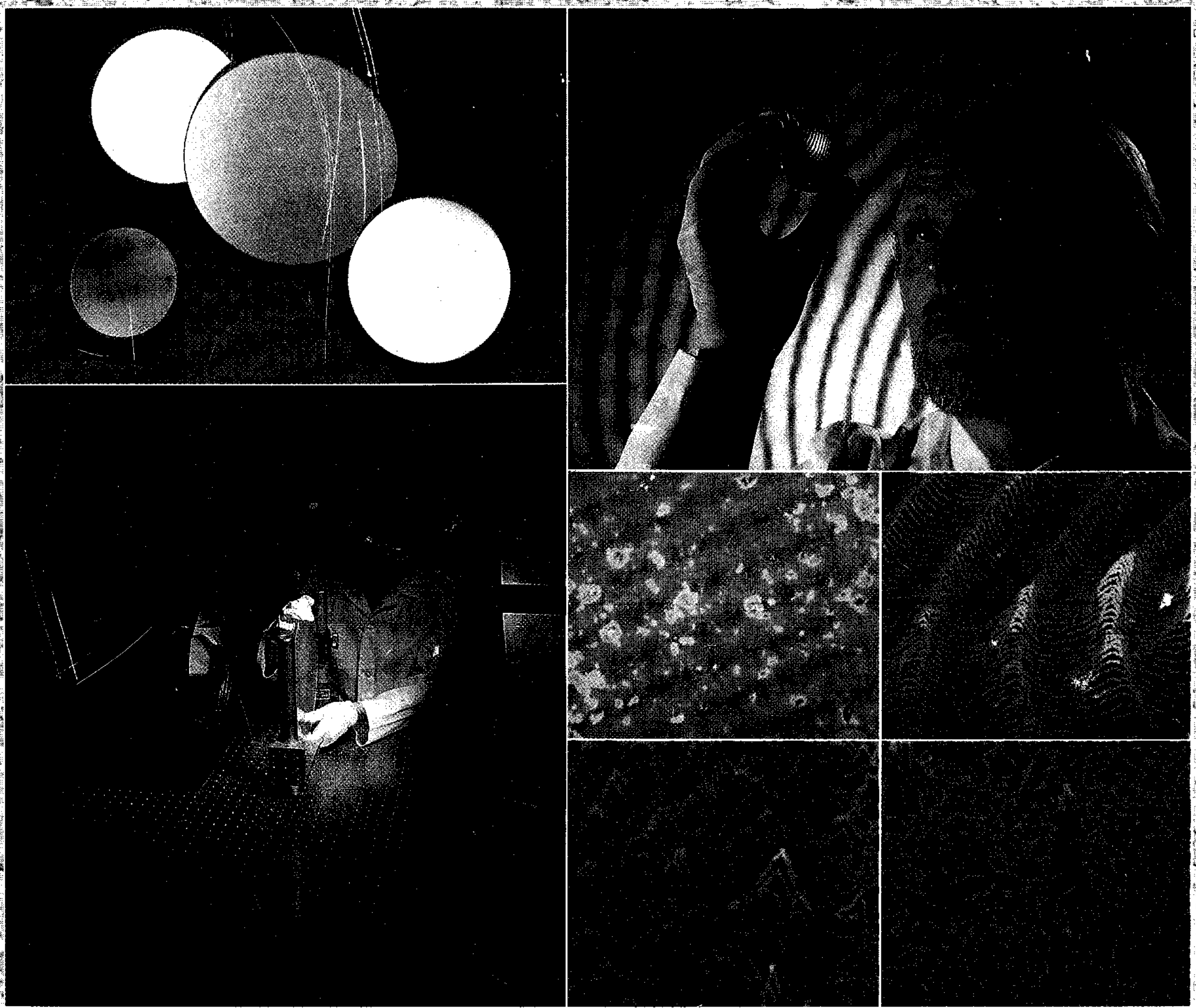
RST Plus

Technical Reference Manual



WYKO

CORPORATION

RST Plus Technical Reference Manual

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WYKO CORPORATION

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What's in this Manual?

The *RST Technical Reference Manual* provides technical information about your RST Plus surface measurement system. This manual is intended to help customers who ask questions that are beyond the basic operational questions—questions like:

> "Do I use VSI or PSI?"
>
> "What are all of these different analyses?"
>
> "What does my processed data mean and what can I do with it?"
>
> "What are all of these different surface parameters?"

☞ This technical reference manual is not a procedure manual; rather, it is a conceptual manual. It contains information that is *not* found in your system's online help or your *RST Plus Operator's Guide*. When you use these three resources together, you should have a thorough understanding of how to use your system to its fullest capabilities.

Here's a preview of what you'll find in this manual:

Chapter 1, How the RST Plus Works, discusses the theory of operation for VSI and PSI. It describes the differences between these modes, their measurement applications, and their limitations. This chapter also discusses system performance in terms of range, resolution, and accuracy. Finally, it provides guidelines for using the combined VSI + PSI mode.

Chapter 2, Surface Parameters, provides information about the typical surface parameters that your RST Plus can calculate. This chapter includes definitions and calculations for each parameter. Suggested uses, advantages, and disadvantages are also included.

Chapter 3, Analysis Options, describes the more specialized calculations and analysis options available with your RST Plus system. These include histogram, bearing ratio, slopes, surface area, volume, line width, step height, PSD, autocovariance, BRDF, texture analysis, stylus analysis, multiple region analysis, and dissimilar materials analysis. By reading about each of these, you may find additional analyses that can help quantify your surface.

Chapter 4, About Processed Data, discusses ways to interpret and enhance your processed data. After reading this chapter, you'll learn when to use techniques such as subtracting a reference surface, removing terms, filtering, averaging, and masking to improve the quality of your data. This chapter also discusses how your data may become distorted.

Appendix A, About Surface Profiling, discusses general surface profiling terms and standards. This appendix complements the material in Chapter 2.

Appendix B, Database and Custom Display Editor Parameters, lists each database and custom display editor parameter by its block name and extended name. A brief description of each parameter is also included.

Appendix C, Exporting Data and Graphics, describes how to export data files and screen capture graphics from Vision™ into other applications.

Appendix D, System Specifications, includes general specifications for your RST Plus system. It also includes a very useful table of magnification objective specifications. If you install expansion boards, such as a local area network (LAN) board, first check the address settings provided in this appendix for conflicts.

What's New in this Edition?

If you received the first edition of the *RST Technical Reference Manual* (October, 1994), you probably want to know what's new in this second edition. The new material in this manual includes:

- VSI + PSI combined measurement mode (Chapter 1)
- Additional surface parameters, S and S_m (Chapter 2)
- Fractal roughness, autocovariance, BRDF, stylus analysis, multiple region analysis, and dissimilar materials analysis (Chapter 3)
- Height threshold analysis mask (Chapter 4)
- Updated database and custom display editor parameters list (Appendix B)
- Revised procedures for exporting data and graphics (Appendix C)
- System interrupts and address settings (Appendix D)

Chapter 1

How the RST Plus Works

This chapter explains how the RST Plus surface profiling system measures both smooth and rough surfaces. It also discusses the system's performance, and provides a list of additional technical references.

Theory of Operation

The RST Plus is a non-contact optical profiler that uses two technologies to measure a wide range of surface heights. Phase-shifting interferometry (PSI) mode allows you to measure smooth surfaces, while vertical-scanning interferometry (VSI) mode allows you to measure rough surfaces and steps.

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 passes through a red narrow-band filter and through a microscope objective to the sample surface. A beam splitter reflects half of the incident beam to the reference surface. See Figure 1-1. The beams reflected from the sample and the reference surface recombine at the beam splitter to form interference fringes. These fringes are the alternating light and dark bands you see when the surface is in focus.

During the measurement, a piezoelectric transducer (PZT) linearly moves a mirror a small, known amount to cause a phase shift between the objective 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.

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 correctly reconstructed. Thus, conventional phase-shifting interferometry is limited to fairly smooth, continuous surfaces. To resolve rougher surfaces, the RST Plus uses vertical-scanning interferometry techniques.

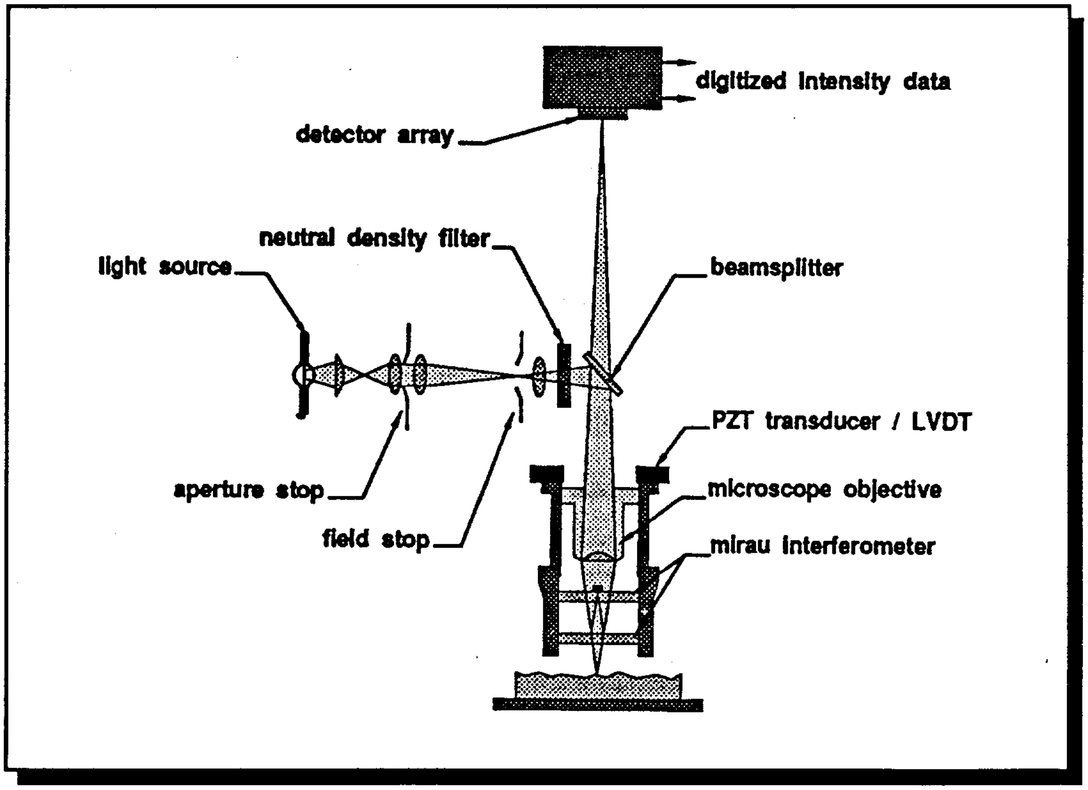

Figure 1-1. An Interference Microscope

VSI Mode

Vertical scanning-interferometry is a newer technique than phase-shifting interferometry. 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 not filtered, and the system measures the degree of fringe modulation, or coherence, instead of the phase of the interference fringes.

In vertical-scanning interferometry, a white-light beam passes through a microscope objective to the sample surface. A beam splitter reflects half of the incident beam to the reference surface. The beams reflected from the sample and the reference surface recombine at the beam splitter to form interference fringes.

During the measurement, the reference arm containing the interferometric objective moves vertically to scan the surface at varying heights. A linearized piezoelectric transducer 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.

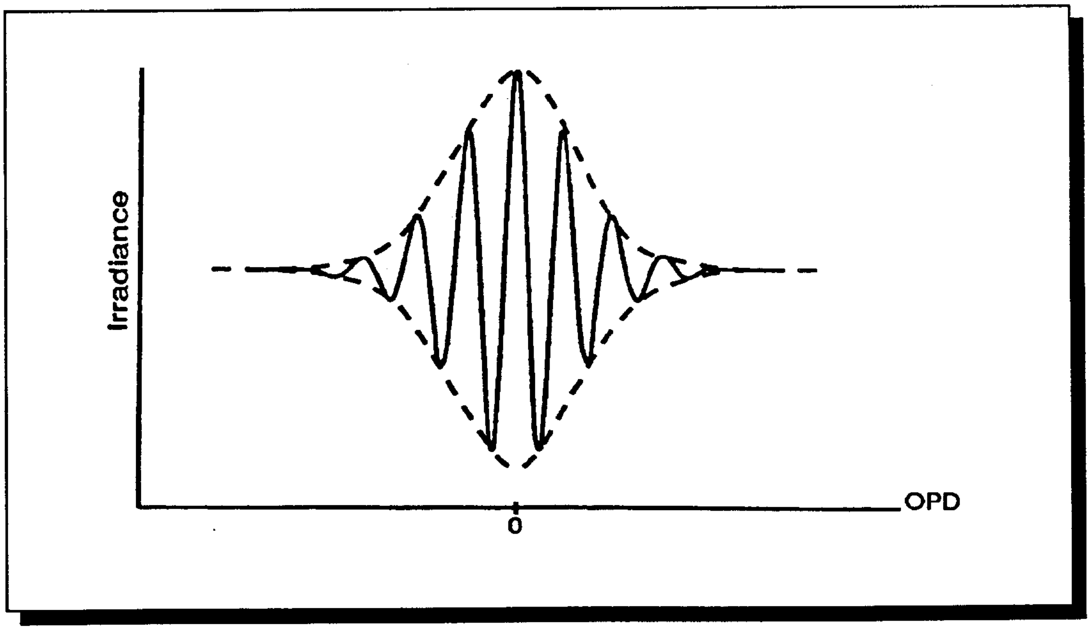

Figure 1-2. Fringe Contrast through Focus

The system scans through focus (starting above focus) at-evenly spaced intervals as the camera captures frames of interference data. 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.

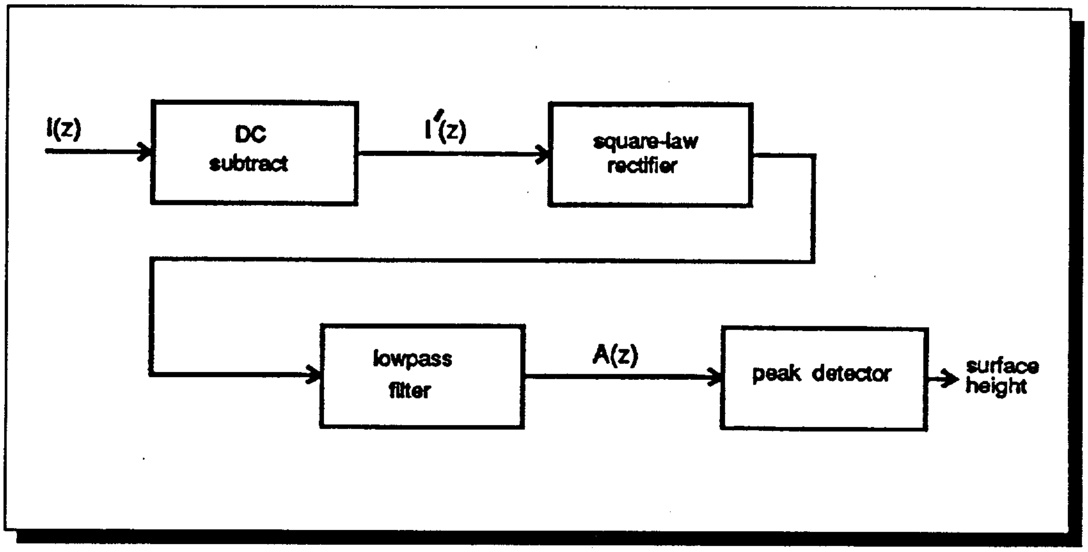

Figure 1-3. VSI Algorithm

Operational Differences between PSI and VSI

The previous sections explained the theoretical principles of phase-shifting and vertical-scanning interferometry techniques. It is important that you understand the differences between the two 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.

- VSI requires unfiltered white light for measurements; PSI requires filtered light.
- VSI vertically scans through a specified distance—the magnification objective actually moves through focus. PSI causes a phase-shift at a single focus point—the magnification objective does not move through focus.

- VSI uses an algorithm that processes fringe modulation data from the intensity signal to calculate surface heights. PSI uses an algorithm that processes phase data from the intensity signal to calculate surface heights. Each algorithm has limits; each one is very reliable within its limitations.

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. The light is not filtered during VSI measurements.

As mentioned previously, white light has a short coherence length. This means 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 depends on a 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 when you null the fringes. 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 red-light source works best for phase-shifting interferometry* because it has a longer coherence length than white light. 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.

☞ Although you must use the correct light source during a measurement, 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 make sure you're at precise focus, use white light and center the highest-contrast fringe.

How Do Scanning and Focusing Differ for VSI and PSI?

In vertical-scanning interferometry, the arm holding the magnification objective actually moves 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 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 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. (But don't forget to switch to red light to make the measurement.)

☞ 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.

What Are the Measurement Ranges of VSI and PSI?

Vertical-scanning and phase-shifting interferometry each have their own measurement ranges. In a general sense, VSI measures "rough" surfaces, while VSI measures "smooth" surfaces. These two modes allow you to measure a wide range of smooth and rough surfaces.

In VSI, the irradiance signal is sampled at fixed intervals as the 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; and finally, the peak of the lowpass 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. With this algorithm, the surface height resolution is approximately 3 nm rms for a single measurement on a smooth, highly reflective sample. For resolving surfaces smoother than this, you need to use PSI. The range of heights that VSI can profile is limited only by the range of the PZT to perform the translation through focus. For RST Plus, the range is up to 500 μm.

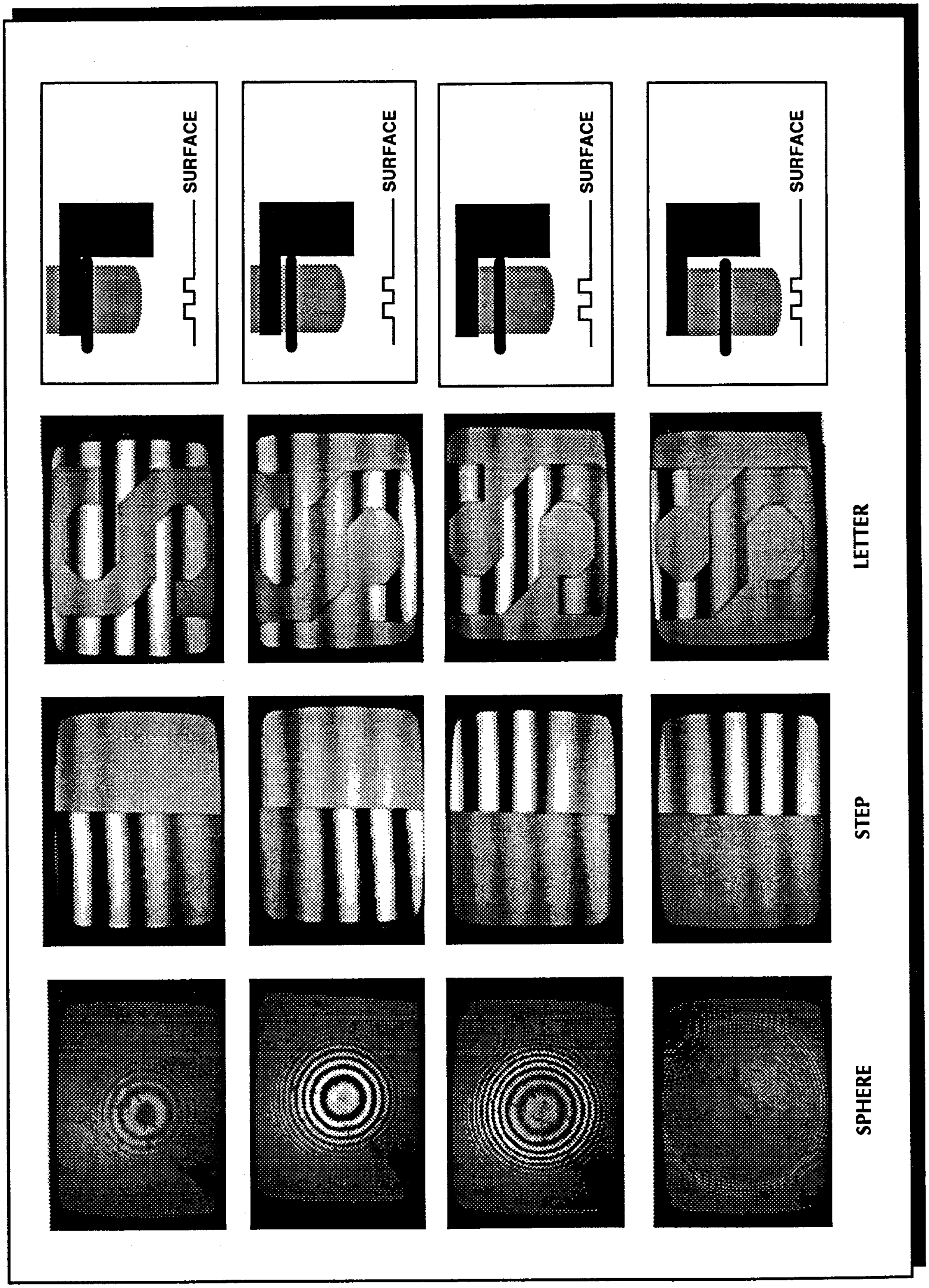

Figure 1-4. Fringes Moving through Focus in VSI Mode

In PSI, a narrow bandpass filter is placed in the optical path, and six intensity frames of data are recorded as the PZT is moved a distance of $\pi/2$, or $\lambda_0/8$[1], 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. If the surface has discontinuities or steep slopes, the phase may change more than π, or $\lambda/2$ in optical path difference (OPD), between adjacent pixels. When this happens, the removal of discontinuities in the integration algorithm is not reliable and you will see integration errors in your data. Integration errors are evident as discontinuities between lines of data on the surface map. Thus, PSI is reliable for smooth surfaces in which the height change between two adjacent points is not more than approximately 160 nm. For height changes greater than this, you need to use VSI. PSI can accurately resolve smooth surfaces of less than 3 Å rms for a single measurement.

VSI + PSI Mode

The previous section described the measurement ranges of using VSI mode or PSI mode alone. 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 VSI measurement to determine the relative heights of the steps. Then the system automatically switches to PSI mode and makes another measurement to resolve the surfaces 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.

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[1] $\lambda_0/8$ is the center wavelength of the bandpass filter.

System Performance

Appendix D of this manual contains detailed specifications on the capabilities of your RST Plus system. The following sections briefly describe range, resolution, and accuracy of the RST Plus system.

The performance of your RST Plus system depends to some extent on your measurement technique. To obtain optimum system performance, always use a well-calibrated system and consistent measurement techniques. Some helpful measurement techniques are described in Chapter 4 of your *RST Plus Operator's Guide*.

Range

Range refers to the greatest vertical distance the RST Plus can accurately measure. The limits of dynamic range for each mode are listed in Table 1-1. In PSI mode, the maximum height resolved between adjacent pixels is 160 nm. If you try to use PSI mode for higher steps, you will see integration errors (lines of discontinuity) in your data.

Table 1-1. Ranges of PSI and VSI

Mode	Range
PSI	160 nm
VSI	500 µm

Resolution

Resolution refers to the smallest distance the RST Plus can accurately measure. It can be in terms of lateral or vertical resolution. If your application deals with surface heights and roughness, vertical resolution may be critical. If your application deals with surface heights *and* lateral measurements of surface features, both vertical and lateral resolution may be critical.

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 "see."

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 detector-limited. 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

As described in the section entitled "What Are the Measurement Ranges of VSI and PSI?", each mode has different resolution limits. Resolution values for PSI and VSI are listed in Table 1-2 . The values are in terms of R_q and are based on measurements of a smooth surface (10 Å or less).

Table 1-2. Vertical Resolutions 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 1-2, you get better resolution when you average multiple measurements.

You can determine the resolution of your system by taking the difference of two measurements from the same location on the sample. The resulting data is essentially the noise limit of your system, or the lowest 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 RST Plus, always use consistent and correct measurement techniques. Also make sure environmental noise is minimized by setting up the system and vibration isolation table as described in Chapter 1 of your *RST Plus 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. WYKO recommends you use a known standard that has been calibrated by NIST.

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

Slight deviations in the objective NA, objective magnification, and the MMD magnification may also affect accuracy. These values are set at the factory after calibration, but you can recalibrate them if you wish. Directions for the following calculations are provided in Appendix D of your *RST Plus Operator's Guide*:

- Setting the NA calculation of an objective
- Setting the magnification calculation of an objective
- Setting the magnification calculation of a multiple magnification detector (MMD) lens

To correct for aberrations in the interferometer's optics, generate a reference surface of the internal reference mirror and subtract it from your measurements. This removes aberrational effects, which are significant for very smooth surfaces. 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 Chapter 4, "About Processed Data."

Additional References

If you would like more information about interferometry, RST Plus technology, or system performance, refer to the literature listed below. Contact WYKO Corporation for literature not published in trade journals.

☞ Some of the following literature was written from experimental work performed with earlier versions of WYKO's optical profilers. Because RST Plus is based partly on early 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

The RST Plus surface profiling system computes 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

Before you read about the individual surface parameters, read this introductory section to familiarize yourself with some common surface topography and surface profile terms. You may also want to read Appendix A, "About Surface Profiling."

☞ This chapter describes the surface parameters that a variety of analyses calculate—you may not use all of them to characterize your surface. Where appropriate, both the 2D and 3D equations are included.

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 also on 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 superimposed. 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. (The RST Plus provides a way to do this. For more information, see "Terms Removal" in Chapter 4).

Surface Profile Definitions

The surface profile is the most useful tool for examining surface texture. It can provide a visual sense of the surface, and it is also the foundation for surface calculations. These calculations are based on standard terms defined as follows:

- The **reference mean line** is the datum within the profile to which the measurement is related. The mean line is a straight line that runs centrally through the peaks and valleys, dividing the profile so as to enclose equal areas above and below the line. This line is labeled **M** in Figure 2-1. The **reference mean surface** is the three-dimensional reference surface about which the topographic deviations are measured.

- The **sampling length** is the nominal interval within which a single value of a surface parameter is determined. The sampling length is labeled **l** in Figure 2-1. The **sampling area** is the area within which a single value of a surface parameter is determined.

- The **evaluation length** is the length over which the values of surface parameters are evaluated. This length is labeled **L** in Figure 2-1. The **evaluation area** is the total area over which the values of surface parameters are evaluated. For meaningful statistics, the evaluation length or area should contain a number of sampling lengths/areas. Evaluation length or area is also called assessment length or area.

- 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 surface. The Z(x) function is the curved line in Figure 2-1.

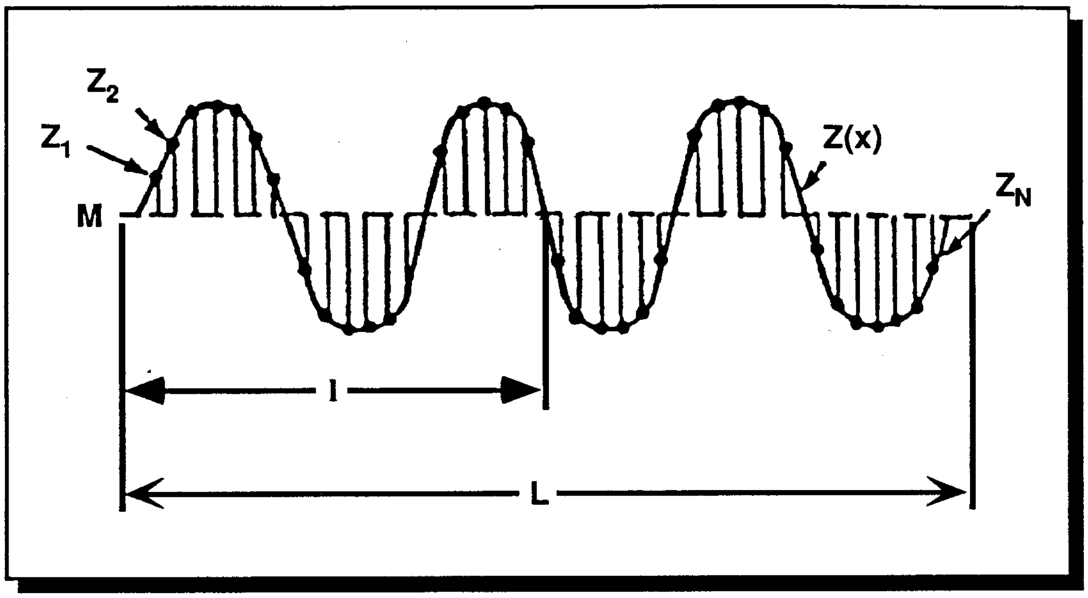

Figure 2-1. Surface Profile Definitions

Types of Surface Parameters

Surface measurement systems calculate surface parameters associated with roughness, peaks, valleys, profile symmetry, spatial frequency, and randomness. Each of these parameters is discussed in the next sections. Usually you cannot define a surface or process with a single parameter. You will probably use multiple parameters in meaningful combination based on an application's functional requirements.

When you evaluate roughness, peak, and valley numbers, keep in mind there are three general types of parameters: averaging, extreme value, and averaged extreme value.

- **Averaging** parameters specify the average of *all* heights in a defined length or area. R_a (average roughness) and R_q (root mean square roughness) fall into this category. Historically, R_a was easier to calculate graphically from a profile without the use of sophisticated computers. However, with the use of such computers in today's measuring instruments, R_q is also easy to calculate. For statistical work, rms values are more meaningful than arithmetic averages.
- **Extreme value** parameters specify only the greatest height (in terms of peaks and valleys.) R_p, R_v, and R_t fall into this category. These parameters may not be very repeatable because they deal with one-time occurrences.

- **Averaged extreme value** parameters specify the average of a defined and limited set of extreme values within a defined length. R_{pm}, R_{vm}, and R_z fall into this category. It is more practical to define a set of extreme values that are averaged than to depend on a single extreme value.

R_a

Definition

R_a, *roughness average*, is the mean height as calculated over the entire measured array. Measurement is made perpendicular to the direction of the lay, and R_a values are quoted in micrometers or micro-inches.

Calculation

Mathematically, R_a is the arithmetic average of the absolute values of the measured height deviations taken within the evaluation length or area and measured from the mean line or surface.

The R_a value may be obtained by adding individual height values without regard to sign and dividing the sum by the number of data points N in the profile or array.

The digital approximation for the two-dimensional R_a is:

$$R_a = \frac{(|Z_1| + |Z_2| + |Z_3| + \ldots |Z_N|)}{N}$$

and for the three-dimensional R_a:

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

where N and M are the number of data points in each direction of the array.

Uses

R_a is normally used to describe the roughness of machined surfaces. It is a stable, easily implemented parameter. R_a is a useful parameter for detecting general variations in overall profile height characteristics and for surveillance of an established manufacturing process. When R_a changes, it usually signifies something has changed in the process. It could be a change in the tool, the coolant, the material, or any other machine-related factor.

Advantages and Disadvantages

R_a over one sampling length represents the average roughness; therefore, the effect of a single spurious, non-typical peak or valley will be averaged out and have only a small influence on the value. R_a cannot detect differences in spacing or the presence or absence of infrequently occurring high peaks and deep valleys; therefore, R_a gives no information as to the shape of the irregularities or profile and must be replaced by some other parameter when these are of functional importance and the process produces them.

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 averages out the detail needed to quantify and analyze complex engineered surfaces. In fact, it is possible to see markedly different surface profiles between samples with the same R_a.

R_q

Definition

R_q, *root mean square (rms) roughness,* is the rms average of the measured height deviations taken within the evaluation length or area and measured from the mean linear surface.

Calculation

R_q is obtained by squaring each value over the evaluation length or area, then taking the square root of the mean. Compared with the arithmetic average, rms has the effect of giving extra weight to the higher values.

The digital approximation for the two-dimensional R_q is:

$$R_q = \sqrt{\frac{Z_1^2 + Z_2^2 + Z_3^2 + \ldots Z_N^2}{N}}$$

and for the three-dimensional R_q:

$$R_q = \sqrt{\frac{1}{MN}\sum_{k=1}^{M}\sum_{j=1}^{N} Z_{jk}^2}$$

Uses

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

Advantages and Disadvantages

R_q over one sampling length represents the average rms roughness; therefore, the effect of a single spurious, atypical peak or valley will be averaged out and have only a small influence on the value. R_q, like R_a, cannot detect differences in spacing or the presence or absence of infrequently occurring high peaks and deep valleys; therefore, R_q gives no information as to the shape of the irregularities or profile. A surface with a high spatial frequency may have the same R_q value as a surface with a low spatial frequency, but behave radically different. Because height values are squared in the calculation, R_q is more sensitive to peaks and valleys than R_a. This makes it a better parameter for discriminating between different types of surfaces.

If a surface has a profile that contains no large deviations from the mean surface level, the values of R_a and R_q will be similar. However, if there are appreciable numbers of large bumps or holes, the largest values of the profile height function will dominate the surface statistics and R_q will be larger than R_a.

If the surface is wavy, i.e., has roughness components of long surface spatial wavelengths, the value calculated for the rms roughness will in general depend on what length L is used for the calculation. Further, if the data points represent averages of height variations over small areas on the surface, the rms value will depend on the size of the areas. For these reasons, there is no unique rms roughness value for a surface. The rms roughness value depends on the following:

- The length L of the surface profile (maximum surface spatial wavelength)
- The surface area being averaged for each measurement (lateral resolution)

- The distance between data points (sampling distance)

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

☞ In the past, WYKO used the parameter called "RMS" to describe root mean square roughness. Because "RMS" is no longer an industry-recognized parameter, R_q replaces RMS. These terms are equivalent in WYKO's measuring instruments because they are computed using the same equation.

R_p and R_{pi}

Definition

R_p, *maximum profile peak height*, is the distance between the highest point of the surface and the mean line within the evaluation length, or area. It is the maximum height of the profile above the mean line for the entire data set. Figure 2-2 shows R_p for an evaluation length that contains five sampling lengths.

R_{pi} is the distance between the highest point of the profile and the mean line within a sampling length segment labeled i. In Figure 2-2, each sampling length would have its own R_p (R_{p1}, R_{p2}, ... R_{p5}).

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.

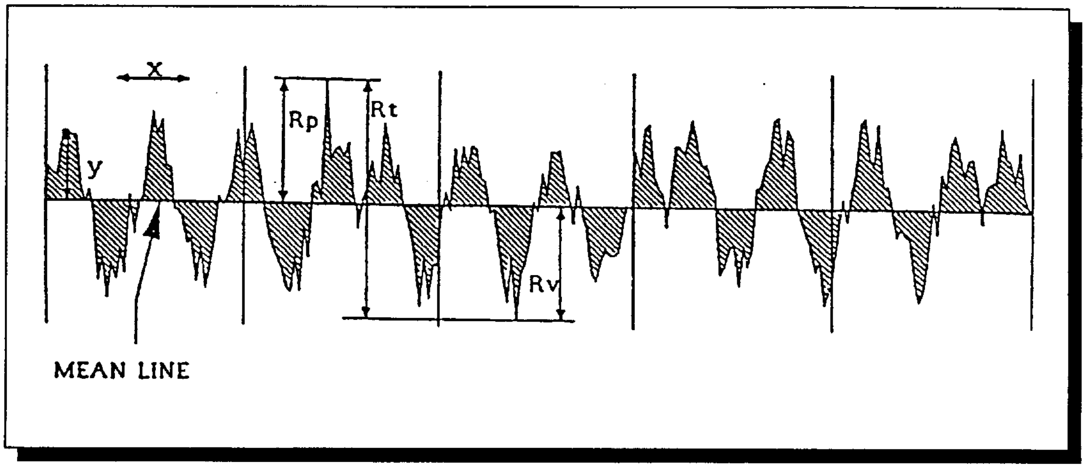

Figure 2-2. Definition of R_p, R_v, and R_t

R_v and R_{vi}

Definition

R_v, *maximum profile valley depth,* is the distance between the lowest point of the surface and the mean line within the evaluation length, or area. It is the maximum depth of the profile below the mean line for the entire data set. Figure 2-2 shows R_v for an evaluation length that contains five sampling lengths.

R_{vi} is the distance between the lowest point of the profile and the mean line within a sampling length segment labeled i. In Figure 2-2, each sampling length would have its own R_v (R_{v1}, R_{v2}, ... R_{v5}).

Uses

The valleys in a surface profile 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 and R_{ti}

Definition

R_t, *maximum height of the profile*, is the vertical distance between the highest and lowest points of the surface within the evaluation length. It is the maximum peak-to-valley height of the profile calculated over the entire measured data array. Figure 2-2 shows R_t for an evaluation length that contains five sampling lengths.

R_{ti} is the maximum peak-to-valley height within the sampling length segment labeled i. In Figure 2-2, each sampling length would have its own R_t (R_{t1}, R_{t2}, ... R_{t5}).

Calculation

R_t is the sum of the maximum profile peak height (R_p) and the maximum profile peak depth (R_v).

$$R_t = R_p + R_v$$

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_{pm}

Definition

R_{pm}, *average maximum profile peak height,* is the average of the successive values of R_{pi} calculated over the evaluation length. It is the mean peak height for the entire data set. R_{pm}(DIN)[1] contains five sampling lengths within an evaluation length, as shown in Figure 2-2.

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[1] In the DIN Standard 4768, the evaluation length consists of five sampling lengths.

Calculation

The calculation of R_{pm} is given by:

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

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.

R_{vm}

Definition

R_{vm}, *average maximum profile valley depth,* is the average of the successive values of R_{vi} calculated over the evaluation length. It is the mean peak valley for the entire data set.

Calculation

The calculation of R_{vm} is given by:

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

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.

R_{tm}

Definition

R_{tm}, *average maximum height of the profile*, is the average of the successive values of R_{ti} calculated over the evaluation length. This parameter is the same as R_z(DIN)[2] when there are five sampling lengths within an evaluation length, as shown in Figure 2-2.

Calculation

The equation for R_{tm} is given by:

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

where N is the number of sampling lengths or cut-offs.

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.

R_z

Definition

R_z, *average maximum height of the profile*, is the average of the successive values of R_{ti} calculated over the evaluation length. R_{ti} is the vertical distance between the highest and lowest points of the profile within a sampling length. It is the average

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[2] Ibid.

of the greatest peak-to-valley separations. Note that the points used for determining R_z are *profile* peak and valleys (must cross the mean line), not *local* peaks and valleys. R_z (DIN) contains five sampling lengths per evaluation length.

Calculation

R_z is calculated using the following:

$$R_z = \frac{1}{N}\left[(H_1 + H_2 + \ldots H_N) - (L_1 + L_2 + \ldots L_N)\right]$$

where H_i are the highest points and L_i are the lowest points found in this analysis.

Uses

R_z is rapidly gaining acceptance as a useful “short stroke” parameter 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

The ten-point height has the advantage over a peak-to-valley height (roughness) 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}

Definition

R_{sk}, *skewness*, is a measure of the asymmetry of the profile about the mean line. R_{sk} 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 surface level. The degree of asymmetry can be seen when the profile height data is plotted against the amplitude density to produce an amplitude distribution function (ADF) curve.

Calculation

For a digitized profile, R_{sk} is calculated using the following:

$$R_{sk} = \frac{1}{R_q^3}\frac{1}{N}\sum_{j=1}^{N} Z_j^3$$

where N is the number of ordinates chosen in a profile record length.

Uses

If the profile consists of a nearly smooth surface, but with deep scratches or pits, the profile will clearly be asymmetric and will have a definite skewness. If different surfaces have the same R_a or R_q values, you can distinguish between these surfaces by looking at the skewness of their profiles. Surfaces that are smooth but are covered with particulates such as dust or spatters of evaporated material will have a 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 nonconventional machining processes. If you look at the surface profile 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.

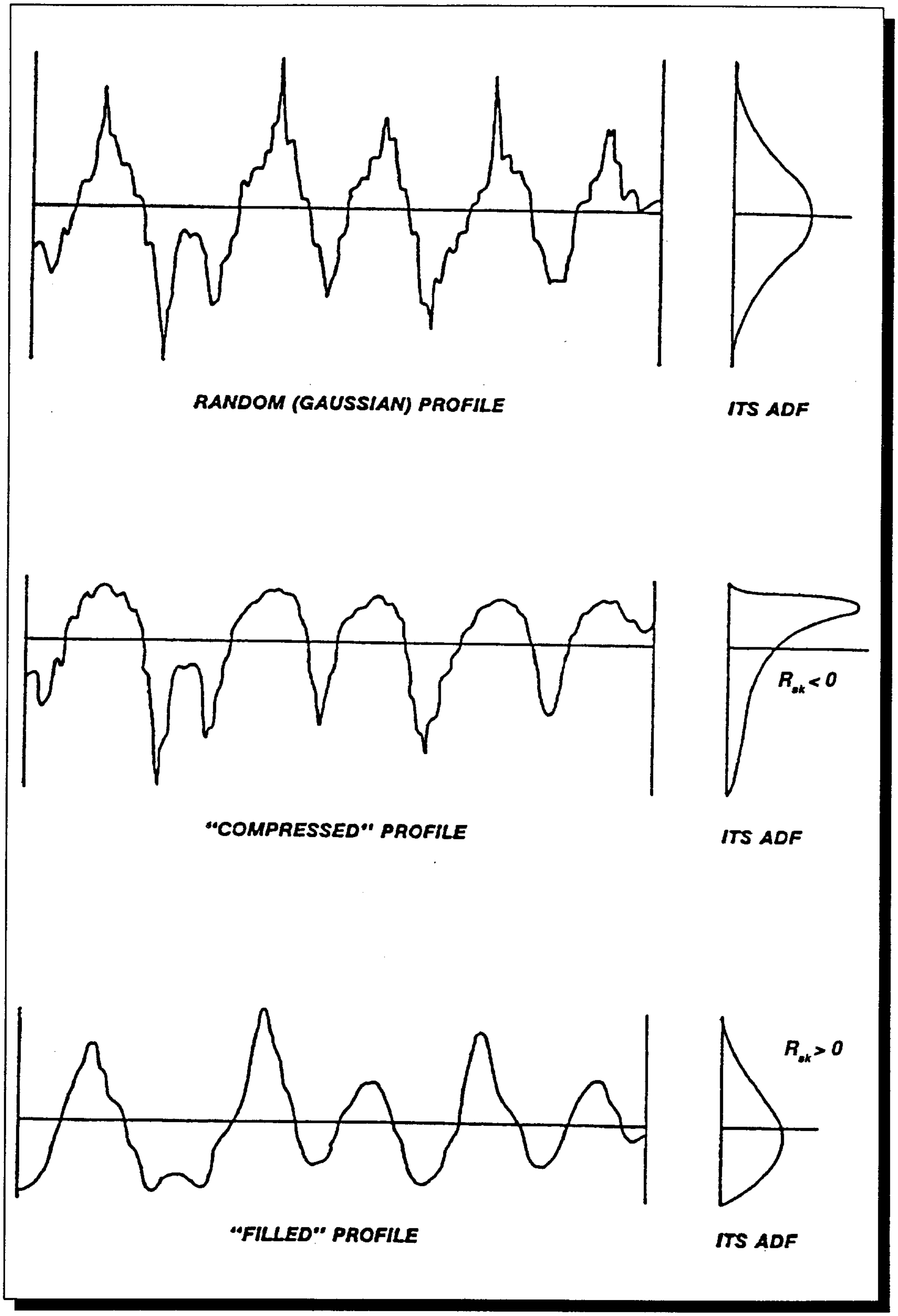


Figure 2-3. Examples of Skewed Profiles

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 R_{sk} exceeds ±1.5, do not use R_a alone to characterize the surface.

Advantages and Disadvantages

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

R_{ku}

Definition

R_{ku}, *kurtosis*, is a measure of the peakedness of the profile about the mean line. 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.

Calculation

For a digitized profile, R_{ku} is calculated using the following:

$$R_{ku} = \frac{1}{R_q^4}\frac{1}{N}\sum_{j=1}^{N} Z_j^4$$

Uses

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

The kurtosis value is high when a high proportion of the profile heights fall within a narrow range of heights. If most of the surface features are concentrated close to the mean surface level, the kurtosis will be different than if the height distribution contains a larger surface level (i.e., proportionately more bumps and scratches).

Kurtosis is also a measure of the randomness of profile 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. Profiles 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 profile data.

PC

Definition

PC, *peak count*, is the number of peaks per unit length (in cm or inches) measured at a specific peak count level which is the vertical distance (in μm or μin) 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.

Calculation

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 for one inch or centimeter along the nominal profile are counted. See Figure 2-4. 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.

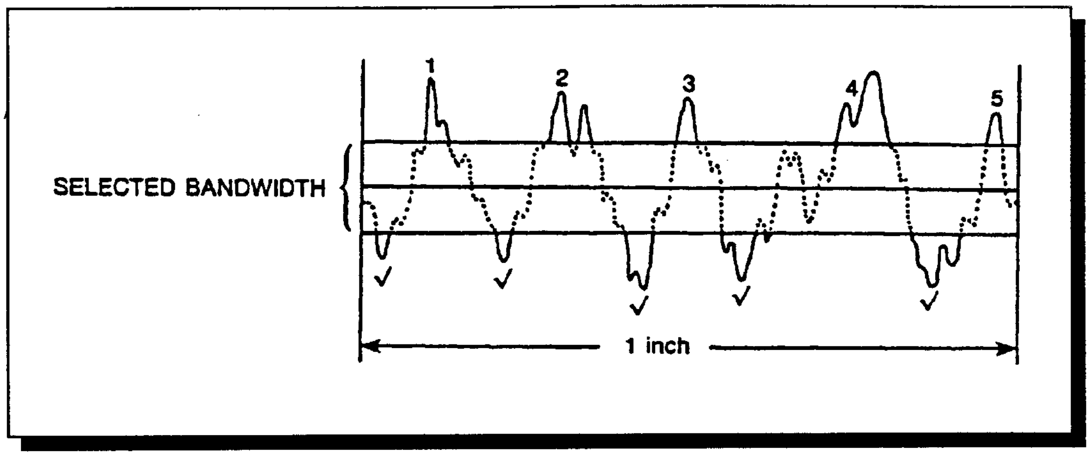


Figure 2-4. Definition of PC

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

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

where N is the number of peak counts and L is the assessment length.

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 2-5.

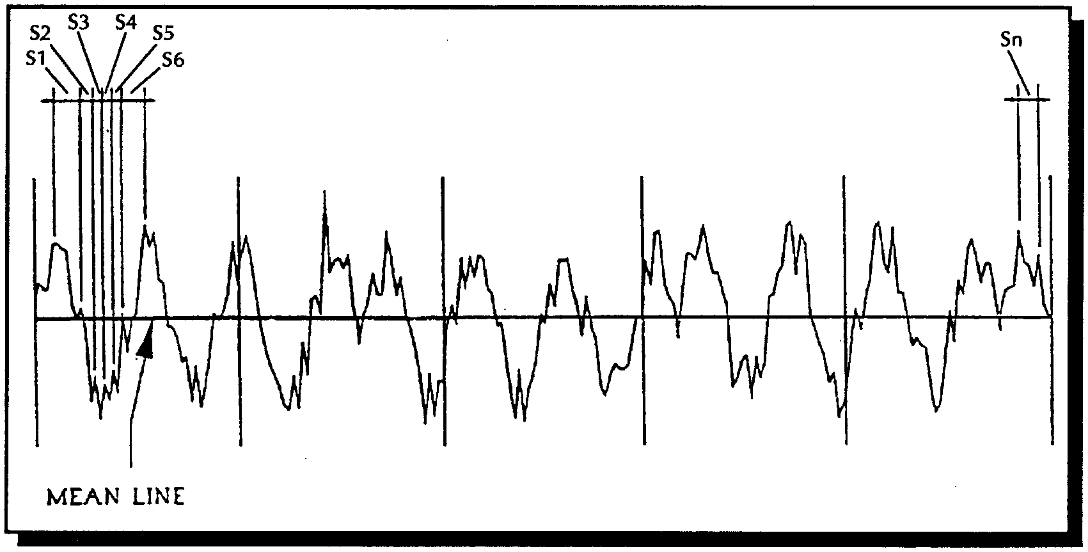


Figure 2-5. Definition of S

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 2-6. S_m is an ISO-recognized standard parameter.

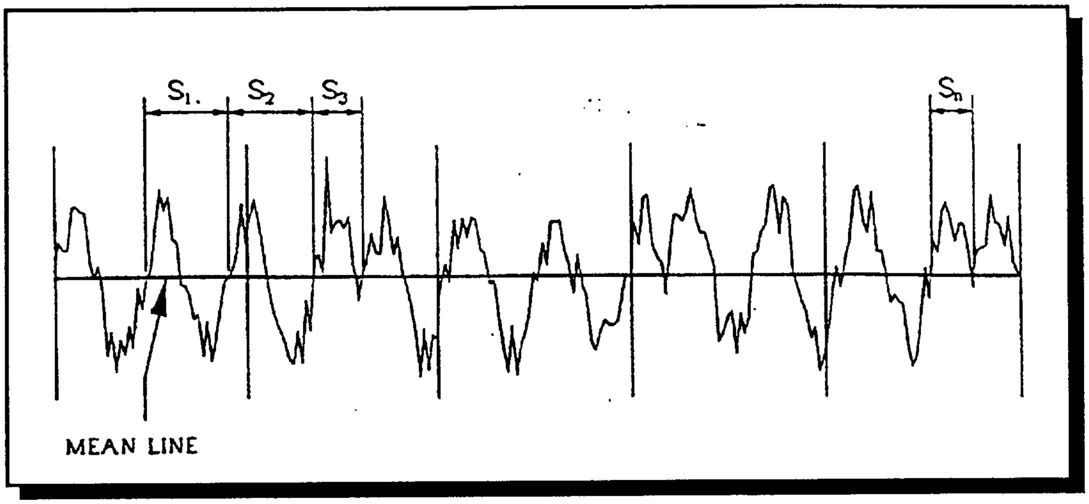


Figure 2-6. Definition of S_m

☞ 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 Figures 2-5 and 2-6.

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:

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

In the above equation, d_0 is the sampling interval between the profile points. The value of d_0 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 hill and down dale to traverse 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 of importance 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_0) 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 RST Plus calculates 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."

❖❖❖

Chapter 3

Analysis Options

The RST Plus performs several types of data analyses to provide information about the surface profile. 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 is a distribution plot which shows the distribution of individual surface height values in histogram form. The histogram indicates how often various heights occur in the data array. The horizontal axis indicates the individual height values. The vertical axis shows the number of data points contained within equally spaced intervals (bins).

The distribution histogram also includes a Gaussian curve drawn over the histogram. This curve is based on the rms, the number of points in the data set, and the current bin size, which is set by the user. It allows you to compare a normal distribution to the actual distribution of the data set. Figure 3-1 shows a histogram 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 data set 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

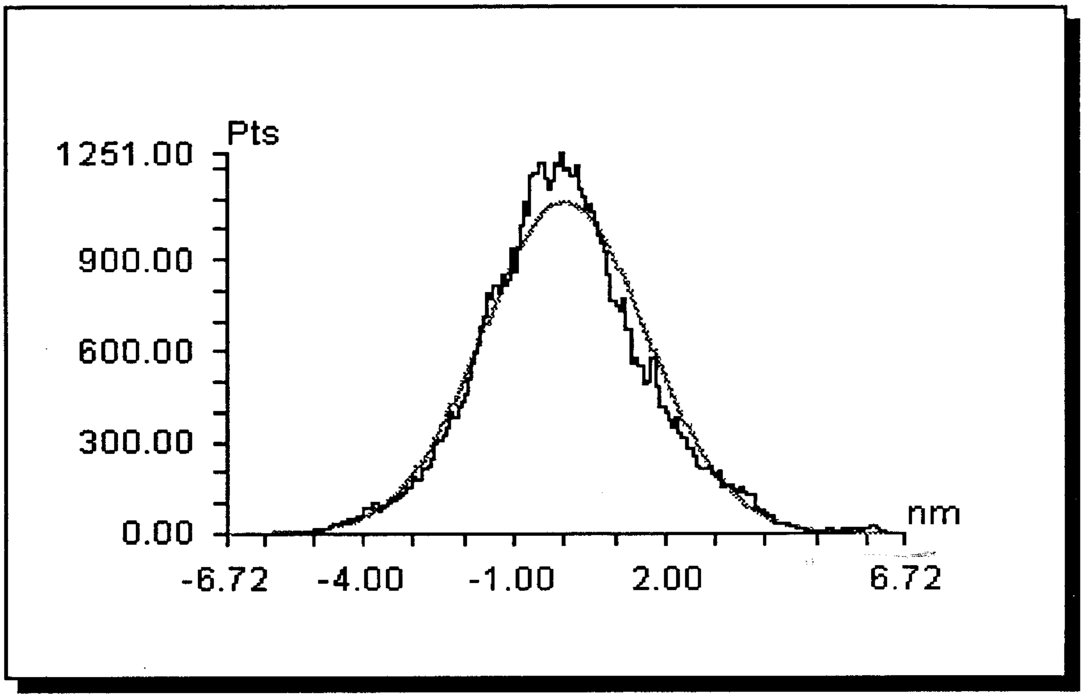


Figure 3-1. Histogram of Near Gaussian Surface

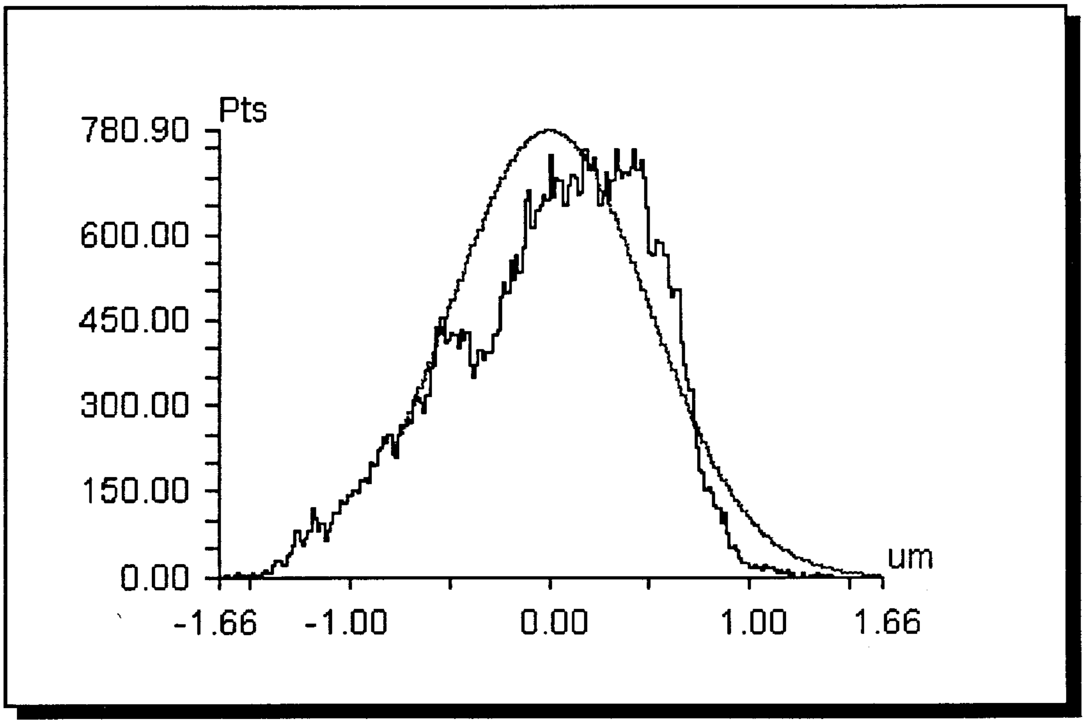


Figure 3-2. Histogram of a Skewed Surface

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.

Uses

The histogram gives you insight about the statistics of the data set. By interpreting the histogram, you can determine the amount of noise in the data. A data set 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

The *bearing length* is the length of the bearing surface at a depth p below the highest peak, or at a selected distance above or below the mean line. The *bearing area* is the area of the surface cut by a plane at this particular depth. Bearing length is a two-dimensional measurement, and bearing area refers to the corresponding three-dimensional measurement.

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.

Figure 3-3 shows a 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.

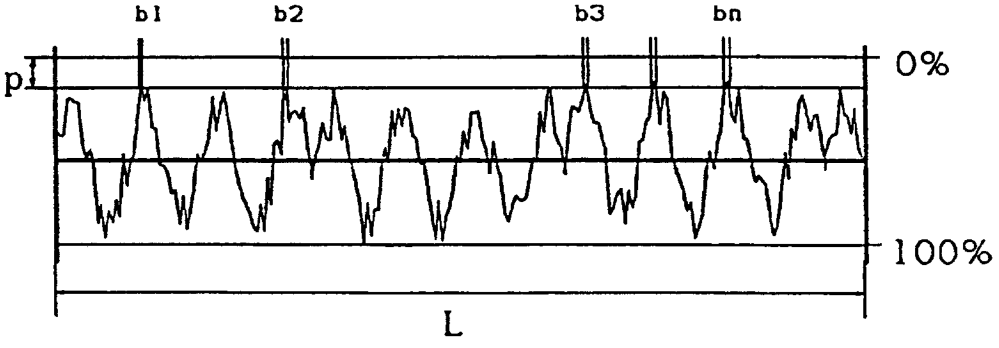


Figure 3-3. Bearing Length

The *bearing ratio* t_p, also known as the *material ratio*, is the ratio of the bearing length to the assessment length L. The *bearing area ratio* is the ratio of the bearing area to the total evaluation area. As with bearing length and bearing area, the bearing ratio is a two-dimensional measurement, whereas the bearing area ratio is a three-dimensional measurement.

☞ In RST Plus, the bearing ratio, bearing area, or bearing area ratio always refers to the three-dimensional measurement. Throughout the rest of this manual we will refer only to this three-dimensional measurement.

The *bearing ratio curve*, also known as the *material ratio curve*, is a graphical representation of the t_p parameter in relation to the profile level. As illustrated in Figure 3-4, the bearing ratio curve shows how the profile 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 profile, 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 profile.

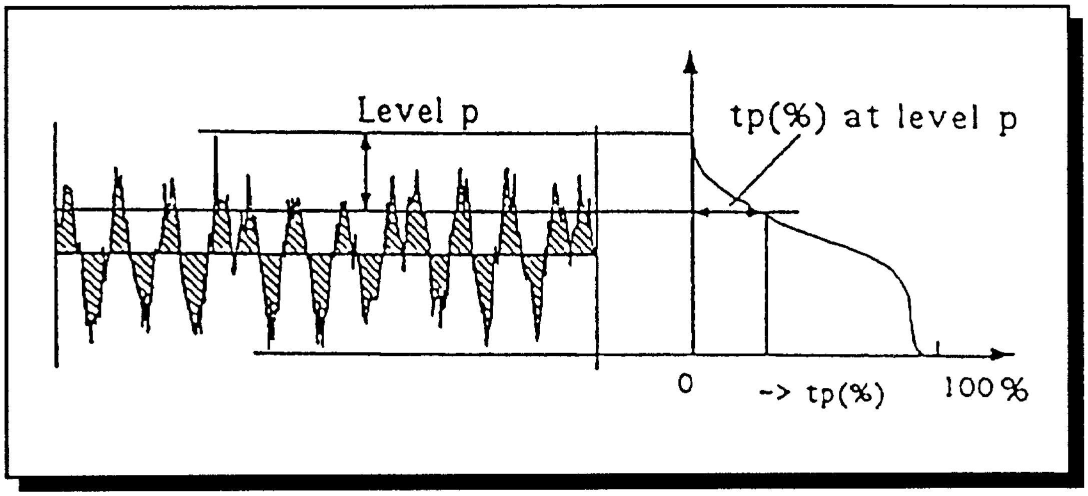


Figure 3-4. Bearing Ratio Curve

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 RST Plus, the left (t_{p1}) and right (t_{p2}) bearing ratio percentages used for the calculation of H_{tp} are specified by the user.

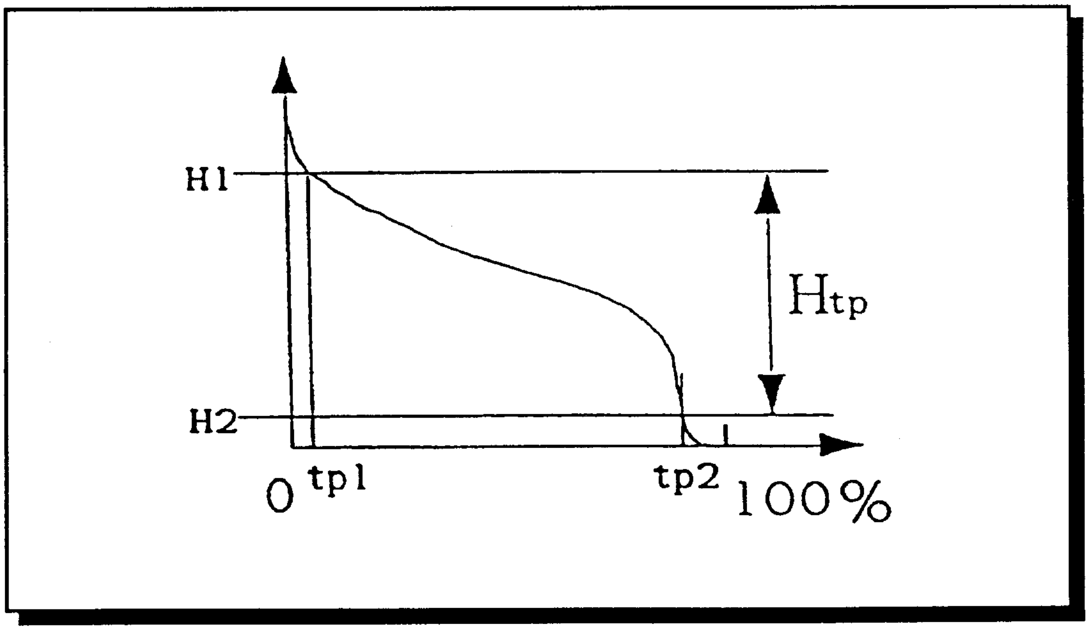


Figure 3-5. Bearing Ratio Curve Showing t_{p1}, t_{p2}, H_1, H_2, and H_{tp}

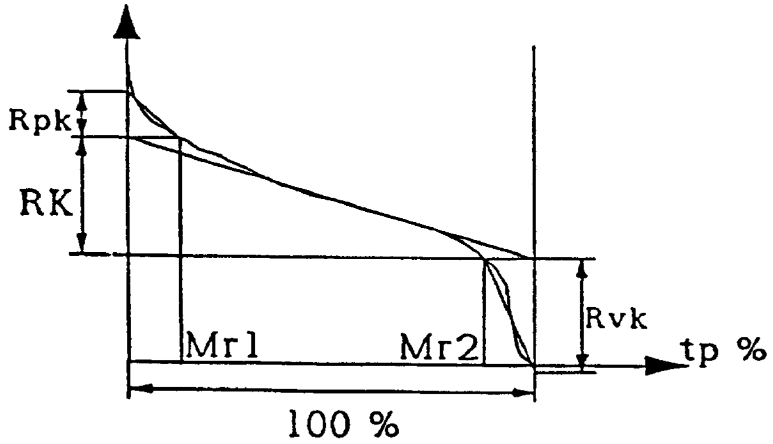


Figure 3-6. Bearing Ratio Curve Showing R_K, R_{pk}, R_{vk}, M_{r1}, and M_{r2}

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 is the area of individual islands at depth p and A is 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.

- 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).

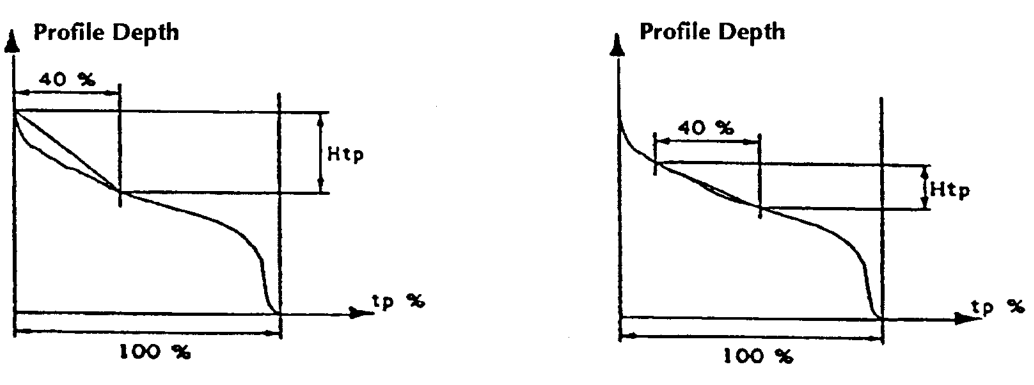
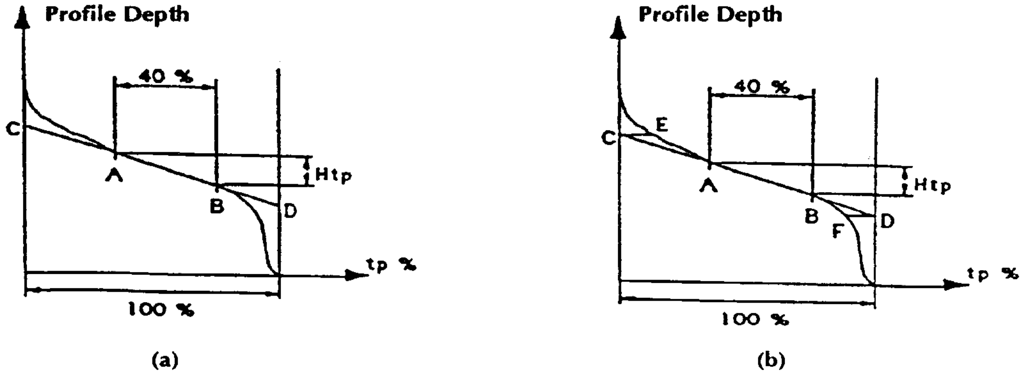


Figure 3-7. Finding Minimum H_{tp} at 40% Separation



(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.

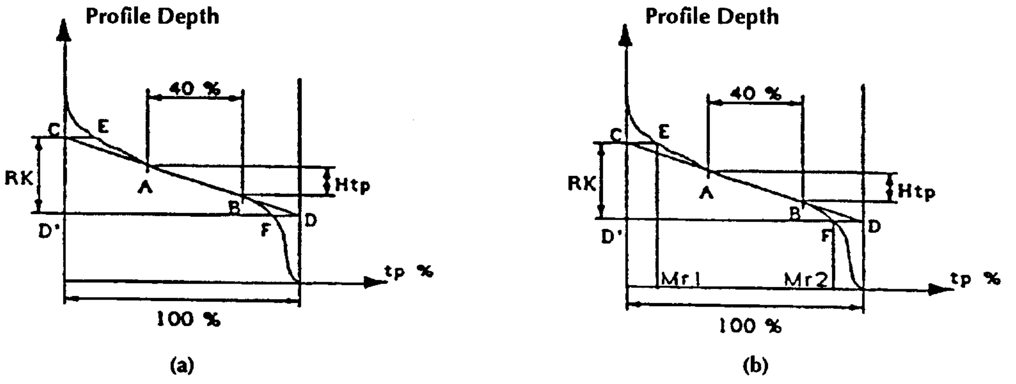


Figure 3-9. Derivation of R_K, M_{r1}, and M_{r2}

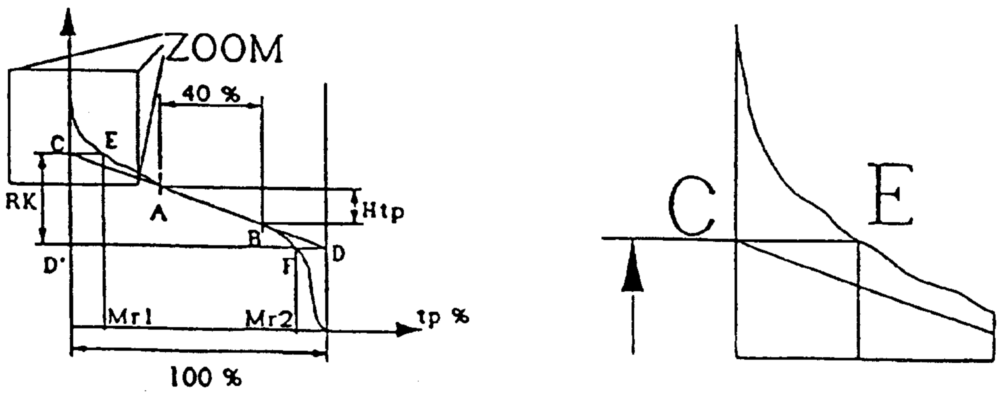


Figure 3-10. Zooming in on the Area around R_K and R_{pk}

- The size of the area bounded by CE, the profile depth axis, and the bearing ratio curve, as shown in Figure 3-11, is calculated. This area is labeled Area1 and is equivalent to the parameter V_1.
- R_{pk} is calculated as the height of the triangle with an area equal to Area1, shown as Area2 in Figure 3-11 (b). The base of this triangle is CE, and R_{pk} is the height which is on the profile depth axis between C and where the hypotenuse intersects the profile depth axis.

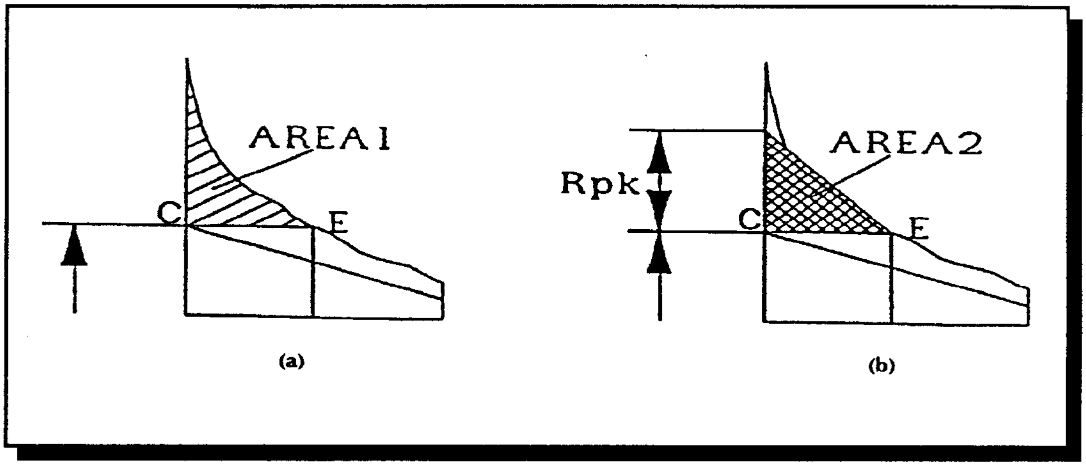


Figure 3-11. Calculating V_1 and R_{pk}

- 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.

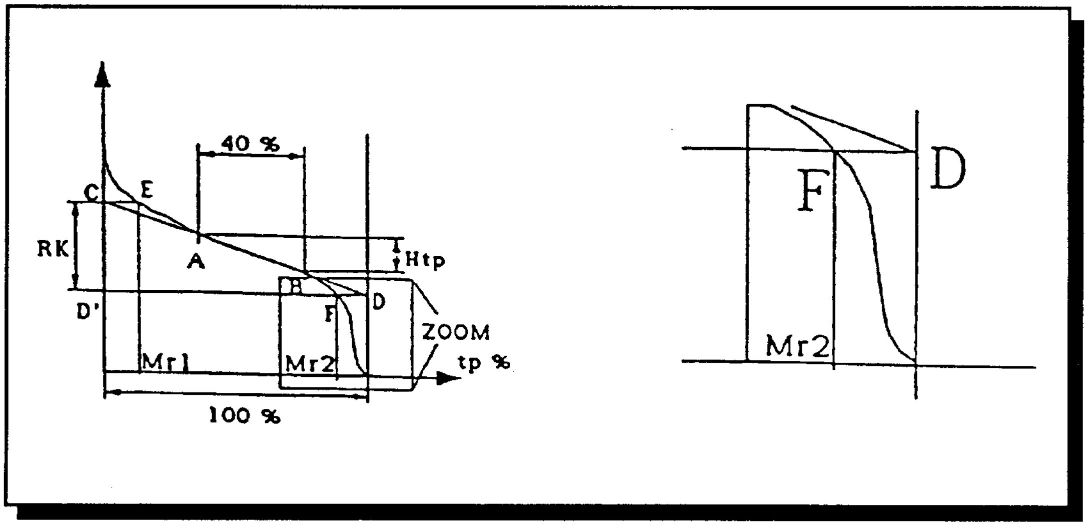


Figure 3-12. Zooming in on the Area around R_{vk}

- The size of the area bounded by DF, the ordinate drawn at $t_p = 100\%$, and the bearing ratio as shown in Figure 3-13 (a), is calculated. This area is labeled Area3, and is equivalent to the parameter V_2.

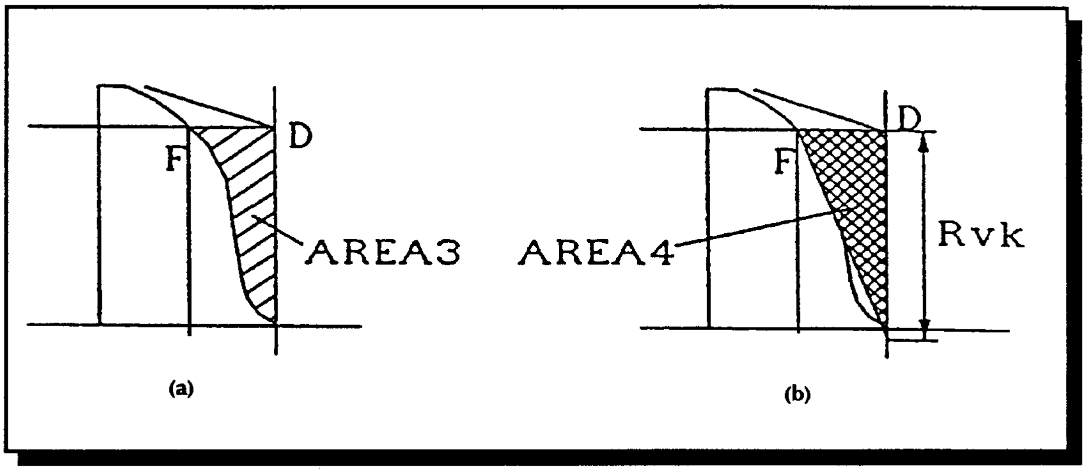


Figure 3-13. Calculating V_2 and R_{vk}

- R_{vk} is calculated as the height of the triangle with an area equal to Area3, labeled Area4 in Figure 3-13 (b). The base of this triangle is DF, and R_{vk} is the height of the triangle which is on the ordinate at t_p = 100% between D and where the hypotenuse intersects the ordinate at t_p = 100%.

Note that R_{vk} exceeds below the lowest valley of the profile. 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* equal R_t.

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

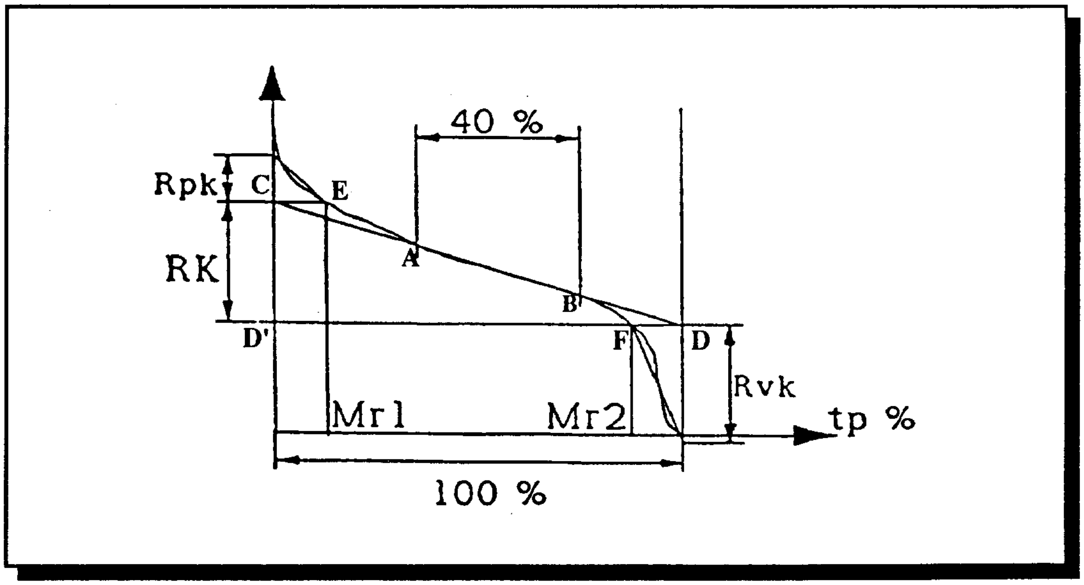


Figure 3-14. Bearing Ratio Curve Parameters

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 profile. As the peaks wear and the bearing line (i.e., the top line of the remaining profile) descends down the profile, the length of the bearing surface (the length of the profile in contact with the lapping plate) increases. t_p attempts to estimate the available bearing surface after the surface has worn down a specified amount. There is good reason to assume that a high percentage of material near the top of the profile 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 short 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

X and Y Slopes

Definition

The RST Plus Vision™ software displays a Contour or 3D plot showing the rate of change (steepness) of the sample's horizontal (X) or vertical (Y) surface. 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.

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:

$$\text{slope} = \frac{1}{d_0}\left|Z_{j+1} - Z_j\right|$$

where d_0 is 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 looking at surface data in a different way. X and Y slopes can be used to view and analyze such anomalies as disk wear tracks or disk blistering due to a head crash.

Viewing X and Y slopes in 3D and using the Shade options can be quite useful in gathering data on these anomalies. Imagine that you had a surface with a scratch on it. To get a better idea of where this scratch is and what it looks like, 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 in RST Plus by using shading with X and Y slopes in 3D 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

Power Spectral Density (PSD)

Definition

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. PSD(*f*), *power spectral density*, is the Fourier decomposition of the measured surface profile into its component spatial frequencies (*f*).

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.

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. What has actually happened is 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, the program computes an average lines power spectrum in the X (or Y) direction. The output represent the average profile power in X (or Y) at each spatial frequency.

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:

$$PSD(f) = \frac{d_o}{N}\left|\sum_{j=1}^{N} Z_j \exp\left[-i2\pi f(j-1)d_0\right]\right|^2$$

where $i = \sqrt{-1}$, d_0 is the sampling length, Z_j is the amplitude function, the spatial frequency *f* is equal to K/L, and K is an integer that ranges from 1 to N/2.

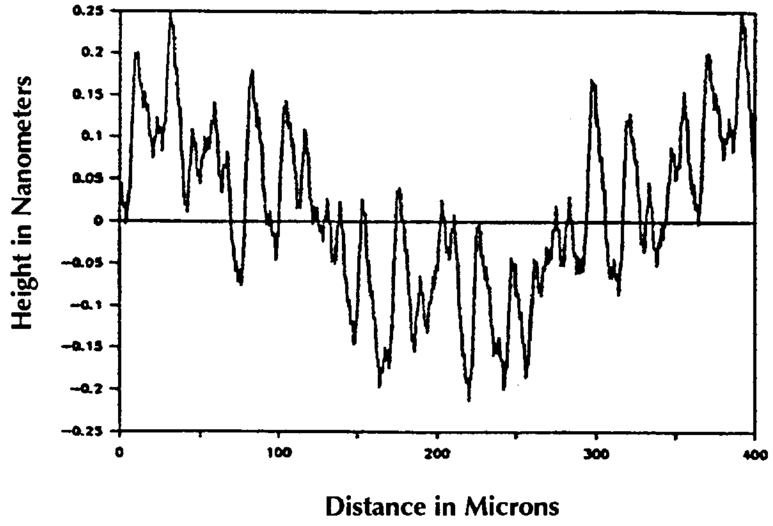


Figure 3-15. Synthesized Surface Profile

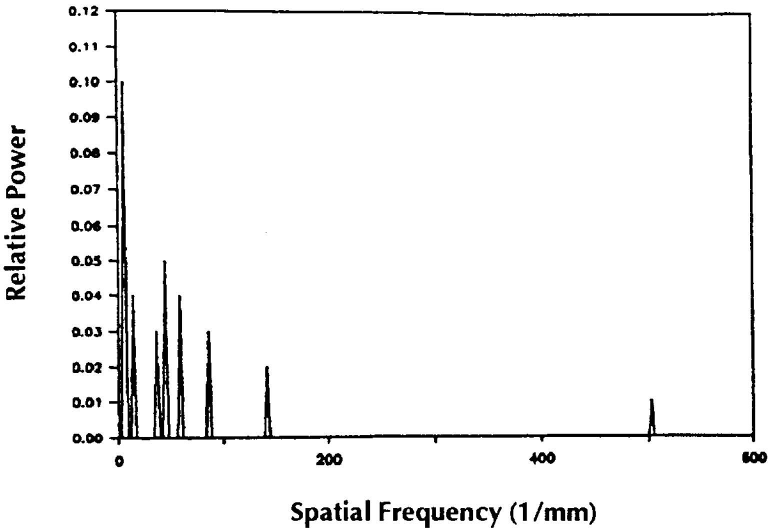


Figure 3-16. Power Spectrum of the Synthesized Surface

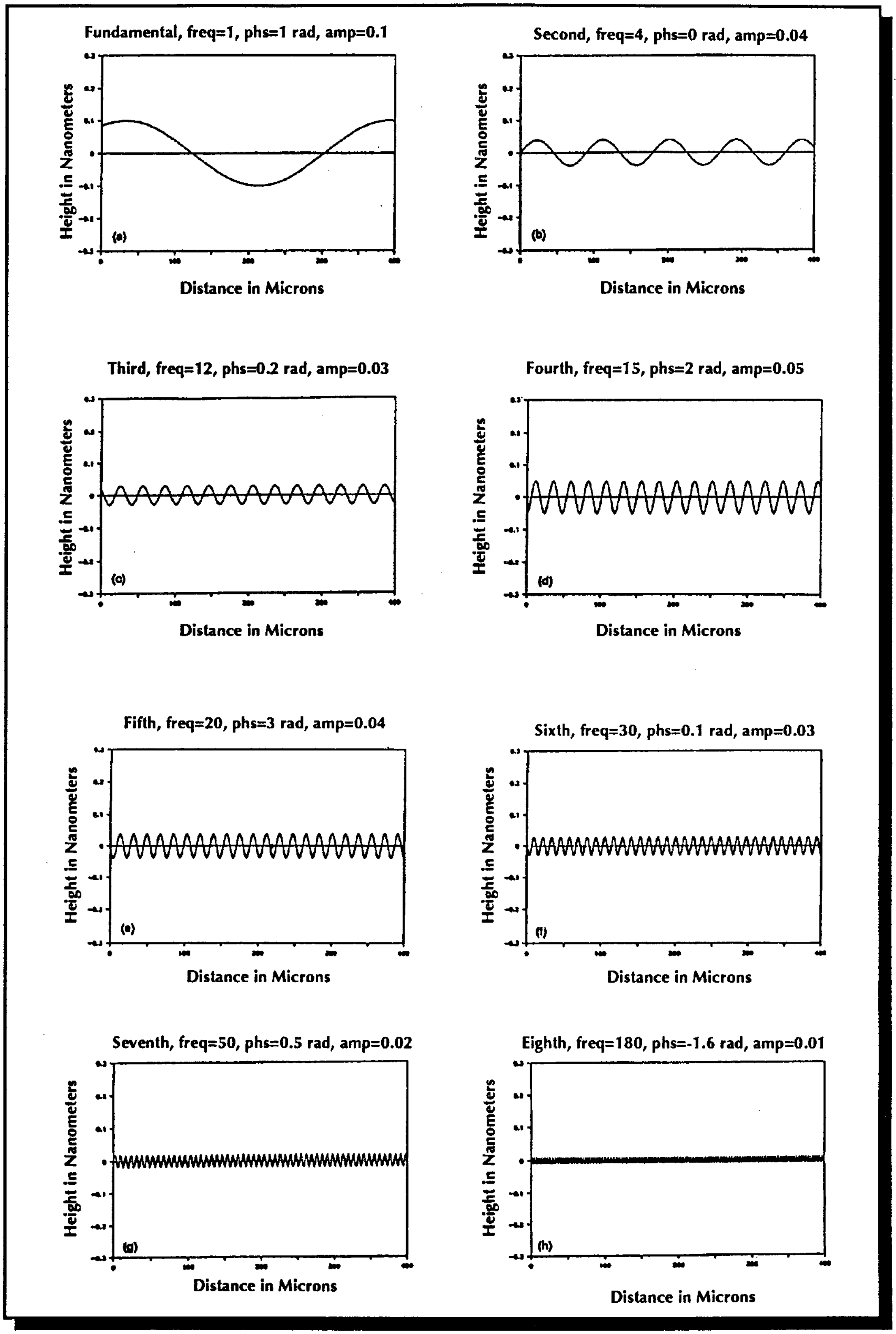


Figure 3-17. Surface Profile - Fundamental through Eighth Component

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).

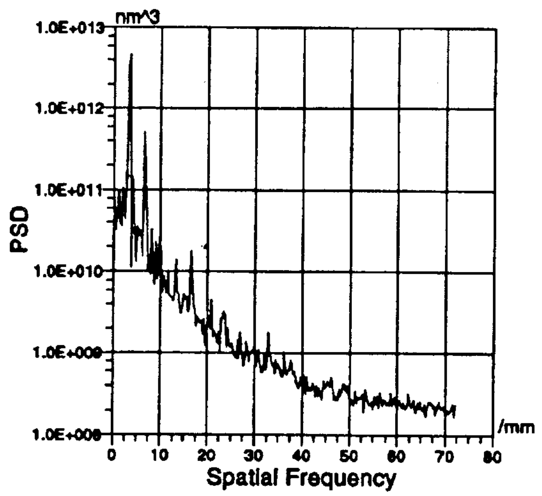


Figure 3-18. Average X PSD Plot of Surface with Repetitive Features

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.

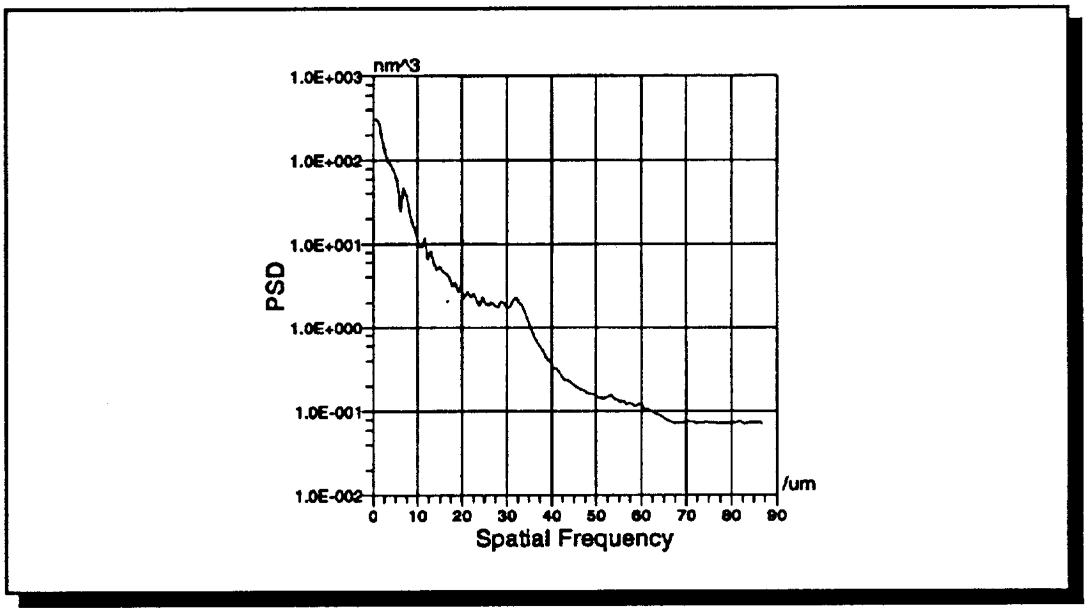


Figure 3-19. Average X PSD Plot of Surface with Random Features

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.

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 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 and B are ISO-standard constants and f is the spatial frequency. The program uses a linear least-squares fit of the following equation to determine A and B:

$$\log\left(PSD(f)\right) = \log\,(A) - B\,\log\,(f)$$

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 corresponds to the program's low frequency cutoff option and 1/C corresponds to the high frequency cutoff option.

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

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

RMS, a PSD-based roughness that is similar to R_q, is given by the following equation for a continuous case:

$$RMS = \left[\int_{1/D}^{1/C} PSD(f)\,df\right]^{1/2}$$

The digital approximation for RMS is:

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

where Δf is 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

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 bases 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:

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

where:

$$\tau_x = j' d_{0x}, \quad \tau_y = j'' d_{0y}, \quad f_x = K/L_x, \quad f_y = J/L_y$$
$$-N/2 < j' < N/2, \quad -M/2 < j'' < M/2$$

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 autocovariance 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.

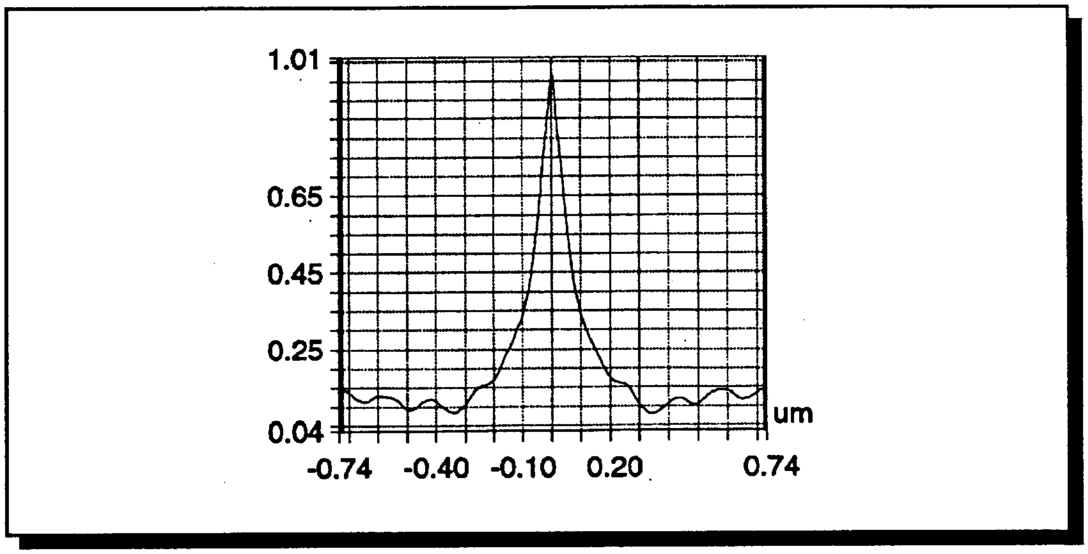


Figure 3-20. Autocovariance Function of Surface with Low Correlation

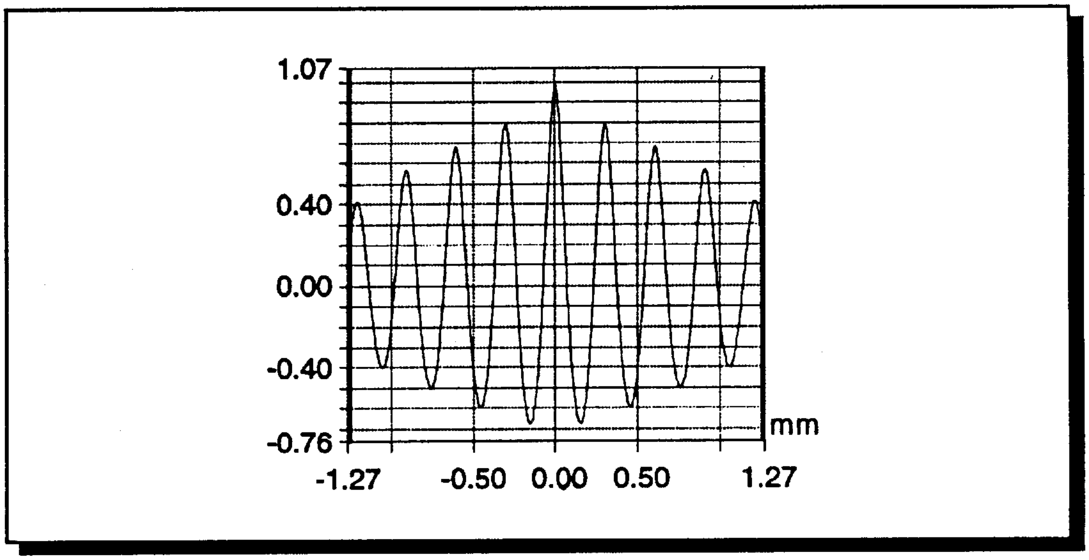


Figure 3-21. Autocovariance Function of Surface with Dominant Spatial Frequency

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.

Bidirectional Reflectance Distribution Function (BRDF)

Definition

BRDF, *bidirectional reflectance distribution function*, describes the amount of power scattered at various angles when light impinges on a surface. The scatter angles are relative to the specular reflection direction. The BRDF is dependent on the angle of incidence and the incident wavelength, as well as surface factors such as reflectance, roughness, contamination, etc.[1]

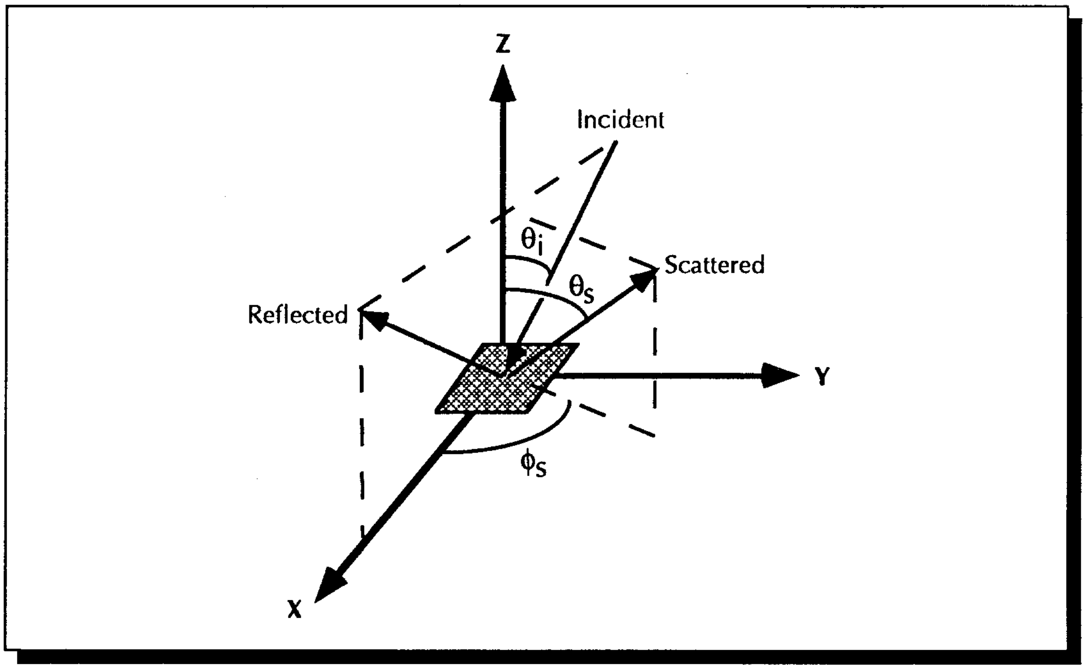


Figure 3-22. Angles Used in BRDF

Figure 3-22 shows the angles used in BRDF. These angles and their corresponding nomenclature in Vision™ are described as follows:

θ_i	The angle of incidence, measured relative to the Z axis. In Vision™, this angle is referred to as **Incidence Angle**.
θ_s	The angle at which scattered light is detected, measured relative to the Z axis. In Vision™, this angle is referred to as **Scatter Angle**.

---

[1] J. C. Stover, "Optical Scatter: an Overview," *Proc. SPIE* 1530, 2-6 (1991).

ϕ_s	The angle at which scattered light is detected, measured relative to the X axis (the plane of incidence). In Vision™, this angle is referred to as **Out-of-Plane Scatter**.

Calculation

The BRDF calculation in Vision™ is based on the work of Church, et. al.[2], and utilizes the 2D power spectral density (PSD) of the surface. The calculation is based on two input parameters: the angle of indicence, θ_i, and the out-of-plane scatter angle, ϕ_s. The range of scatter angles over which BRDF can be calculated is determined by the angle of incidence and by the spatial sampling of the objective used to measure the surface.

BRDF is calculated from the following equation:

$$BRDF(f_x, f_y) = \frac{16\pi^2}{\lambda^4}\sqrt{R(\theta_i)R(\theta_s)}\cos\theta_i\cos\theta_s PSD(f_x, f_y)$$

where the angles are as described above, and $R(\theta_i)$ and $R(\theta_s)$ are the reflectivity of the surfaces as functions of θ_i and θ_s, respectively (both are assumed equal to one). PSD (f_x,f_y) is interpolated from the 2D PSD array at the position f_x,f_y determined by:

$$f_x = \frac{1}{\lambda}(\sin\theta_s\cos\phi_s - \sin\theta_i)$$

$$f_y = \frac{1}{\lambda}\sin\theta_s\sin\phi_s$$

You can specify the out-of-plane scatter angle to be -45° to +45°, where an angle of 0° is in the plane of incidence (i.e., the X axis). You can specify the incidence angle to be 0° to +85°, where an angle of 0° means the light source points directly down on the surface.

The program calculates the BRDF two hundred times between the maximum and minimum possible scatter angles. If you want to change this number, add the following line to the `[BRDF]` section of the `wyko.ini` file:

```
BRDFsize = xxx
```

(Replace `xxx` with the desired number.)

---

[2] E. L. Church, et. al., "The Prediction of BRDFs from Surface Profile Measurements," *Proc. SPIE* 1165, 136-150 (1989).

The BRDF output shows the BRDF as a function of the scatter angle. You should normally use a logarithmic scale for the BRDF axis (the Y axis); otherwise, all you will see is a peak corresponding to the specular reflection. A logarithmic scale for the scatter angle axis (the X axis) has better resolution for smaller scatter angles.

Uses

BRDF measurements are useful for measuring the scattering properties of optical blacks and zinc selenide, an infrared window material.[3] You can use BRDF measurements of clean and dust-covered reflective surfaces to relate BRDF to cleanliness levels, which are measures of surface particle densities.

Summit Analysis

Definition

Summit analysis looks for peaks, or summits, and analyzes the data in terms of these summits. A summit is defined as any point that is higher than its four nearest neighbors in X and Y by a *summit threshold* value, and higher in absolute Z than the maximum data value minus the *summit cutoff* value. A summit and its neighbors (points 1, 2, 3, and 4) are shown in Figure 3-23.

To understand summit analysis, it is important to know the following definitions:

Summit Threshold:	The minimum distance a point must rise above all four of its nearest neighbors to be identified as a summit. This is a user-specified parameter.
Summit Cutoff:	The distance below the maximum data value where a summit is allowed to occur. The summit cutoff can be expressed as a percentage of total range, height from top, or absolute height. This is a user-specified parameter.
Summit Height:	The height of the summit point relative to the mean plan. See Figure 3-23.

---

[3] J. M. Bennett and L. Mattsson, "Introduction to Surface Roughness and Scattering," Optical Society of America, 1989, p. 30-31, 72.

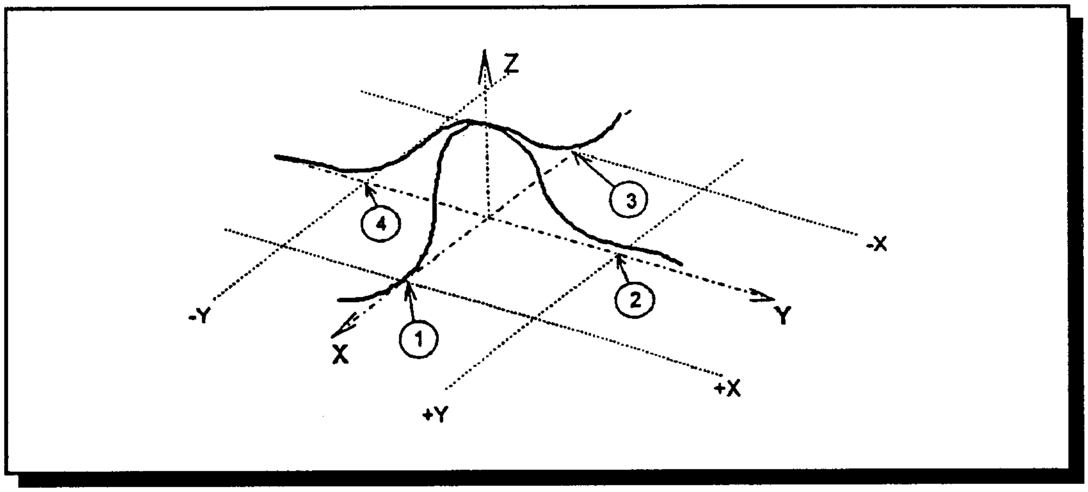


Figure 3-23. Summit Height

Mean Summit Height: The mean height of all summits calculated across the data array.

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

Summit Base: The point at which by moving outward from a summit point, the slope goes to zero or reverses. See Figure 3-24.

Summit XY Radius: The distance from the summit point to the summit base. See Figure 3-24.

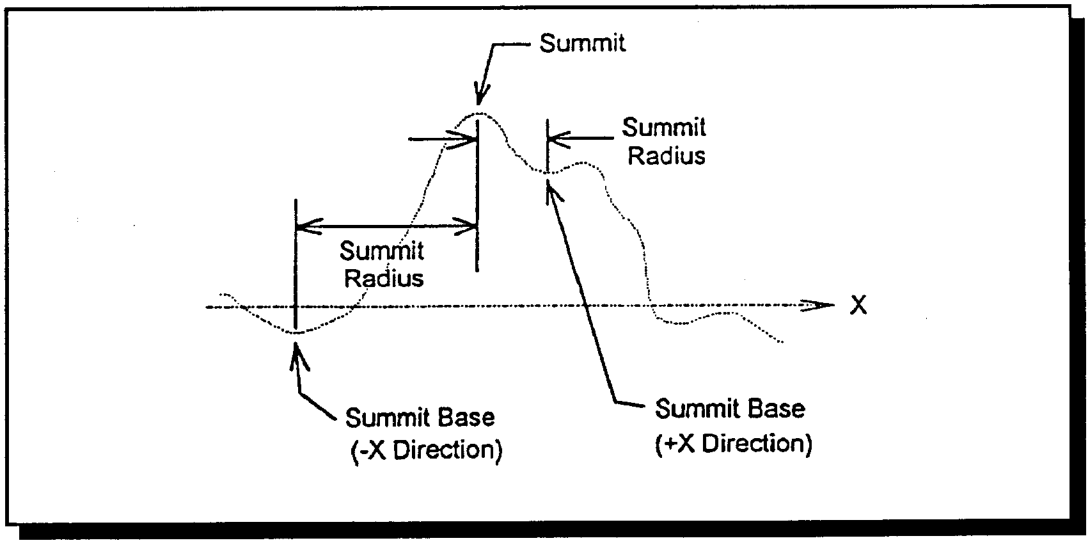


Figure 3-24. Summit Radius and Summit Base

Summit Diameter:	Twice the summit XY radius.
Summit Curvature:	A measure of the sharpness of a peak found using a summit and one of its nearest neighbors.
Summit Radius of Curvature:	The inverse of the summit curvature found by using a summit and one of its nearest neighbors.
Summit Count:	Provides a count of the number of summits identified based on the user-specified threshold.
Summit Slope:	The slope of a line connecting a summit and a valley along a profile in one direction. See Figure 3-25.

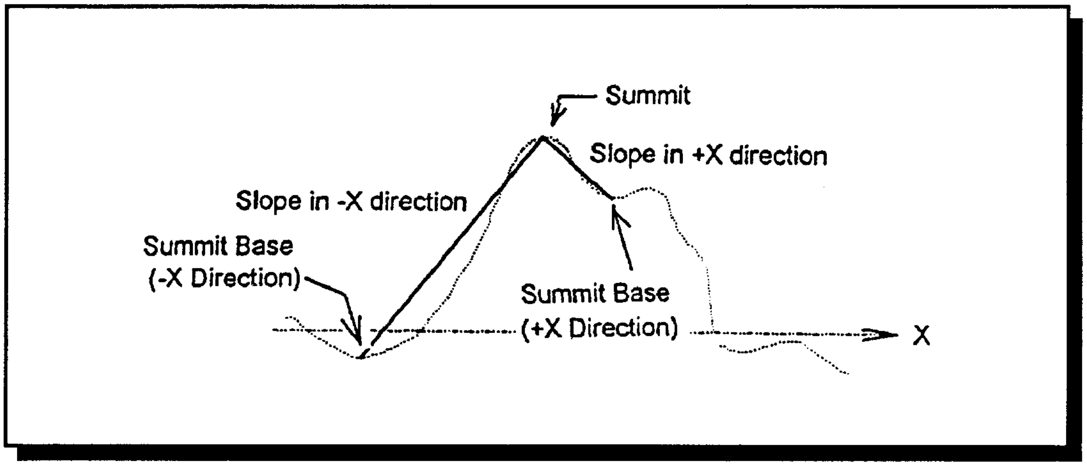


Figure 3-25. Summit Slope

Radius Count Threshold:	The minimum radius of curvature a peak must have to be indentified as a summit.
X and Y Crossings:	These are the zero X and Y crossings found by scanning the data in the X or Y direction for all rows, counting the number of times the data crosses zero (i.e., adjacent points have opposite signs), and dividing by the total distance scanned (number of rows times the row length). See Figure 3-26.

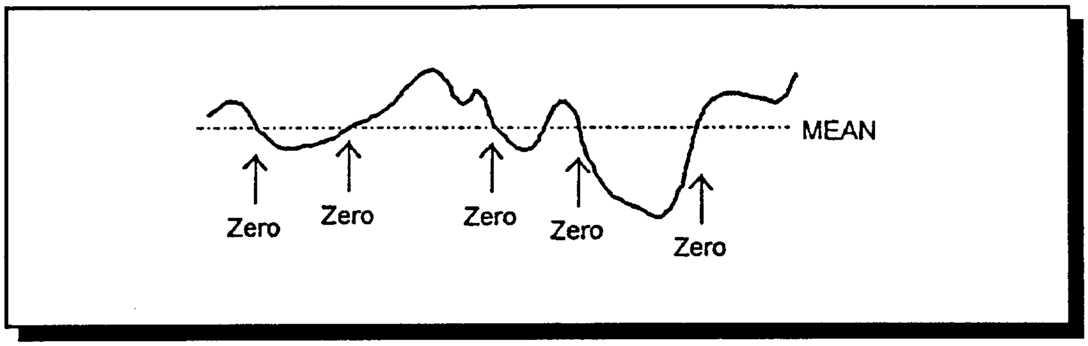


Figure 3-26. XY Crossings

Calculation

Given that h_i is the summit height at a given point i and N points, the mean summit height is calculated using the following:

$$\bar{h} = \frac{\sum_{i=1}^{N} h_i}{N}$$

The standard deviation, or RMS, is calculated using:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} \left(h_i - \bar{h}\right)^2}{N}}$$

The base of a summit is found by moving outward from the summit point and looking for a point where the slope goes to zero, or reverses. All summits are found. If any of the nearest neighbors are found to be bad pixels, then the point is not a summit.

The summit slope is determined by searching in the +X direction for the first valley, or base. The slope is the absolute value of the height difference between the summit point and the base divided by the distance in the X direction (summit XY radius), as shown:

$$\text{slope}_{+x} = \left| \frac{y_{s(+x)} - y_{v(+x)}}{x_{s(+x)} - x_{v(+x)}} \right|$$

If the edge of the data set is reached before the base is found, the value at the edge of the data is used to find the slope. This step is repeated for the -X, +Y, and -Y directions. The four slope values are then averaged to find the average summit slope.

The summit curvature is found by:

$$C = \frac{1}{r} = \frac{2h}{x^2}$$

where r is the radius, h is the height difference between the summit and one of its nearest neighbors, and x is the lateral distance between the summit and its nearest neighbor. This step is repeated for the -X, +Y, and -Y directions.

The four curvature values are averaged to find the average summit curvature, as given below:

$$\overline{C}_s = \frac{C_{+x} + C_{-x} + C_{+y} + C_{-y}}{4}$$

The average radius is calculated by averaging 1/curvature for each of the four directions, given as follows:

$$\overline{r}_s = \frac{\frac{1}{C_{+x}} + \frac{1}{C_{-x}} + \frac{1}{C_{+y}} + \frac{1}{C_{-y}}}{4}$$

where r = 1/curvature

Uses

Summit analysis provides analysis of random height variations such as those found in the measurement of film, plastics, magnetic tape, magnetic disks, and other magnetic media. Summit analysis provides a method of quantifying the “bumps” or texture of a three-dimensional surface.

Summit Histograms in RST Plus provide further analysis of the surface area. The Histogram plot is a distribution plot which shows the distribution of individual surface values in histogram form. The histogram indicates how often various surface values occur in the data array. Summit Histograms provide analysis of summit heights, slopes, curvatures, and radii. The horizontal axis indicates the individual values. The vertical axis shows the number of data points contained within equally spaced intervals (bins). Histograms are explained in greater detail later in this chapter.

Measurement Limitations

Summit analysis is extremely sensitive to the user selection of summit threshold and summit cutoff values. These analyses are also very susceptible to noise.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
RadiusCt	Summit Radius Count
Radius Thresh	Summit Radius Thresh
SummitCt	Summit Count
SummitCutoff	Summit Cutoff
SummitCvAvg	Summit Curve Avg
SummitCvRa	Summit Curve Ra
SummitCvRp	Summit Curve Rp
SummitCvRq	Summit Curve Rms
SummitCvRv	Summit Curve Rv
SummitDensity	Summit Density
SummitDiaAvg	Summit Diameter Avg
SummitDiaRa	Summit Diameter Ra
SummitDiaRp	Summit Diameter Rp
SummitDiaRq	Summit Diameter Rms
SummitDiaRv	Summit Diameter Rv
SummitHtAvg	Summit Height Avg
SummitHtRa	Summit Height Ra
SummitHtRp	Summit Height Rp
SummitHtRq	Summit Height Rms
SummitHtRv	Summit Height Rv
SummitMinCv	Summit Min Curve
SummitRdAvg	Summit Radius Avg
SummitRdRa	Summit Radius Ra
SummitRdRp	Summit Radius Rp
SummitRdRq	Summit Radius Rms
SummitRdRv	Summit Radius Rv
SummitSlAvg	Summit Slope Avg
SummitSlRa	Summit Slope Ra
SummitSlRp	Summit Slope Rp

SummitSlRq	Summit Slope RMS
SummitSlRv	Summit Slope Rv
SummitSpacing	Summit Spacing
SummitThresh	Summit Threshold
XCrossings	X Crossings
YCrossings	Y Crossings

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 data set. 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 volume of "water" the surface must hold in order to completely "submerge" it. See Figure 3-27.

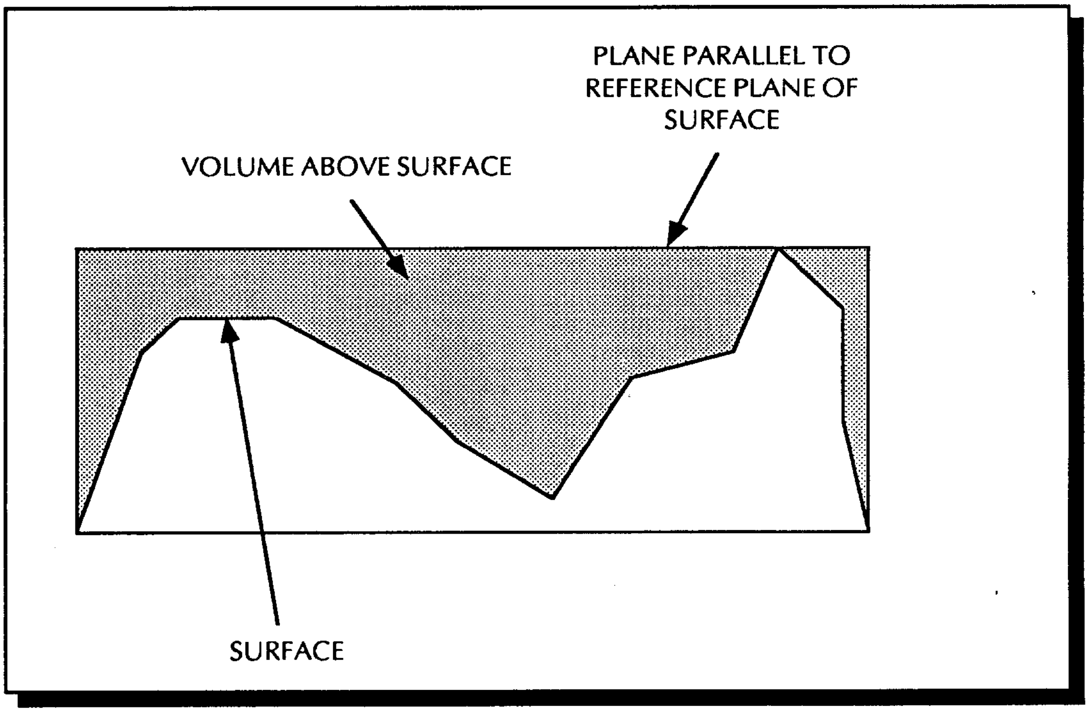


Figure 3-27. Volume

Calculation

The area of the volume above the surface is calculated to find the volume value. The data being analyzed may also be inverted, which would give the volume of material rather than the volume of air. The normalized surface volume, or volume per unit area, is the ratio of the total volume above the surface over the lateral area below 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.

Measurement Limitations

The spatial frequency content of the surface determines if the normalized surface volume remains constant regardless of the amount of surface measured.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
NormVolume	NormVolume
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.

Calculation

The line width measurement routine is depicted in Figure 3-28. 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.

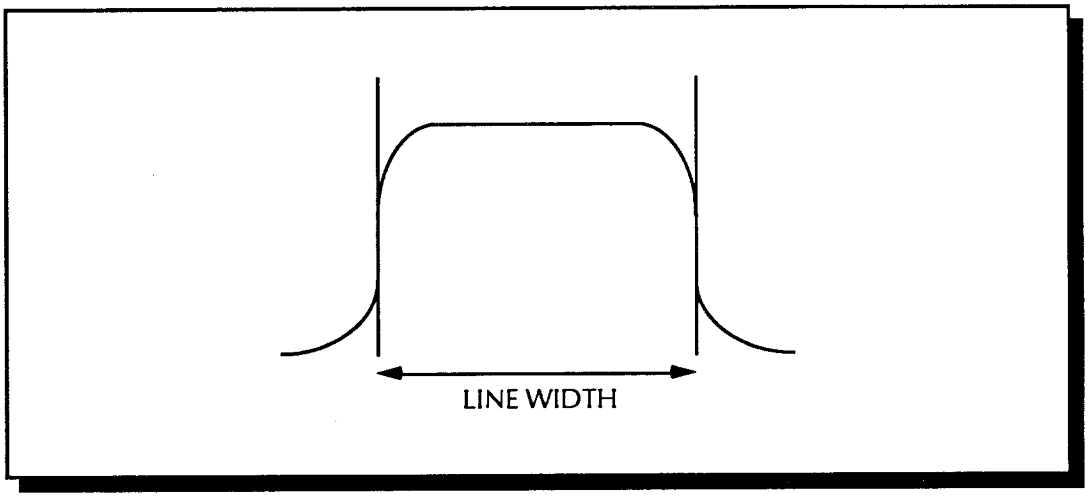


Figure 3-28. Basic Line Width Measurement Routine

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. Refer to Figure 3-29. In this figure, the final line width would be (L1 +L2 + L3 + ... + Ln)/n, with an associated standard deviation.

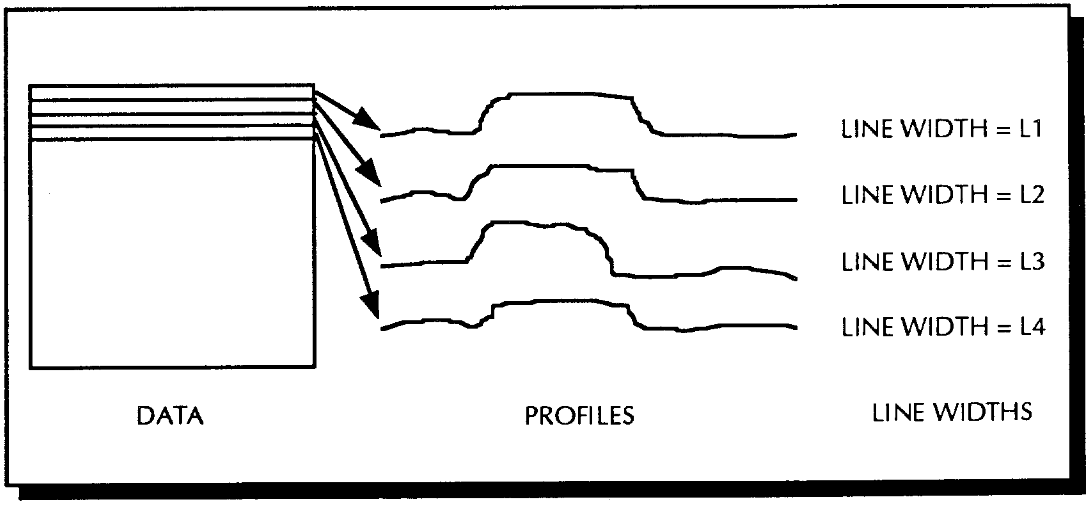


Figure 3-29. Final Line Width with Standard Deviation

Uses

Line width measurements are useful in the semiconductor industry to measure photoresist lines on silicon.

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. For certain types of samples, you can correct for these phase changes by using Dissimilar Materials analysis (described later in this chapter).

Related Database Parameters

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

Step Height

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 RST Plus. See Figure 3-30. In general, lines are scanned in the horizontal direction, perpendicular to the step transition.

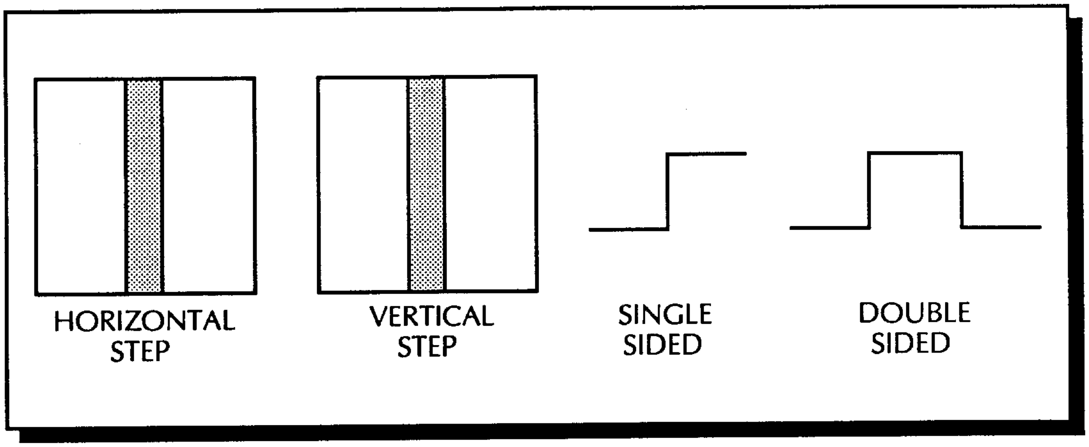


Figure 3-30. Step Definitions

Calculation

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 3-31 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.

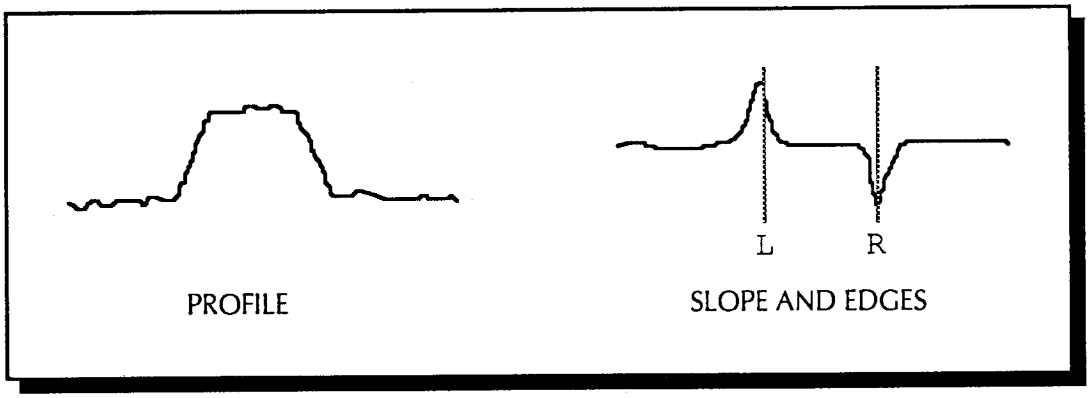


Figure 3-31. Edge Determination

For single-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(s) 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. Refer to Figure 3-32.

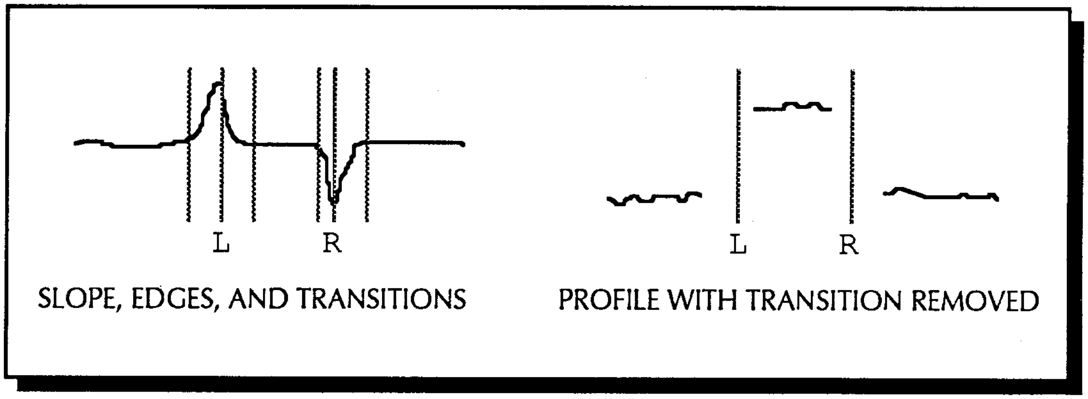


Figure 3-32. Transition Zone Determination

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. Refer to Figure 3-33. 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.

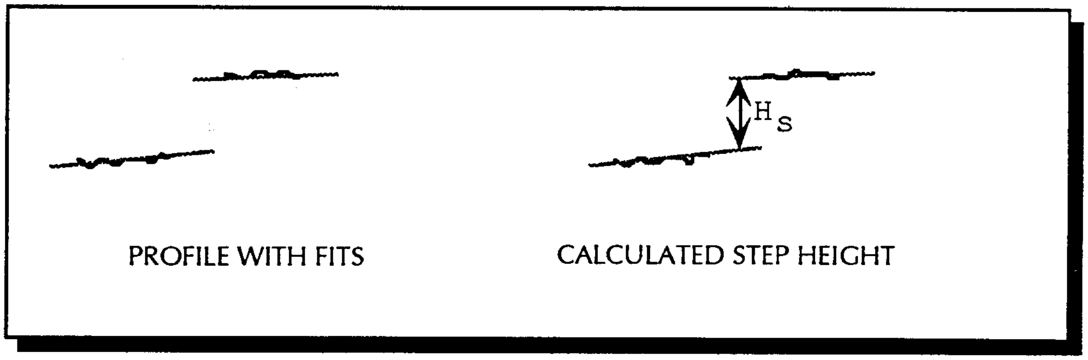


Figure 3-33. Line Fitting for Single-Sided Step Heights

When RST Plus 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 3-34.

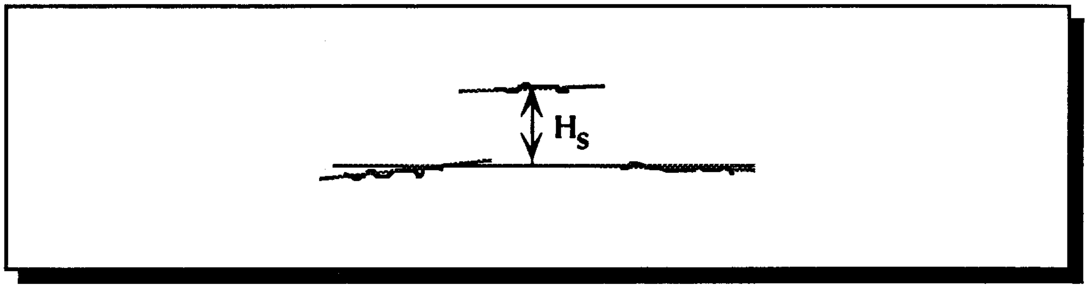


Figure 3-34. Average Double-Sided Step Height Calculation

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. Refer to Figure 3-35. In this figure, the final step height would be (S1 + S2 + S3 + S4 + ... + Sn)/n, with an associated standard deviation.

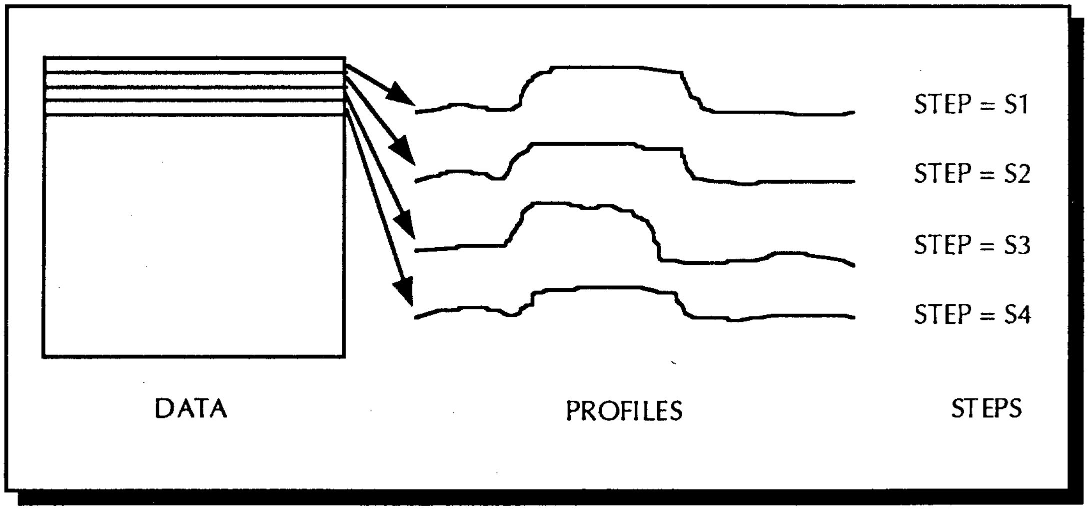


Figure 3-35. Final Step Height with Standard Deviation

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 RST Plus to calibrate VSI measurements.

Measurement Limitations

For accurate measurements for 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. Chapter 4 describes how phase changes between dissimilar materials can affect measurements. For certain types of samples, you can correct for these phase changes by using Dissimilar Materials analysis (described later in this chapter).

Related Database Parameters

☞ See online help for additional step parameters associated with Tpc heads and wall angle calculations.

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
RightWdth	Step R-Width
RightWidthStdev	Step R-Width StDev

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.

Calculation

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

The surface parameters calculated in stylus analysis are listed in Table 3-1. In the stylus analysis software, you select which group(s) of parameters to calculate from the Results Options box on the Stylus Filters dialogue box.

Table 3-1. Surface Parameters Calculated in Stylus Analysis

Results Options Group	Parameters Calculated
R_a, R_q, R_{sk}, R_{ku}	R_a, R_q, R_{sk}, R_{ku}
Delta, Lambda	Δ_a, Δ_q, λ_a, λ_q
R_t, R_p, R_v, S	R_t, R_p, R_v, R_z, R_{max}, R_{pm}, R_{vm}, S, S_m
Bearing, PC	H_{tp}, R_K, R_{pk}, R_{vk}, M_{r1}, M_{r2}, PC

☞ The calculation of λ_a and λ_q requires the Delta, Lambda group, in addition to the R_a, R_q, R_{sk}, R_{ku} group, because λ_a and λ_q are a function of R_a and R_q.

These surface parameters have been described earlier in this manual. Refer to Chapter 2, "Surface Parameters," and the section describing bearing ratio earlier in this chapter.

Long Wave Cutoff

The **long wave cutoff** value sets the filter for attenuating 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.")

Short Wave Cutoff

The **short wave cutoff** value sets the filter for attenuating 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 and Recursive 2RC. Both filter types attenuate (dampen) spatial frequency components by applying a transmission factor to the amplitude.

The 2RC filter mimics the effect of passing the signal through an analog 2RC electronic circuit. This filter may introduce phase distortion, thus altering the appearance of surfaces with abrupt features.

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.

The transmission function for each of these filters is 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.

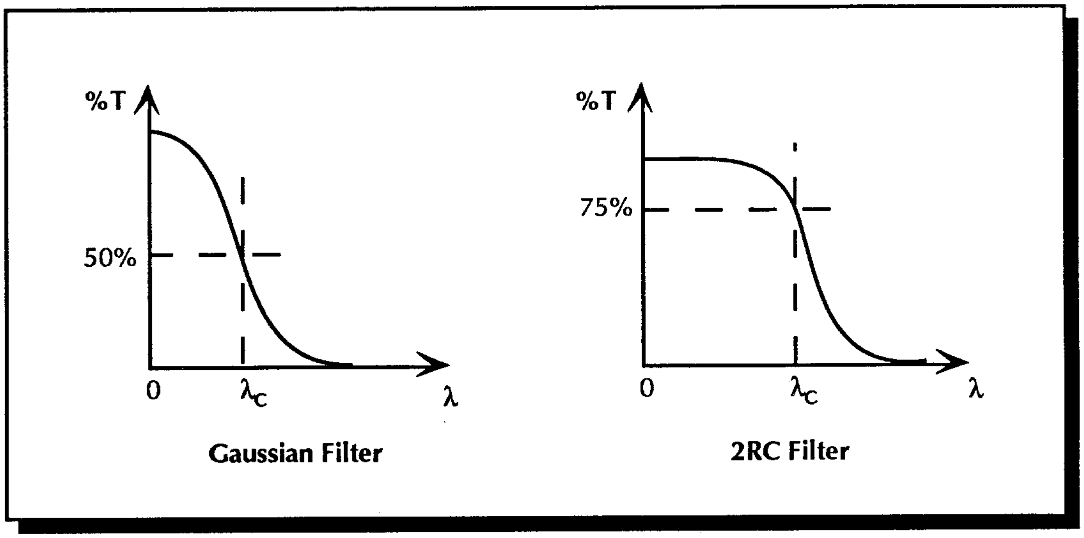


Figure 3-36. Transmission Functions of the Gaussian and 2RC Filters

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.

Number of Sample Lengths

The digital filters used in the stylus analysis algorithm introduce edge effects near the edges of the data set. These effects appear within one sample length from each edge. Therefore, the first and last sample length are not included in the calculation of the surface parameters when filtering is on. However, you can use the entire data set when filtering is off. Typically, five sample lengths are used with a traversing length of seven.

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.")

☞ 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 RST Plus results to those you would obtain from stylus measurements. Typically, choose a 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 dialogue box, which you access by selecting **Analysis » Processed » Options**.

Measurement Limitations

Some of the measurement parameters for stylus analysis depend on other parameters and whether you enter your own value or use **Auto Select**. 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 is able to 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.

☞ Another important point about stylus analysis is that other digital filtering techniques available through the Processed Options dialogue 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 RST Plus 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 a 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 in which the value is a power of ten times 8 or 25 and is the longest assessment length below 0.8 mm. For example, if you use the 20X objective with a 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 Tables 3-2 and 3-3.

Table 3-2. 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 (**Auto Select** is also enabled if it is off).

Table 3-3. 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 data set 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
S_Flt_Type	Stylus Filter Type
S_lng_cut	Stylus Long Cutoff Freq
S_Pc_ht	Stylus Pc Height
S_sht_cut	Stylus Short Cutoff Freq
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 Lengths
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

Related Database Parameters (continued)

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
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

Related Database Parameters (continued)

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

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

How Regions Are Identified

The software program identifies multiple regions on the sample in one of three ways—by separation, by height, 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.

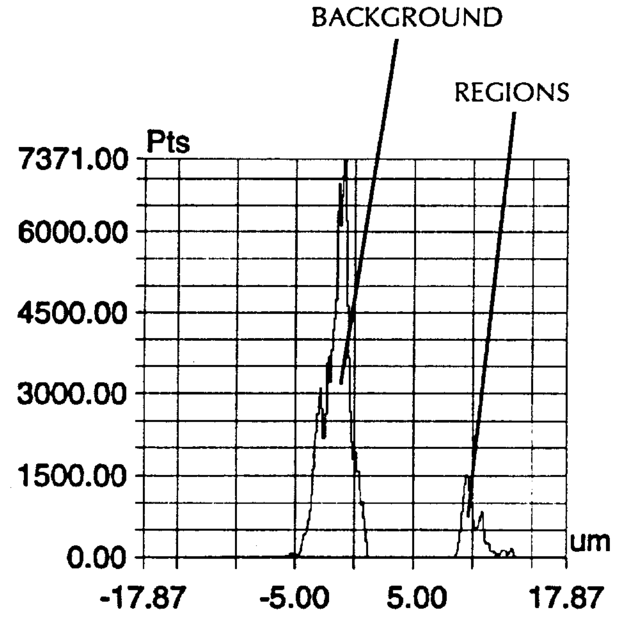


Figure 3-37. Histogram of Surface with One Level of Regions

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.

When you select the **Threshold** method for finding regions, the program uses a height threshold to define the cutoff between the background and the high regions on the surface. (The threshold method works only for high regions.) This method is best for surfaces in which the edges of the high regions gradually blend into the background surface without producing clean boundaries between features. A histogram of this type of surface doesn't show two distinct peaks, so the program can't 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.

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 the figure the threshold is arbitrarily set at 1 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.

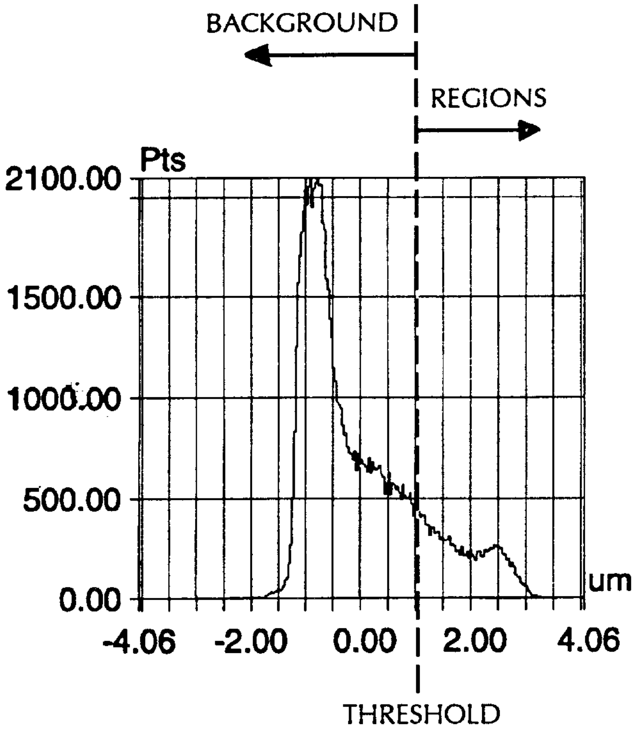


Figure 3-38. Threshold on Histogram of Surface Lacking Background/Regions Separation

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 regions (peaks or bumps) if you turn on the **Find Peaks** option. Otherwise, it identifies regions as low regions (valleys or indents).

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.

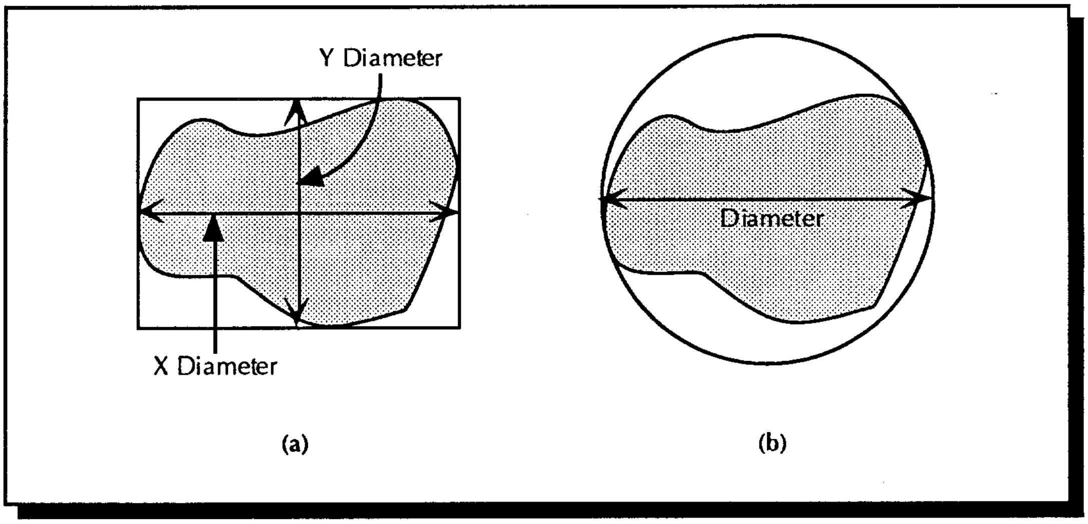
☞ You can write the region statistics to a comma-separated-variable (csv) file, which can then be imported into a spreadsheet program. On the Parameter Output File section of the Multiple Region Statistics dialogue box, click the **On** check box and enter a filename with a `.csv` extension.

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 4, "About Processed Data," and your system's online help.

For multiple region statistics, the following definitions apply:

R_t, R_p, R_v	*Peak and Valley Heights:* These standard surface parameters are discussed fully in Chapter 2, "Surface Parameters."
R_a, R_q	*Roughness Values:* These standard surface parameters are discussed fully in Chapter 2.

R_{sk}, R_{ku}	*Skew and Kurtosis*: These standard surface parameters are discussed fully in Chapter 2.
Mean	*Mean Height*: 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 data set.
Data Points	*Data Points*: The number of valid data points in the region.
X Diameter Y Diameter	*Island X Diameter, Island 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	*Island Average Diameter*: The average of the *X Diameter* and *Y Diameter* parameters:

$$XY\ Diameter = \frac{X\ Diameter + Y\ Diameter}{2}$$

Diameter	*Island Diameter*: When a circle is drawn to encompass the region (island), this is the diameter of the circle. See Figure 3-39 (b).

Area	*Island Area*: The number of pixels in the region (island) multiplied by the area of one pixel: $Area = Number\ of\ Pixels \times Area\ of\ Pixel$
A Diameter	*Island Area Diameter*: *A Diameter* can be thought of as an equivalent diameter, or the diameter if the valid data points were arranged in a circle. *A Diameter* is calculated from the equation for the area of a circle, where the area is assumed to be the number of valid data points (with a unit area per data point). Note that the area for this calculation is not the same as the *Island Area* parameter described above.
Volume	*Island Volume*: The area multiplied by the mean height: $Volume = Island\ Area \times Mean\ Height$
X Sag Y Sag	*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.

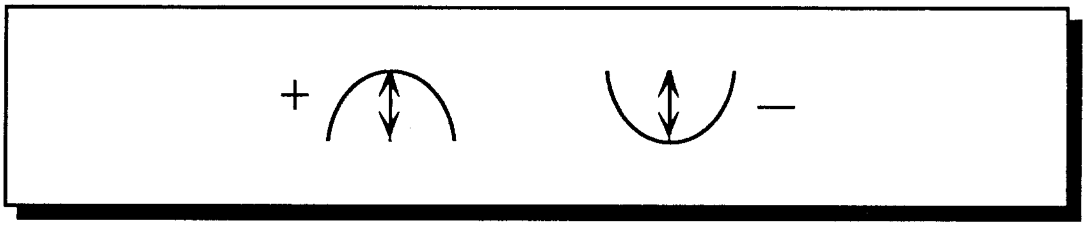


Figure 3-40. Sag Sign Conventions

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

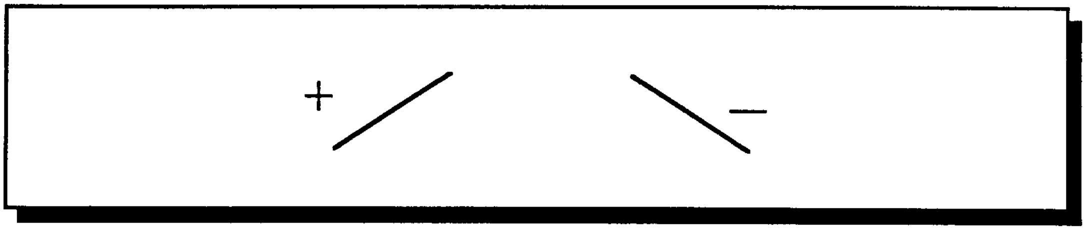


Figure 3-41. Tilt Sign Conventions

Incline *Relative Incline*: The incline of a specific island relative to the reference island:

$$Incline = \arctan\left(\frac{h}{d}\right)$$

where h is the difference between the mean island heights and d is the distance between the island centers, as shown in Figure 3-42.

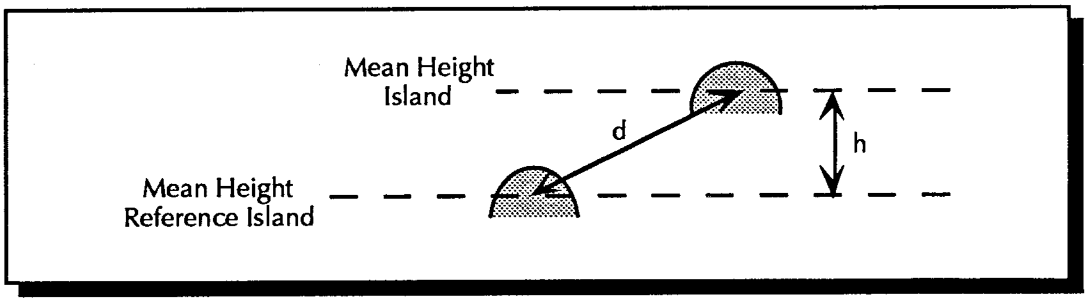


Figure 3-42. Incline Parameters

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

The multiple region analysis program can analyze surfaces with either one or two height levels of high or low regions (in addition to the background). 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 several different heights and surfaces in which the multiple regions are the same height as other general surface features.

In the analysis, the regions must be distinquished 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 dialogue box.

2. Use the **Threshold** method for finding regions. This method specifies a cutoff between the regions and the background. For more information, see the section entitled "How Regions Are Identified."

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

Related Database Parameters (continued)

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

Dissimilar Materials Analysis

Definition

Dissimilar materials analysis eliminates phase change effects inherent in the analysis of optically dissimilar materials. Phase change effects occur when you measure a sample in which the materials in the field of view have different optical constants. Each material has its own phase change upon reflection, which results in a phase change error during the calculation. The phase change error causes the measured height values to be offset from the true values. The dissimilar materials analysis program allows you to enter optical constants or a height offset for the various materials on your sample's surface, and then it uses these parameters to calculate new, corrected surface height data.

Dissimilar materials analysis is the general name for a program that allows you to measure either dissimilar opaque islands or transparent thin films. The distinction between these two types of samples is discussed later in the sections entitled "Calculation" and "Measurement Limitations."

Calculation

The dissimilar materials analysis program uses the material optical constants and the measured surface heights between dissimilar regions to calculate the absolute phase shift for each material. Once the error due to phase shift differences is determined, the true surface heights are corrected.

The method the program uses to calculate corrected surface heights depends on whether the sample contains dissimilar opaque materials or a transparent thin film. The differences between these two types of samples are:

- Dissimilar materials are considered opaque islands, and they may or may not have a substrate layer below them. Because the materials are opaque, there is no phase change upon reflection from an underlying material; however, there is a phase change across the surface.

- A thin film is considered transparent, and it must have a substrate layer below it. Because the film is transparent, there is an additional phase change upon reflection from the underlying substrate. The program accounts for this phase change when you set up the dissimilar materials program with parameters for the film and substrate.

Identifying Material Regions

Before the calculation begins, the program initially labels the different regions on the sample. You will notice this when you make a measurement or open a stored dataset with a special dissimilar materials CDF template as the default output. The contour plot that is displayed shows the labeled material regions. (You can change the labels for each different region by double-clicking on a region with the left mouse button and changing the settings in the Material Association dialogue box.)

For samples in which the dissimilar materials are completely isolated from each other like islands, the program scans the data across the array in the X direction to identify the material regions. Internally, the program assigns sequential index number to the regions according to the order in which they are identified. If the material regions on your sample are not completely isolated, you may be able to use a detector or analysis mask to create a distinct separation between the regions.

For samples in which the dissimilar materials touch each other or blend into each other at the edges, the program uses a histogram of heights to identify the material regions. In the case of a sample where a material is depositied on a substrate, a portion of the substrate *must* be exposed for both the material and the substrate to have unique peaks on the histogram. Figure 3-43 uses a thin film sample to show what is acceptable and unacceptable for the dissimilar analysis program. The film in the illustration could also be an opaque layer.

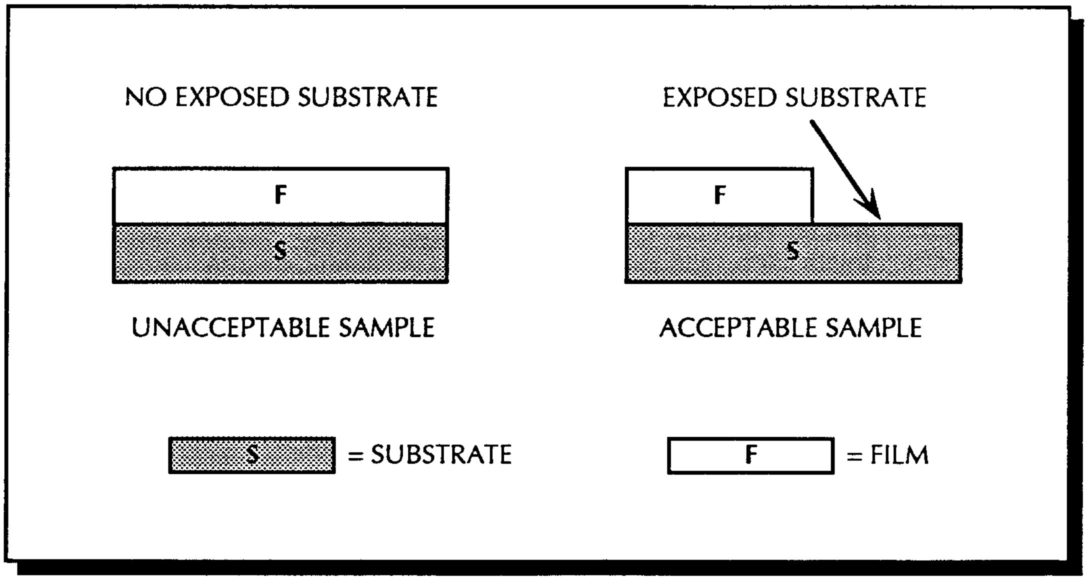


Figure 3-43. Thin Film Samples with and without Exposed Substrate

When a sample has a clearly-defined vertical boundary separating the dissimilar materials, the histogram of heights shows a clean separation between the peaks corresponding to each material region. For samples that don't have a clean separation, the region where the edge of one material blends into the edge of the next material is considered a "transition region." Surface heights in the transition region cause the taller region to appear shorter and the shorter region to appear taller. This results in a measured height difference that is smaller than it should be, which in turn causes inaccurate surface height corrections in the dissimilar materials calculation.

Figure 3-44 shows a histogram of a sample in which the dissimilar material regions lack a distinct separating boundary. Compare this to Figure 3-45, which shows a histogram of a sample in which the dissimilar material regions are cleanly separated. Figure 3-46 shows two-dimensional profiles of samples with and without distinct separating boundaries between the dissimilar materials.

☞ The discussion above on separating boundaries and transition regions applies to opaque materials on substrate and thin films on substrate.

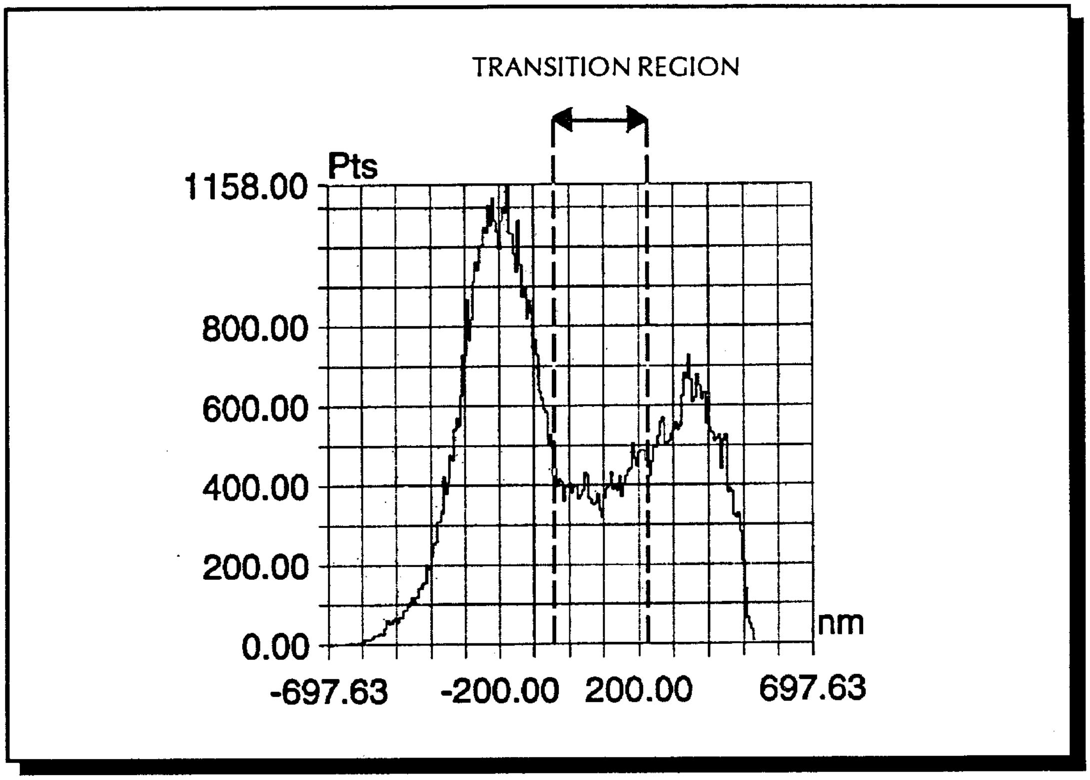


Figure 3-44. Histogram of a Sample with Poor Separation between Regions

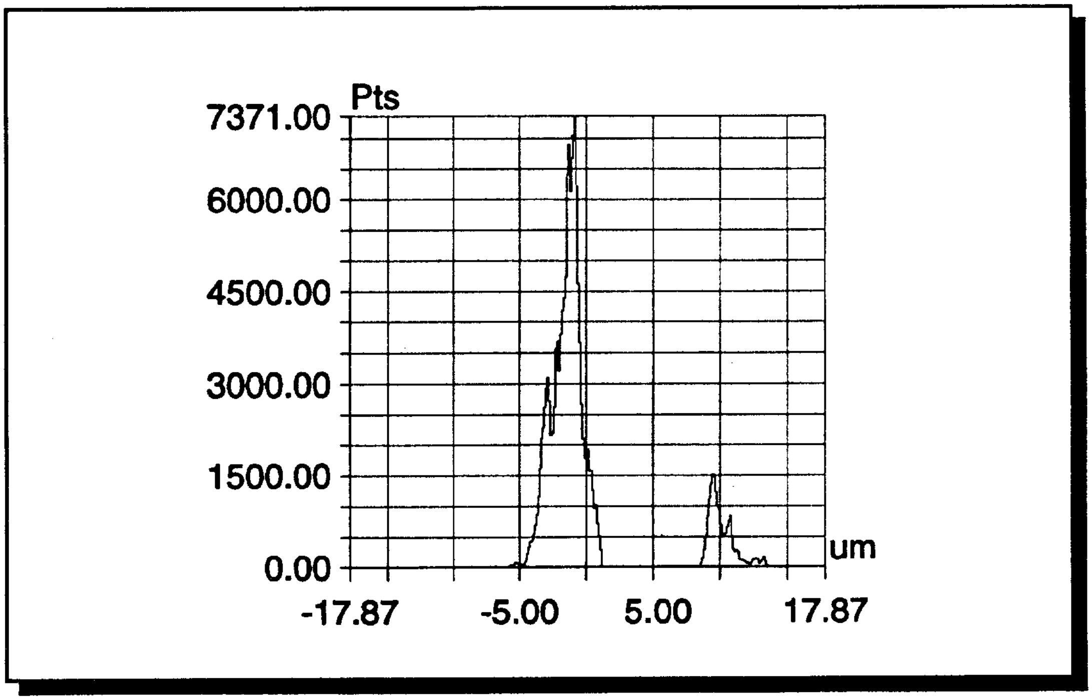


Figure 3-45. Histogram of a Sample with Distinct Separation between Regions

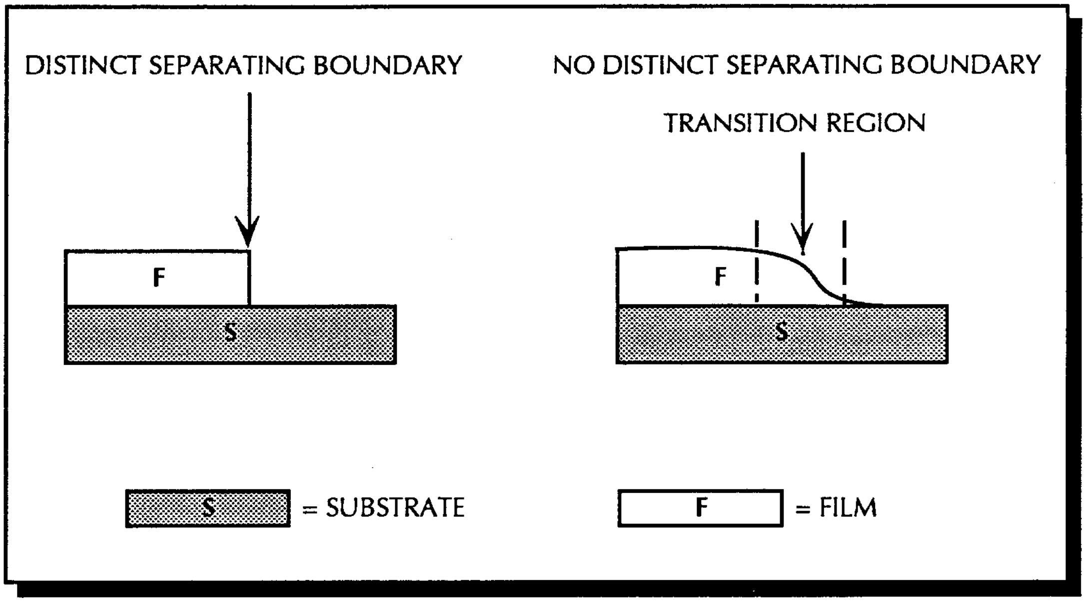


Figure 3-46. Profiles of Regions with and without Distinct Separating Boundaries

To reduce the effect of the transition region on the surface height measurement, turn on the **Erode/Dilate Regions** option on the Dissimilar Materials Analysis dialogue box. This trims a user-specified number of pixels around each region to create a more distinct separation. The number of pixels to trim depends on the sample, but a rule of thumb is to start with two pixels. You should use the **Erode/ Dilate Regions** option if your sample has complicated geometries or if your sample has continuous features that can't be easily separated with a detector or analysis mask.

Uses

Dissimilar materials analysis is useful for measuring surface height differences on semiconductors, magnetic heads, thin films, and other samples with regions of dissimilar materials or thin films.

Measurement Limitations

As mentioned earlier, dissimilar materials analysis can analyze two types of samples: dissimilar opaque materials and transparent thin films. Dissimilar materials are separate, dissimilar opaque regions with or without an opaque substrate below them. A thin film is a single-layer transparent film on an opaque substrate. Figure 3-47 shows examples of both types of samples.

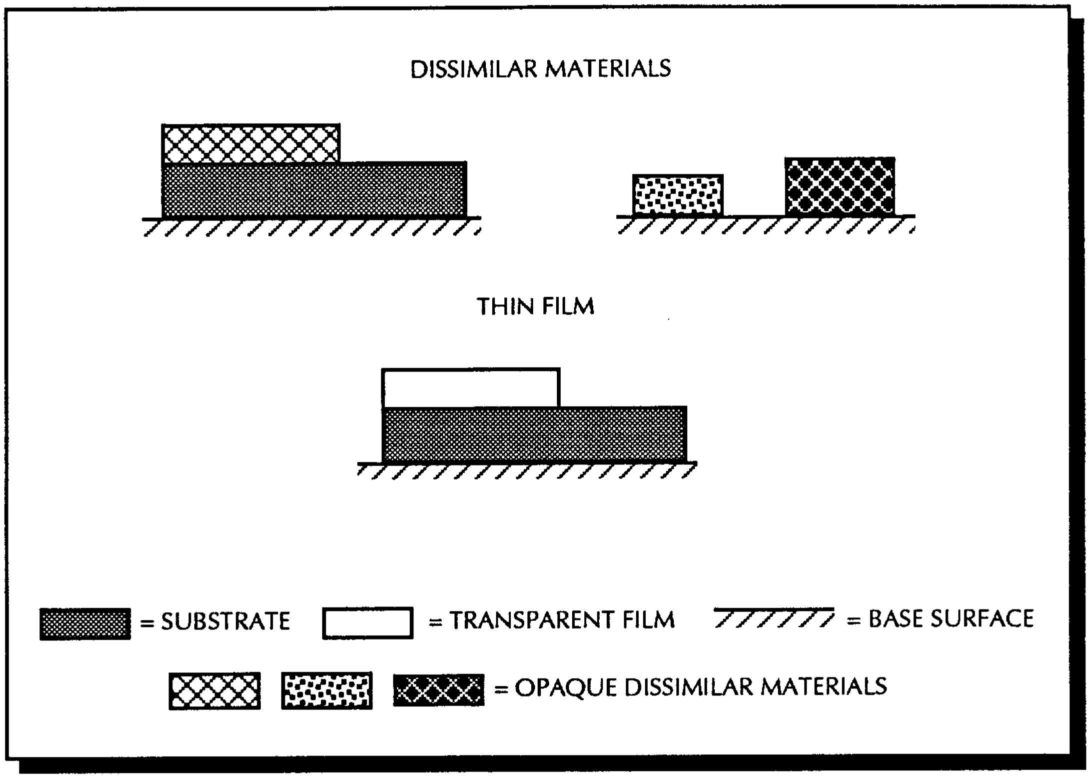


Figure 3-47. Examples of Dissimilar Material and Thin Film Samples

To obtain meaningful results from dissimilar materials analysis, your sample should meet the following criteria:

- The surface should include two or more optically dissimilar materials. For example, opaque dissimilar substrates; opaque islands on a dissimilar substrate; or a transparent film on a dissimilar substrate.
- The surface should include at least one region of exposed substrate. If your sample has a continuous film, you'll need to remove the film in one region to expose some of the substrate.

☞ Dielectric substrates, materials in which the imaginary component of the refractive index (k) is zero, are optically similar. Dielectric materials include SiO_2, glass, and diamond.

Procedure

To analyze samples using dissimilar materials analysis, you first assign material labels and optical constants to the materials on the sample. To improve results, you can create a detector or analysis mask to remove unwanted regions or to create separations between the dissimilar material regions. You can also remove terms to adjust tilted surfaces. Once you have set your options, turn on the **Dissimilar Materials Analysis** option to begin the calculation. For a detailed procedure, refer to your system's online help.

Determining Material Optical Constants

The dissimilar materials analysis program uses the real and imaginary index of refraction values for each material during the calculation. These terms are commonly referred to as the "n" and "k" values, respectively. WYKO recommends the following methods for determining these material constants:

- Measure these optical properties with an ellipsometer. Make sure the wavelength you use for the ellipsometer measurements matches the wavelength you will use for your RST Plus measurements.
- Look up these optical properties in technical handbooks. Several common materials and their optical constants are provided in physics, materials, and/or optical handbooks. If the wavelengths listed do not include the wavelength you will use for your RST Plus measurements, use linear interpolation to determine a correct value.

Making Repeated Measurements of Similar Samples

You can use the dissimilar materials program to make repeated measurements of similar samples. After you set up the program with the correct material labels and constants, you don't have to re-set these parameters between measurements as long as you orient every sample in the same way.

When islands are identified and numbered by the order in which they are found, a slight change in sample orientation can result in mismatched user labels and computer index numbers. For example, in the array on the left side of Figure 3-48, region A would be identified first and numbered internally as index #1. If a new sample with the same features is rotated slightly, as in the array on the right side of Figure 3-48, region B would be identified first and numbered internally as index #1. A mismatch between the label and index number can result in erroneous data.

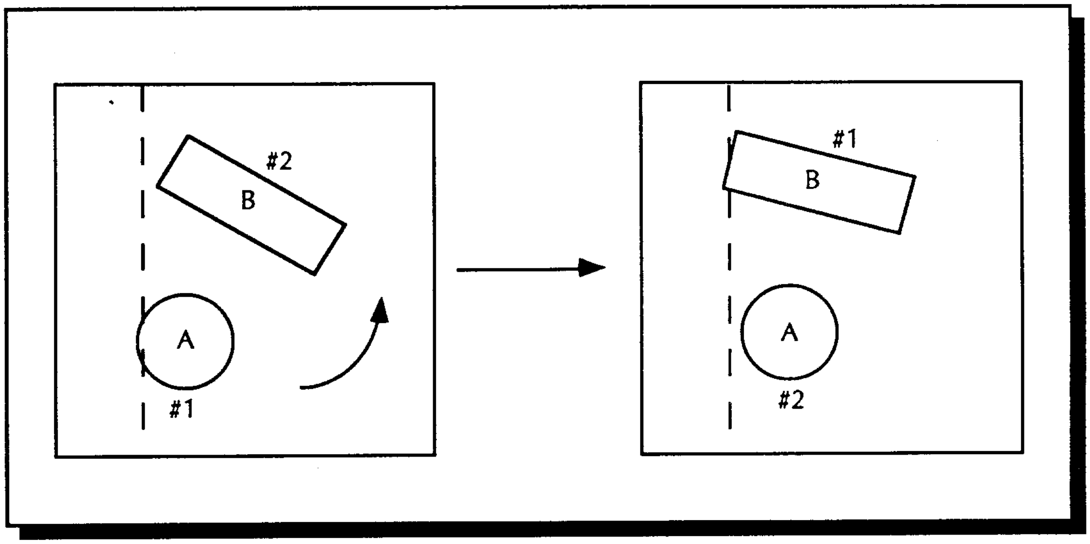


Figure 3-48. Affect of Incorrect Sample Orientation for Isolated Regions

☞ Guidelines for making repeated measurements are provided in your system's online help.

Related Database Parameters

BLOCK NAME	EXTENDED NAME
DisH_AB	Dismat Height (A-B)
DisH_AC	Dismat Height (A-C)
DisH_AD	Dismat Height (A-D)
DisH_AE	Dismat Height (A-E)
DisH_BC	Dismat Height (B-C)
DisH_BD	Dismat Height (B-D)
DisH_BE	Dismat Height (B-E)
DisH_CD	Dismat Height (C-D)
DisH_CE	Dismat Height (C-E)
DisH_DE	Dismat Height (D-E)
DisMNameA	Dismat Material Name A
DisMNameB	Dismat Material Name B
DisMNameC	Dismat Material Name C
DisMNameD	Dismat Material Name D
DisMNameE	Dismat Material Name E
DisSNameA	Dismat Substrate Name A
DisSNameB	Dismat Substrate Name B

Related Database Parameters (continued)

DisSNameC	Dismat Substrate Name C
DisSNameD	Dismat Substrate Name D
DisSNameE	Dismat Substrate Name E

❖❖❖

Chapter 4

About Processed Data

This chapter describes how some of the software features of the RST Plus system can affect processed data. It also discusses anomalies that might appear in the processed data.

Reference Subtraction

The discussion about accuracy in Chapter 1 mentions that you can generate a reference surface of the interferometer's internal optical system and subtract that reference from your measurements. This is especially important in PSI mode when you're 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:

$$\textit{measured value} = \textit{test surface} + \textit{reference surface}$$

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, you can see how the contribution of the reference surface might 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.

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, 40X	< 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. 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.

The RST Plus software includes an algorithm for generating a reference surface from a mirror. Once this is done, you can subtract the file from your measurements. Your *RST Plus Operator's Guide* and online help describe how to do these procedures.

Data Restore

The RST Plus system, which uses digital data processing techniques, provides rapid and accurate calculations of surface height data. However, there may be times when data drop-outs occur because specific conditions are not met during the measurement or the processing. This results in missing data points. The RST Plus system includes a special algorithm (patent pending) that can restore these data points.

The **Data Restore** option provides a way to restore data points that might not have been processed properly, resulting in "missing" data. The algorithm identifies missing data points in a two-dimensional array and interpolates between valid data points to fill in the missing data.

☞ To ensure accurate interpolation of missing data points, use the **Data Restore** option only when 95% or more of the data points are valid.

Terms Removal

The RST Plus software provides a way for you to remove characteristics that are either inherent in a sample or that occur from the way you took the measurement. When you remove terms, you are able to remove the general shape of the surface, leaving its microstructure, as discussed in Chapter 1. This eliminates shapes that distort or distract from the true surface features.

While removing terms generally enhances the analysis, it's possible to introduce distortions. The terms removal options are listed below. You may select one option at a time, or in some cases, you may find it beneficial to select the last two options together.

- remove *no* terms
- remove *tilt* only
- remove *curvature* and *tilt*
- remove *cylinder* and *tilt*

Typically, tilt is an aspect of the interferometer configuration, while curvature and cylinder are inherent to the sample itself. Consequently, most analyses should be performed with tilt removed, while curvature and cylinder should be removed only from samples of certain shapes.

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

☞ If terms are removed from the data, this is indicated under the "Terms Removed" section on the output display.

Tilt

Typically, you select **Tilt Only** to remove the amount of tilt that occurred in a measurement due to how many tilt fringes were present when you took the measurement. Even if you have nulled the fringes, 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

You 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.

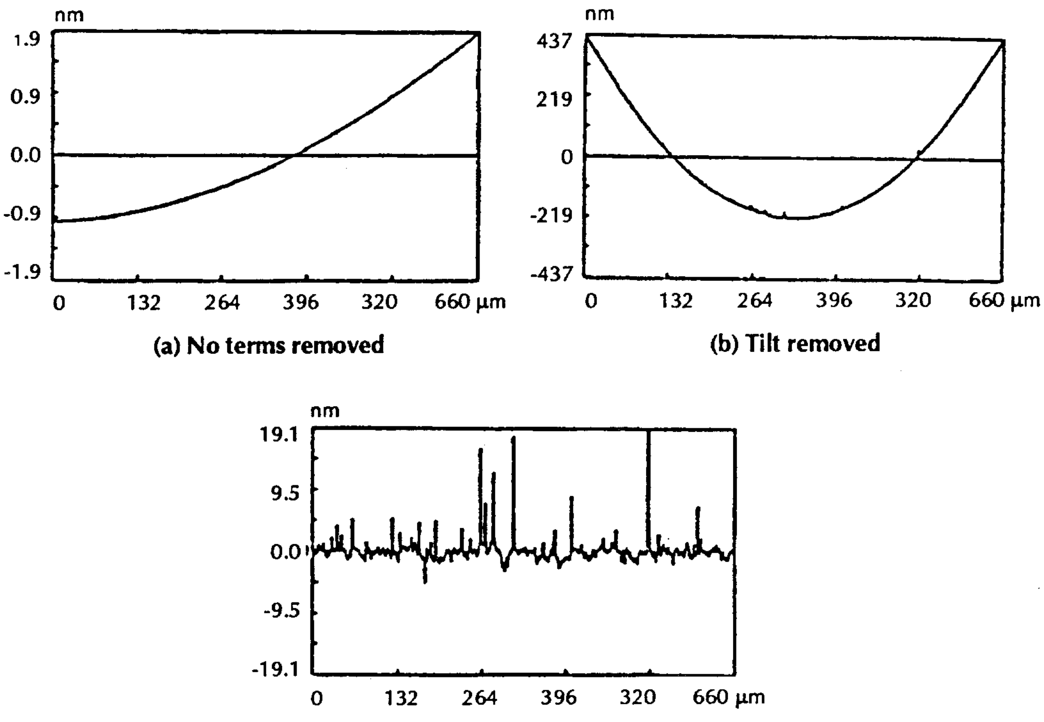
Cylinder and Tilt

You 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're 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. Subtracting curvature and cylinder in addition to tilt serves to flatten the data. Removing terms over a surface that isn't 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 (a terms mask is described later in this chapter). 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 a spherically curved 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.



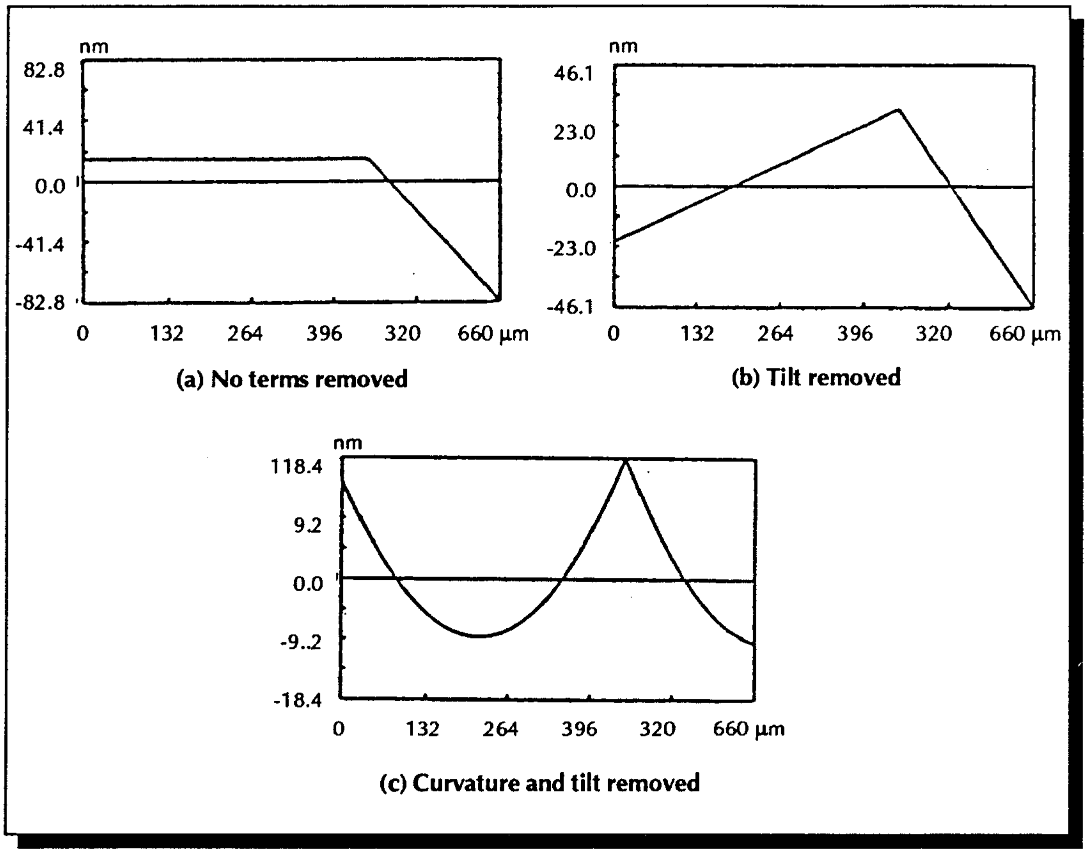
(a) No terms removed

(b) Tilt removed

(c) Curvature and tilt removed

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

Figure 4-2 shows a set of data for a surface with a ramp on it. 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 curvature and tilt removed. For this sample, Figure 4-2 (a) is the correct profile, based on no terms removed. The distortions shown in Figure 4-2 (b) and 4-2 (c) illustrate how removal of terms can actually misrepresent the actual surface.



(a) No terms removed

(b) Tilt removed

(c) Curvature and tilt removed

Figure 4-2. Profile of Surface with a Ramp, Showing Distortion from Terms Removal

Average

The RST Plus allows 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 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 averages processed data from stored data sets.

Filters

The RST Plus 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**. If you don't want data smoothing, make sure you select **None**. 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 way the program smooths the center point depends on the type of smoothing you select. These are described next.

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

The digital data filtering options are **Digital Low Pass** and **Digital High Pass**. 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. Therefore, digital filtering is limited to the 256 x 256 array size.

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, as the name implies. 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.

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, as the name implies. 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're 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're using stylus analysis filters to filter the data, make sure all other filters (such as those described above) are turned off. Otherwise, you will be filtering the data twice.

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. The program includes a detector mask, which is applied during a measurement, and two masks that are applied after the measurement. The latter two, an analysis mask and a terms mask, allow you to modify processed data.

☞ All of the masking options are described fully in the program's online help.

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 not detected by the detector. This permanently eliminates masked data points from the raw data.

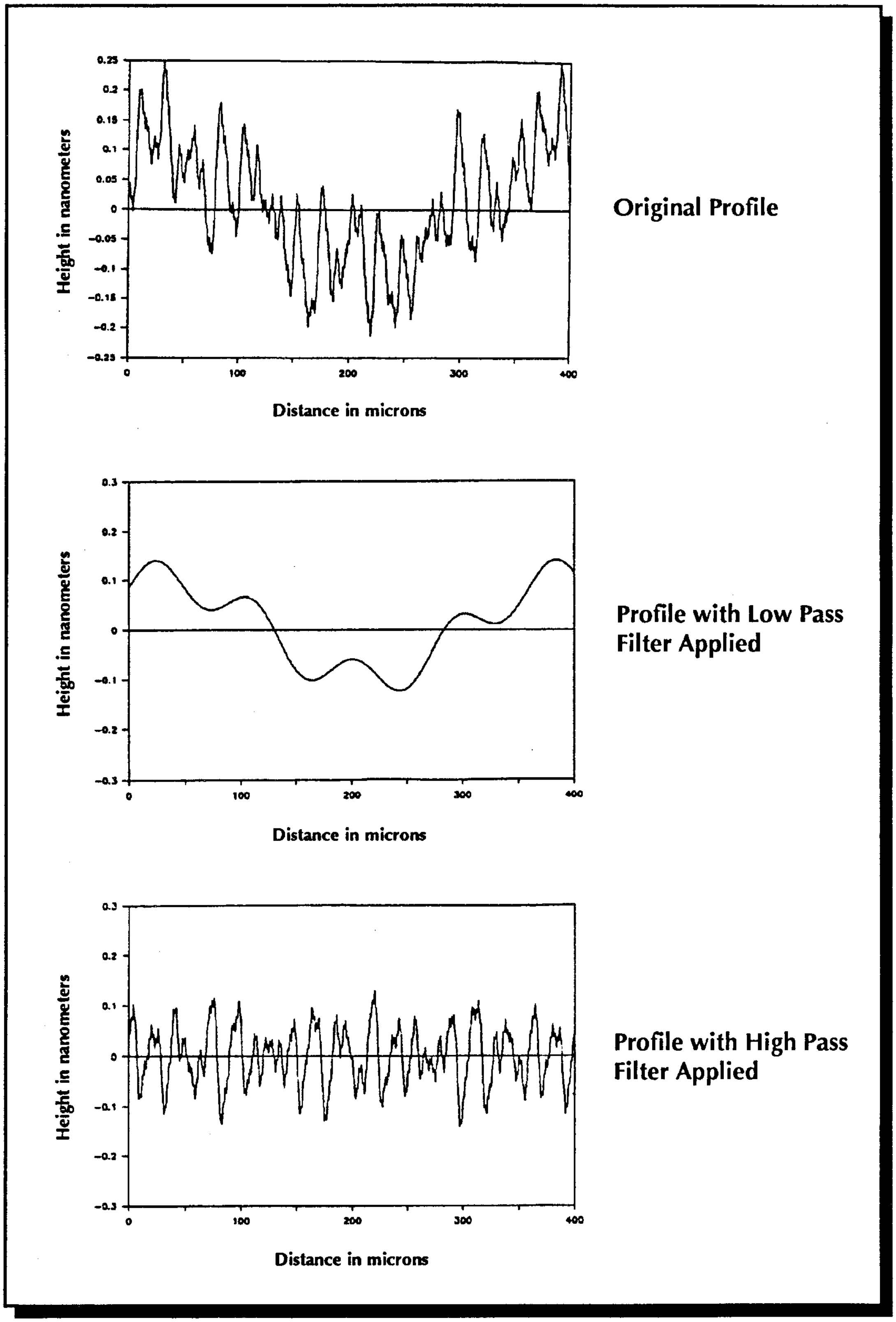


Figure 4-3. Profile with Low and High Pass Filters Applied

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 aren't pertinent to the analysis. You can also use a detector mask to create well-defined boundaries between regions for special analyses, such as multiple region analysis and dissimilar material analysis.

Analysis Mask

An analysis mask blocks designated areas of data during an analysis. It doesn't permanently affect the raw data—it's only effective when it's applied to the data When you use an analysis mask, surface statistics such as R_a and R_q are not calculated on the masked data.

You can use an analysis mask to block or pass portions of the data. You can also 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 really part of the surface.

Height Threshold Mask

A special type of analysis mask is the height threshold mask. This mask allows you to block or pass data based on a user-specified height threshold. 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 dialogue box.

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's 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. With a terms mask, you can fit tilt over one side of the step (the base or the top), and the rest of the data set is adjusted accordingly. This provides a more accurate way to fit terms, since it's based on the best fit plane over the flat part of the sample, and not both planes that make up the entire step.

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

☞ Refer to online help for instructions on creating, saving, and applying masks.

Integration Errors

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. Integration errors occur when the height difference between two adjacent pixels is too abrupt for the system to resolve.

As mentioned in Chapter 1, the maximum resolvable height difference between adjacent points in PSI mode is approximately 160 nm. 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 4-4 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, not steps.

To avoid integration errors:

- Use VSI mode if the height changes are too abrupt for PSI to resolve.
- 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.

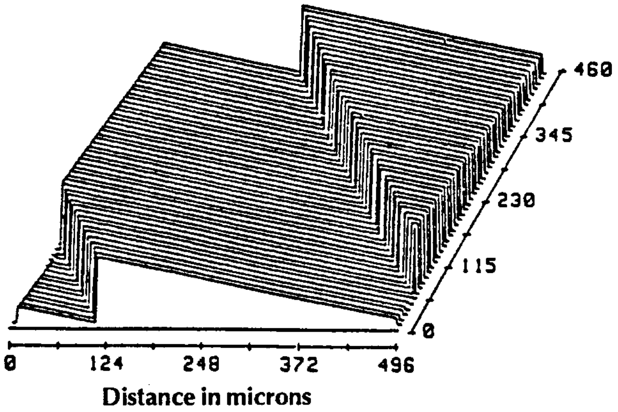


Figure 4-4. Surface with Integration Errors

Phase Change Effects

What Is a Phase Change?

When you illuminate a material, the reflected light exhibits a phase change. 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, which is the difference between the true value and the measured value, can be insignificant, or quite important, depending on the required measurement accuracy and the materials under consideration.

If you're 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.

- Use the dissimilar materials analysis program described in Chapter 3 to automatically calculate the bias. The program applies the calculated bias to the measured data to yield the corrected surface heights.

- 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.

☞ 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 use dissimilar materials analysis to correct for phase change effects, or 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

For more information about phase change upon reflection, contact WYKO for the following literature.

Walter Hahn, "Dissimilar Materials Analysis for SiO_2 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

About Surface Profiling

It has become increasingly important to be able to accurately characterize surface texture.[1] Surface texture is a key factor affecting the functionality and reliability of certain components. It can also act as 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 the 1930s, it was recognized that, to ensure that successive components in a batch all performed equally, the *process* had to be properly controlled.

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.

There are more than 200 different surface-texture parameters, and most of them are meant to separate good parts from bad ones by manipulating the profile data in a particular way. *Surface texture* refers to the locally limited deviations of a surface from the smooth ideal intended geometry of the part. The deviations can be categorized on the basis of their general patterns.

The following description comes from an article by George H. Schaffer:

"Consider a theoretically smooth flat surface. If this [surface] has a ... small hollow in the middle, it is still smooth but curved. Two or more equidistant such hollows produce a wavy surface. As the spacing between such waves decreases, the resulting surface would be considered flat but rough. In fact, surfaces having

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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.*

the same height of irregularities are regarded as curved, wavy, or rough, according to the spacing of these irregularities.

"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 A-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.

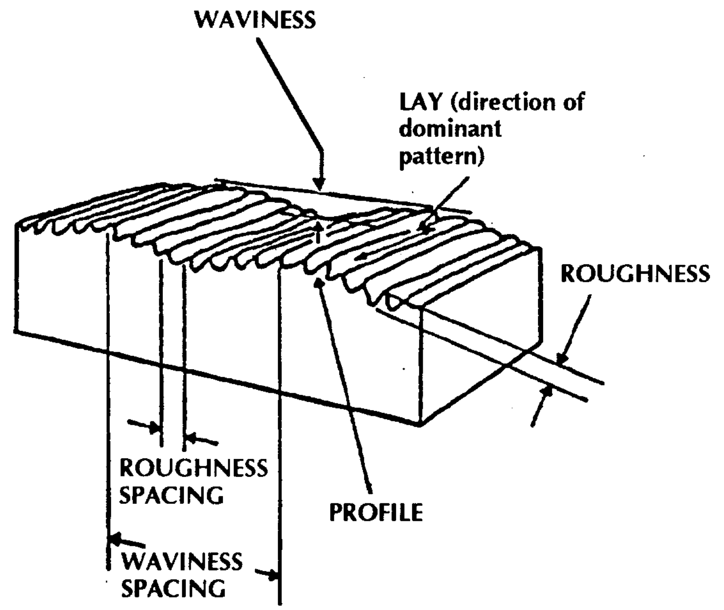

Figure A-1. Surface Characteristics and Terminology

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

"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]

"Surface texture also includes flaws: unintentional, unexpected, and unwanted" irregularities in the surface of a part such as cracks, pits, and scratches.[4] Flaws should be detected prior to measuring the surface texture and should not be part of the measurement data.

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."[5]

The WYKO RST Plus uses optical interferometric techniques to measure the topographic features (parameters) of smooth and rough surfaces. There are two quantities that are of primary importance here: a measure of surface height indicated by the roughness average parameter, Ra, and a measuring of the spacing of the peaks and valleys of the surface roughness, indicated by the wavelength parameter, D (see Figure A-2).

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[3] Ibid.
[4] Ibid.
[5] Ibid.

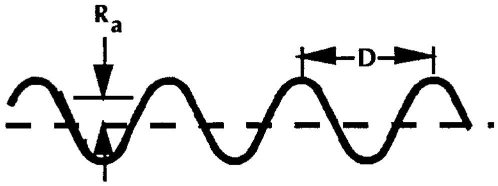

Figure A-2. Two Key Surface Parameters

"Ra is useful for detecting general variations in overall profile height ... But, Ra cannot detect differences in spacing and its distribution or the presence or absence of infrequently occurring high peaks and deep valleys."[6]

Rq is the root-mean-square average of the departures of the roughness profile from the mean line. It is not to be confused with the rms average. The rms average is an approximation; it simply multiplies the measured arithmetic average by 1.111 (a fair approximation when the texture profile is in the shape of a compound sine wave). However, the rms average became obsolete in 1955[7] when more precise instruments were developed for measuring true root-mean-square values.

Figure A-3, 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 RST Plus system.

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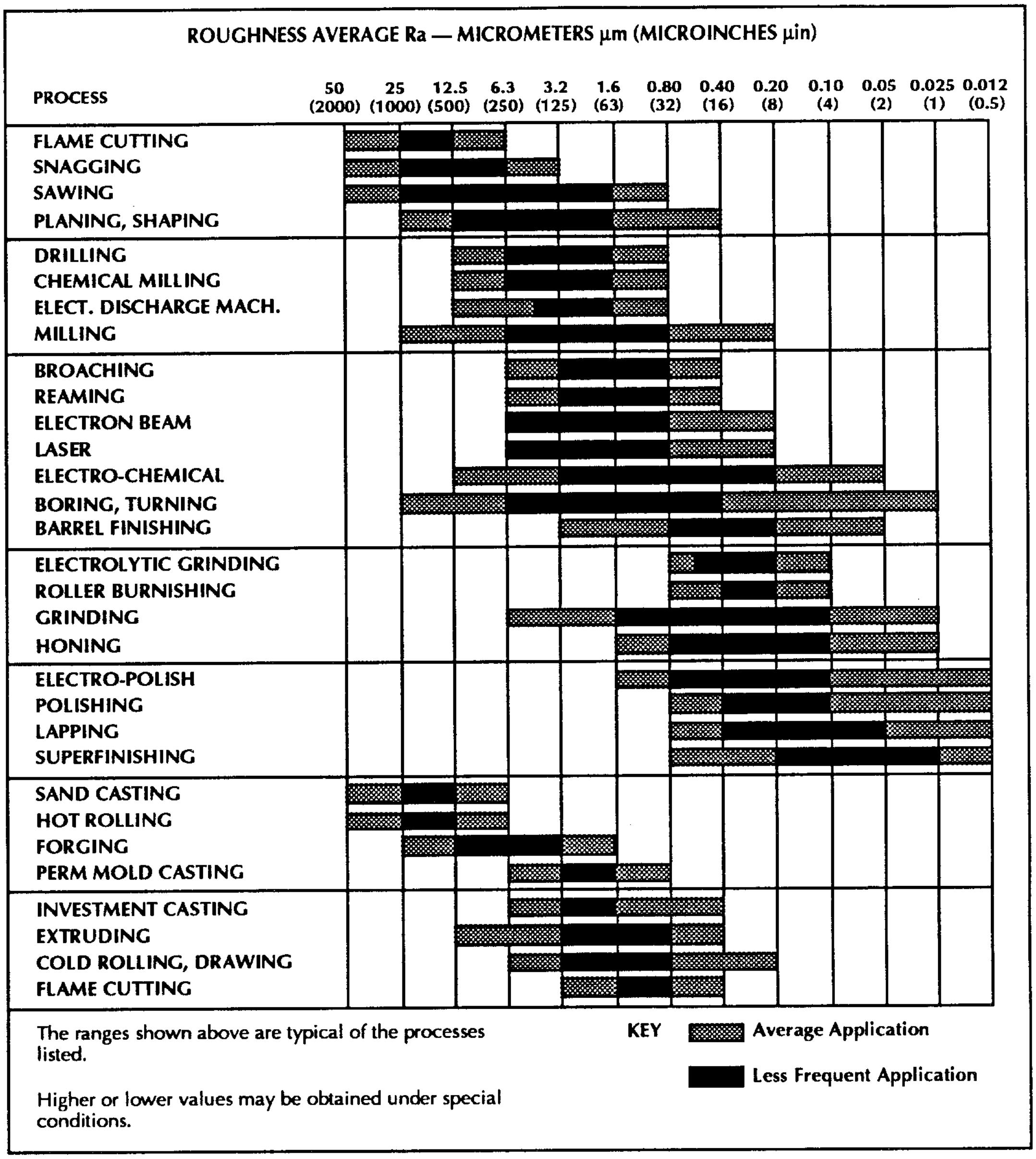
[6] Ibid.

[7] Ibid.



The ranges shown above are typical of the processes listed.

Higher or lower values may be obtained under special conditions.

Figure A-3. Surface Roughness Produced by Common Production Methods (from ANSI Standard B46.1-1985)

Appendix B

Database and Custom Display Editor Parameters

You can choose from the following extended name selections (found within the **Optional entries** listing in the Define Database dialogue box or the **Result** drop-down menu in the custom display editor's Analysis Result dialogue box) for use in creating database or custom display files. The block names are what you'll see in the database list view and in the custom display files that you create.

BLOCK NAME	EXTENDED NAME	DESCRIPTION
Aspect	**Aspect**	Aspect ratio of the detector. Typically not required.
BRDF_AI	**BRDF Angle Incidence**	Incidence angle, θ_i, is measured from the surface normal.
BRDF_As	**BRDF Angle Scatter**	Scatter angle, θ_s, is angle at which the scattered light is detected relative to the surface normal.
CenterWidth	**Step C-Width**	Center region average width calculation.
CenterWidthStdev	**Step C-Width StDev**	Standard deviation of the center region average width calculation.
CylAngle	**Angle Cyl**	Calculated rotational angle of cylinder. Calculated when radius of cylinder term is removed.
Data_Restore	**Data Restore**	Flag indicating if data restore was turned on. True = 1.
Date	**Date**	The date the measurement was taken.
DBName	**Database name (name only)**	Filename of the database used to store measurement results.
DBNameFull	**Database name (full path)**	Path and filename of the database used to store measurement results.
DisH_AB	**Dismat Height (A-B)**	Corrected height between materials labeled A and B.
DisH_AC	**Dismat Height (A-C)**	Corrected height between materials labeled A and C.
DisH_AD	**Dismat Height (A-D)**	Corrected height between materials labeled A and D.
DisH_AE	**Dismat Height (A-E)**	Corrected height between materials labeled A and E.

DisH_BC	**Dismat Height (B-C)**	Corrected height between materials labeled B and C.
DisH_BD	**Dismat Height (B-D)**	Corrected height between materials labeled B and D.
DisH_BE	**Dismat Height (B-E)**	Corrected height between materials labeled B and E.
DisH_CD	**Dismat Height (C-D)**	Corrected height between materials labeled C and D.
DisH_CE	**Dismat Height (C-E)**	Corrected height between materials labeled C and E.
DisH_DE	**Dismat Height (D-E)**	Corrected height between materials labeled D and E.
DisMNameA	**Dismat Material Name A**	Name of material labeled A.
DisMNameB	**Dismat Material Name B**	Name of material labeled B.
DisMNameC	**Dismat Material Name C**	Name of material labeled C.
DisMNameD	**Dismat Material Name D**	Name of material labeled D.
DisMNameE	**Dismat Material Name E**	Name of material labeled E.
DisSNameA	**Dismat Substrate Name A**	Name of substrate labeled A.
DisSNameB	**Dismat Substrate Name B**	Name of substrate labeled B.
DisSNameC	**Dismat Substrate Name C**	Name of substrate labeled C.
DisSNameD	**Dismat Substrate Name D**	Name of substrate labeled D.
DisSNameE	**Dismat Substrate Name E**	Name of substrate labeled E.
Filt_Type	**Filtering**	Flag indicating what type of filtering was used (low pass filter, high pass filter, etc.).
FiltRpm	**Rpm**	Mean value of the ten highest points in the entire surface profile.
FiltRvm	**Rvm**	Mean value of the ten lowest points in the entire surface profile.
FiltRz	**Rz**	Difference between Rpm and Rvm.
H	**Swedish Height**	The Htp value calculated with tp1 = 5% and tp2 = 90%.
Htp	**Bearing Ratio Htp**	Difference between the bearing ratios calculated at bearing ratio tp1 and bearing ratio tp2.
IniName	**Config name (name only)**	Filename of the configuration used when surface was measured.
IniNameFull	**Config name (full path)**	Path and filename of the configuration used when surface was measured.
LArea	**Lateral Surf Area**	Surface area measured in the lateral direction. Number of valid pixels times the x-y size of each pixel.
LeftWidth	**Step L-Width**	Left region average width calculation.
LeftWidthStdev	**Step L-Width StDev**	Standard deviation of the left region average width calculation.
LineN	**Line N**	Number of valid 2D profiles used in line width calculation.
LineStDev	**Line StDev**	Standard deviation of multiple 2D line width calculations.
LineWidth	**Line Width**	Average of a number of 2D line width calculations.
LogNum	**Log Number**	Sequence number used in database logging.
Magnification	**Magnification**	True magnification of the objective used for the measurement.

MeasMode	**Measurement Mode**	Type of measurement used in generating the surface profile (e.g., PSI, VSI, or VSI & PSI).
Mr1	**Bearing Ratio Mr1**	Material component relative to peaks.
Mr2	**Bearing Ratio Mr2**	Material component relative to valleys.
MRAlgorithm	**MultiReg Algorithm**	The island finding routine used to calculate multiple region parameters.
MRAvgADiam	**MultiReg Avg A Diam**	Average area diameter of all regions. Area of a region is the number of valid pixels in the region multiplied by the area of 1 pixel. Area diameter = 2r where r = sqrt(Area/π).
MRAvgArea	**MultiReg Avg Area**	Average area of all regions. The area of a region is the number of valid pixels in the region multiplied by the area of 1 pixel.
MRAvgHeight	**MultiReg Avg Height**	Average measured height of all regions.
MRAvgVolume	**MultiReg Avg Volume**	Average volume of all regions. Volume of a region is the area multiplied by the mean region height.
MRAvgXDiam	**MultiReg Avg X Diam**	Average X diameter of all region. When a box is drawn to encompass the region, the X diameter is the width of the box.
MRAvgXYDiam	**MultiReg Avg XY Diam**	Average XY diameter of all regions. The average XY diameter of a region is the average of the region's X diameter and Y diameter.
MRAvgYDiam	**MultiReg Avg Y Diam**	Average Y diameter of all regions. When a box is drawn to encompass the region, the Y diameter is the height of the box.
MRBackRa	**MultiReg Background Ra**	Arithmetic roughness average of the background data.
MRBackRq	**MultiReg Background Rq**	RMS roughness average of background data.
MRIslands	**MultiReg Islands**	Number of regions found in the dataset based on the options chosen.
MRMaxADiam	**MultiReg Max A Diam**	Maximum area diameter of all regions. The area of a region is the number of valid pixels in the region multiplied by the area of 1 pixel. Area diameter = 2r where r = sqrt(Area/π).
MRMaxADRgn	**MultiReg Max AD Rgn**	Number of the region having the maximum area diameter. Area of an region is the number of valid pixels in the region multiplied by the area of 1 pixel. Area diameter = 2r where r = sqrt(Area/π).
MRMaxADXLoc	**MultiReg Max AD X Loc**	X location of the region having the maximum area diameter. The area of a region is the number of valid pixels in the region multiplied by the area of 1 pixel. Area diameter = 2r where r = sqrt(Area/π).
MRMaxADYLoc	**MultiReg Max AD Y Loc**	Y location of the maximum area diameter. Area of an region is the number of valid pixels in the region multiplied by the area of 1 pixel. Area diameter = 2r where r = sqrt(Area/π).
MRMaxArea	**MultiReg Max Area**	Maximum area of any region. The area is the number of pixels in the region multiplied by the area of 1 pixel.
MRMaxAreaRgn	**MultiReg Max Area Rgn**	Number of the region having the maximum area. The area of a region is the number of pixels in the region multiplied by the area of 1 pixel.

MRMaxAreaXLoc	**MultiReg Max Area X Loc**	X location of the region having the maximum area. The area of a region is the number of pixels in the region multiplied by the area of 1 pixel.
MRMaxAreaYLoc	**MultiReg Max Area Y Loc**	Y location of the region having the maximum area. The area of a region is the number of pixels in the region multiplied by the area of 1 pixel.
MRMaxHeight	**MultiReg Max Height**	Maximum height of any region.
MRMaxHtRgn	**MultiReg Max Ht Rgn**	Number of the region having the maximum height.
MRMaxHtXLoc	**MultiReg Max Ht X Loc**	X location of the region having the maximum height.
MRMaxHtYLoc	**MultiReg Max Ht Y Loc**	Y location of the region having the maximum height.
MRMaxVol	**MultiReg Max Vol**	Maximum volume of any region. The volume of a region is the area of the region multiplied by the mean region height
MRMaxVolRgn	**MultiReg Max Vol Rgn**	Number of the region having the maximum volume. The volume of a region is the area of the region multiplied by the mean region height
MRMaxVolXLoc	**MultiReg Max Vol X Loc**	X location of the region having the maximum volume. The volume of a region is the area multiplied by the mean region height
MRMaxVolYLoc	**MultiReg Max Vol Y Loc**	Y location of the region having the maximum volume. The volume of a region is the area of the region multiplied by the mean region height
MRMaxXDiam	**MultiReg Max X Diam**	Maximum X diameter of any region. When a box is drawn to encompass the region, the X diameter is the width of the box.
MRMaxXDRgn	**MultiReg Max XD Rgn**	Number of the region having the maximum X diameter. When a box is drawn to encompass the region, the X diameter is the width of the box.
MRMaxXDXLoc	**MultiReg Max XD X Loc**	X location of the region having the maximum X diameter. When a box is drawn to encompass the region, the X diameter is the width of the box.
MRMaxXDYLoc	**MultiReg Max XD Y Loc**	Y location of the region having the maximum X diameter. When a box is drawn to encompass the region, the X diameter is the width of the box.
MRMaxXYDiam	**MultiReg Max XY Diam**	Maximum XY diameter of any region. The XY diameter of a region is the average of the region's X diameter and Y diameter.
MRMaxXYDRgn	**MultiReg Max XYD Rgn**	Number of the region having the maximum XY diameter. The XY diameter of a region is the average of the region's X diameter and Y diameter.
MRMaxXYDXLoc	**MultiReg Max XYD X Loc**	X location of the region having the maximum XY diameter. The XY diameter of a region is the average of the region's X diameter and Y diameter.
MRMaxXYDYLoc	**MultiReg Max XYD Y Loc**	Y location of the region having the maximum XY diameter. The XY diameter of a region is the average of the region's X diameter and Y diameter.
MRMaxYDiam	**MultiReg Max Y Diam**	Maximum Y diameter of any region. When a box is drawn to encompass the region, the Y diameter is the height of the box.

MRMaxYDRgn	**MultiReg Max YD Rgn**	Number of the region having the maximum Y diameter. When a box is drawn to encompass the region, the Y diameter is the height of the box.
MRMaxYDXLoc	**MultiReg Max YD X Loc**	X location of the region having the maximum Y diameter. When a box is drawn to encompass the region, the Y diameter is the height of the box.
MRMaxYDYLoc	**MultiReg Max YD Y Loc**	Y location of the region having the maximum Y diameter. When a box is drawn to encompass the region, the Y diameter is the height of the box.
MRMinADiam	**MultiReg Min A Diam**	Minimum area diameter of all regions. The area of a region is the number of valid pixels in the region multiplied by the area of 1 pixel. Area diameter = 2r where r = sqrt(Area/π).
MRMinADRgn	**MultiReg Min AD Rgn**	Number of the region having the minimum area diameter. Area of an region is the number of valid pixels in the region multiplied by the area of 1 pixel. Area diameter = 2r where r = sqrt(Area/π).
MRMinADXLoc	**MultiReg Min AD X Loc**	X location of the region having the minimum area diameter. The area of a region is the number of valid pixels in the region multiplied by the area of 1 pixel. Area diameter = 2r where r = sqrt(Area/π).
MRMinADYLoc	**MultiReg Min AD Y Loc**	Y location of the minimum area diameter. Area of an region is the number of valid pixels in the region multiplied by the area of 1 pixel. Area diameter = 2r where r = sqrt(Area/π).
MRMinArea	**MultiReg Min Area**	Minimum area of any region. The area is the number of pixels in the region multiplied by the area of 1 pixel.
MRMinAreaRgn	**MultiReg Min Area Rgn**	Number of the region having the minimum area. The area of a region is the number of pixels in the region multiplied by the area of 1 pixel.
MRMinAreaXLoc	**MultiReg Min Area X Loc**	X location of the region having the minimum area. The area of a region is the number of pixels in the region multiplied by the area of 1 pixel.
MRMinAreaYLoc	**MultiReg Min Area Y Loc**	Y location of the region having the minimum area. The area of a region is the number of pixels in the region multiplied by the area of 1 pixel.
MRMinHeight	**MultiReg Min Height**	Minimum height of any region.
MRMinHtRgn	**MultiReg Min Ht Rgn**	Number of the region having the minimum height.
MRMinHtXLoc	**MultiReg Min Ht X Loc**	X location of the region having the minimum height.
MRMinHtYLoc	**MultiReg Min Ht Y Loc**	Y location of the region having the minimum height.
MRMinIslSize	**MultiReg Min Island Size**	Multiple region minimum island size as defined by the option chosen.
MRMinVol	**MultiReg Min Vol**	Minimum volume of any region. The volume of a region is the area of the region multiplied by the mean region height.
MRMinVolRgn	**MultiReg Min Vol Rgn**	Number of the region having the minimum volume. The volume of a region is the area of the region multiplied by the mean region height.

MRMinVolXLoc	**MultiReg Min Vol X Loc**	X location of the region having the minimum volume. The volume of a region is the area multiplied by the mean region height.
MRMinVolYLoc	**MultiReg Min Vol Y Loc**	Y location of the region having the minimum volume. The volume of a region is the area of the region multiplied by the mean region height.
MRMinXDiam	**MultiReg Min X Diam**	Minimum X diameter of any region. When a box is drawn to encompass the region, the X diameter is the width of the box.
MRMinXDRgn	**MultiReg Min XD Rgn**	Number of the region having the minimum X diameter. When a box is drawn to encompass the region, the X diameter is the width of the box.
MRMinXDXLoc	**MultiReg Min XD X Loc**	X location of the region having the minimum X diameter. When a box is drawn to encompass the region, the X diameter is the width of the box.
MRMinXDYLoc	**MultiReg Min XD Y Loc**	Y location of the region having the minimum X diameter. When a box is drawn to encompass the region, the X diameter is the width of the box.
MRMinXYDiam	**MultiReg Min XY Diam**	Minimum XY diameter of any region. The XY diameter of a region is the average of the region's X diameter and Y diameter.
MRMinXYDRgn	**MultiReg Min XYD Rgn**	Number of the region having the minimum XY diameter. The XY diameter of a region is the average of the region's X diameter and Y diameter.
MRMinXYDXLoc	**MultiReg Min XYD X Loc**	X location of the region having the minimum XY diameter. The XY diameter of a region is the average of the region's X diameter and Y diameter.
MRMinXYDYLoc	**MultiReg Min XYD Y Loc**	Y location of the region having the minimum XY diameter. The XY diameter of a region is the average of the region's X diameter and Y diameter.
MRMinYDiam	**MultiReg Min Y Diam**	Minimum Y diameter of any region. When a box is drawn to encompass the region, the Y diameter is the height of the box.
MRMinYDRgn	**MultiReg Min YD Rgn**	Number of the region having the minimum Y diameter. When a box is drawn to encompass the region, the Y diameter is the height of the box.
MRMinYDXLoc	**MultiReg Min YD X Loc**	X location of the region having the minimum Y diameter. When a box is drawn to encompass the region, the Y diameter is the height of the box.
MRMinYDYLoc	**MultiReg Min YD Y Loc**	Y location of the region having the minimum Y diameter. When a box is drawn to encompass the region, the Y diameter is the height of the box.
MRStdADiam	**MultiReg Std A Diam**	Standard deviation of the area diameter of all regions.
MRStdArea	**MultiReg Std Area**	Standard deviation of the area of all regions.
MRStdHeight	**MultiReg Std Height**	Standard deviation of the measured height of all regions.
MRStdVol	**MultiReg Std Vol**	Standard deviation of the volume of all regions.
MRStdXDiam	**MultiReg Std X Diam**	Standard deviation of the X diameter of all regions.
MRStdXYDiam	**MultiRegStd XY Diam**	Standard deviation of the XY diameter of all regions.

MRStdYDiam	**MultiReg Std Y Diam**	Standard deviation of the Y diameter of all regions.
Mult	**Mult**	Type of data format used in surface height reconstruction (e.g., floating point, saving 10 bit integer, saving etc.).
NormVolume	**NormVolume**	Volume in BCM units (Billions of Cubic Microns per square inch). Ratio of volume over lateral area.
Note	**Note**	User applied notation.
ObjectiveLabel	**Objective**	Magnification objective label.
Pixel_Size	**Pixel size**	Pixel size is based on magnification, detector pixel size, and array size used in the measurement.
Pupil_diam	**Pupil Diam**	Pupil diameter is the diameter of the aperture of the interferometer. This parameter is typically used only with large aperture interferometers.
Ra	**Ra**	Arithmetic average roughness height over the entire 3D surface.
Radius	**Radius**	Number of pixels in the radius of the circle of valid pixels in the surface profile. Typically used only in large aperture interferometers.
Radius Thresh	**Summit Radius Thresh**	Radius of curvature threshold used for the calculation of summit radius count.
RadiusCt	**Summit Radius Count**	A count of the number of summits with a radius of curvature that exceeds the specified radius of curvature threshold.
RCrv	**Rad Crv**	Calculated when the radius of curvature term is removed.
RCyl	**Rad Cyl**	Calculated when the radius of cylinder term is removed.
RightWidth	**Step R-Width**	Right region average width calculation.
RightWidthStdev	**Step R-Width StDev**	Standard deviation of the right region average width calculation.
RK	**Bearing Ratio RK**	Core roughness depth.
Rku	**Rku**	Kurtosis (a measure of the sharpness) of the entire 3D surface.
Rp	**Rp**	Maximum peak height.
Rpk	**Bearing Ratio Rpk**	Reduced peak height.
Rq	**Rq**	Rms average roughness height over the entire 3D surface (same as RMS).
RRa	**Roughness Ra**	Arithmetic average roughness height over the entire 3D surface after a high pass filter is applied.
RRp	**Roughness Rp**	Maximum peak height after a high pass filter is applied.
RRq	**Roughness Rq**	Rms average roughness height over the entire 3D surface (same as RMS) after a high pass filter is applied.
RRt	**Roughness Rt**	Vertical distance between the highest peak and the lowest valley of the 3D surface (same as P-V) after a high pass filter is applied.
RRv	**Roughness Rv**	Maximum valley depth over the entire 3D surface.
Rsk	**Rsk**	Skewness (a measure of asymmetry) of the entire 3D surface.
Rt	**Rt**	Vertical distance between the highest peak and the lowest valley of the 3D surface (same as P-V).

Rv	**Rv**	Maximum valley depth over the entire 3D surface.
Rvk	**Bearing Ratio Rvk**	Reduced valley depth.
S_Flt_Type	**Stylus Filter Type**	Type of digital filter used in stylus analysis.
S_lng_cut	**Stylus Long Cutoff Freq**	Long wavelength cutoff in mm. Nominal rating of the digital filter that attenuates the long wavelengths (waviness) of the surface profile to yield the roughness profile.
S_Pc_ht	**Stylus Pc Height**	Selectable band width used to find Pc.
S_sht_cut	**Stylus Short Cutoff Freq**	Short wavelength cutoff in mm. Nominal rating of the digital filter that attenuates the short wavelengths (roughness) of the surface profile to yield the waviness profile.
SArea	**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 data set, with bad pixels resulting in no contribution to the calculation.
SAreaIndex	**SArea Index**	Surface area (SArea) divided by lateral surface area.
StageCol	**Stage Column**	Computer controlled XY grid stage column coordinate position.
StageR	**Stage Radius**	Computer controlled stage radial coordinate position relative to the origin where the measurement was taken.
StageRow	**Stage Row**	Computer controlled XY grid stage row coordinate position.
StageTheta	**Stage Theta**	Computer controlled stage rotational theta-coordinate position relative to the x-axis of the stage where the measurement was taken.
StageX	**Stage X**	Computer controlled stage x-coordinate position relative to the home position where the measurement was taken.
StageY	**Stage Y**	Computer controlled stage y-coordinate position relative to the home position where the measurement was taken.
StepAvg	**StepAvg**	Average step height of a number of 2D profiles analyzed for their individual step height values. These step heights can be calculated using single or double step algorithms.
StepLAvg	**StepLAvg**	Average single-sided step height of a number of 2D profiles analyzed for their individual step height values over the left side of a double-sided step.
StepLStdev	**StepLStdev**	Standard deviation of the 2D step height values calculated when determining StepLAvg.
StepN	**StepN**	Number of 2D profiles used then determining StepAvg.
StepRAvg	**StepRAvg**	Average single step height of a number of 2D profiles analyzed for their individual step height values over the right side of a double-sided step.
StepRStdev	**StepRStdev**	Standard deviation of the 2D step height values calculated when determining StepRAvg.
StepStdev	**StepStdev**	Standard deviation of the 2D step height values calculated when determining StepAvg.

SubtractRef	**Subtract Ref**	Flag indicating that subtract reference was turned on. True = 1.
SummitCt	**Summit Count**	Number of summits that are counted over the entire surface profile.
SummitCutoff	**Summit Cutoff**	Distance below the maximum value where a summit is allowed to occur. This is a user-settable parameter.
SummitCvAvg	**Summit Curve Avg**	Average of all of the summit curvatures calculated over the valid surface profile. Summit curvature is defined as the sharpness of a peak.
SummitCvRa	**Summit Curve Ra**	Arithmetic average (Ra) of the summit curvatures.
SummitCvRp	**Summit Curve Rp**	Maximum value (Rp) of the summit curvatures.
SummitCvRq	**Summit Curve Rms**	The RMS of the summit curvatures.
SummitCvRv	**Summit Curve Rv**	Minimum value (Rv) of the summit curvatures.
SummitDensity	**Summit Density**	Number of summits divided by the area of the valid pixels searched.
SummitDiaAvg	**Summit Diameter Avg**	Average of the summit diameters. Summit diameter is defined as two times the summit X-Y radius (distance from the summit point to the summit base).
SummitDiaRa	**Summit Diameter Ra**	Arithmetic average (Ra) of the summit diameters.
SummitDiaRp	**Summit Diameter Rp**	Maximum (Rp) of the summit diameters.
SummitDiaRq	**Summit Diameter Rms**	The RMS of the summit diameters.
SummitDiaRv	**Summit Diameter Rv**	Minimum (Rv) of the summit diameters.
SummitHtAvg	**Summit Height Avg**	Average of the summit heights measured relative to the mean.
SummitHtRa	**Summit Height Ra**	Arithmetic average (Ra) of the summit heights.
SummitHtRp	**Summit Height Rp**	Maximum height (Rp) of all of the summit peaks.
SummitHtRq	**Summit Height Rms**	The RMS of the summit heights.
SummitHtRv	**Summit Height Rv**	Minimum height (Rv) of all of the summit peaks.
SummitMinCv	**Summit Min Curve**	Minimum summit curvature that can be found for the user specified summit threshold and summit cutoff.
SummitRdAvg	**Summit Radius Avg**	Average of all of the summit radii of curvature calculated for each summit.
SummitRdRa	**Summit Radius Ra**	Arithmetic mean (Ra) of the summit radii of curvature.
SummitRdRp	**Summit Radius Rp**	Maximum value (Rp) of the summit radii of curvature.
SummitRdRq	**Summit Radius Rms**	The RMS of the summit radii of curvature.
SummitRdRv	**Summit Radius Rv**	Minimum value (Rv) of the summit radii of curvature.
SummitSlAvg	**Summit Slope Avg**	Sum of the summit slopes (ratio of the height of each summit measured from the summit base to the summit x-y radius) divided by the summit count.
SummitSlRa	**Summit Slope Ra**	Arithmetic average (Ra) of the summit slope averages.
SummitSlRp	**Summit Slope Rp**	Maximum summit slope (Rp).
SummitSlRq	**Summit Slope Rms**	The RMS of the summit slope averages.
SummitSlRv	**Summit Slope Rv**	Minimum (smallest) summit slope (Rv).

SummitSpacing	**Summit Spacing**	Spacing between summits calculated as sqrt (1/summit spacing).
SummitThresh	**Summit Threshold**	Minimum distance a point must rise above all of its nearest neighbors to be identified as a summit. This is a user-settable parameter.
SX_asm_1	**Stylus X Assessment Length**	Total length of the area in the X direction.
SX_D_a_RMS	**Stylus X Delta_a RMS**	Standard deviation of the arithmetic mean of the slopes at all points along lines in the X direction, within the assessment length.
SX_D_q_RMS	**Stylus X Delta_q RMS**	Standard deviation of the RMS mean of the slopes at all points along lines in the X direction, within the assessment length.
SX_Del_a	**Stylus X Delta_a**	Arithmetic mean of the slopes at all points along lines in the X direction, within the assessment length.
SX_Del_a_H	**Stylus X Delta_a High**	Largest arithmetic mean value of the slopes at all points found along each valid line in the X direction, within the assessment length.
SX_Del_a_L	**Stylus X Delta_a Low**	Smallest arithmetic mean value of the slopes at all points found along each valid line in the X direction, within the assessment length.
SX_Del_q	**Stylus X Delta_q**	RMS mean of the slopes at all the points along lines in the X direction, within the assessment length.
SX_Del_q_H	**Stylus X Delta_q High**	Largest RMS mean value of the slopes at all points found along each valid line in the X direction, within the assessment length.
SX_Del_q_L	**Stylus X Delta_q Low**	Smallest RMS mean value of the slopes at all points found along each valid line in the X direction, within the assessment length.
SX_Htp	**Stylus X Htp**	Difference between bearing ratios for lines in the X direction, calculated at bearing ratio tp1 and bearing ratio tp2.
SX_Htp_H	**Stylus X Htp High**	Largest difference between bearing ratios for lines in the X direction, calculated at bearing ratio tp1 and bearing ratio tp2.
SX_Htp_L	**Stylus X Htp Low**	Smallest difference between bearing ratios for lines in the X direction, calculated at bearing ratio tp1 and bearing ratio tp2.
SX_Htp_RMS	**Stylus X Htp RMS**	Standard deviation of the difference between bearing ratios for lines in the X direction, calculated at bearing ratio tp1 and bearing ratio tp2.
SX_Lam_a	**Stylus X Lambda_a**	Arithmetic average wavelength. A measure of the spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SX_Lam_a_H	**Stylus X Lambda_a High**	Largest arithmetic average wavelength. A measure of the largest spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.

SX_Lam_a_L	**Stylus X Lambda_a Low**	Smallest arithmetic average wavelength. A measure of the smallest spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SX_Lam_a_RMS	**Stylus X Lambda_a RMS**	Standard deviation of the arithmetic average wavelength. A measure of the standard deviation spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SX_Lam_q	**Stylus X Lambda_q**	RMS average wavelength. A measure of the spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SX_Lam_q_H	**Stylus X Lambda_q High**	Largest RMS average wavelength. A measure of the largest spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SX_Lam_q_L	**Stylus X Lambda_q Low**	Smallest RMS average wavelength. A measure of the smallest spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SX_Lam_q_RMS	**Stylus X Lambda_q RMS**	Standard deviation of the RMS average wavelength. A measure of the standard deviation spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SX_lines	**Stylus X Num Valid Lines**	Number of valid lines assessed in the X direction.
SX_Mr1	**Stylus X Mr1**	Material component relative to peaks for valid lines in the X direction.
SX_Mr1_H	**Stylus X Mr1 High**	Largest material component relative to peaks for each valid line found in the X direction.
SX_Mr1_L	**Stylus X Mr1 Low**	Smallest material component relative to peaks for each valid line found in the X direction.
SX_Mr1_RMS	**Stylus X Mr1 RMS**	Standard deviation of the material component relative to peaks for each valid line found in the X direction.
SX_Mr2	**Stylus X Mr2**	Material component relative to valleys for lines in the X direction.
SX_Mr2_H	**Stylus X Mr2 High**	Largest material component relative to valleys for each valid line found in the X direction.
SX_Mr2_L	**Stylus X Mr2 Low**	Smallest material component relative to valleys for each valid line found in the X direction.
SX_Mr2_RMS	**Stylus X Mr2 RMS**	Standard deviation of the material component relative to valleys for each valid line found in the X direction.
SX_num_1	**Stylus X Num Sample Lengths**	Number of sample lengths used for lines in the X direction.
SX_Pc	**Stylus X Pc**	Number of local peaks which project through a selectable band centered about the mean line for lines in the X direction, over the assessment length .
SX_Pc_H	**Stylus X Pc High**	Largest number of local peaks which project through a selectable band centered about the mean line for each valid line in the X direction, over the assessment length.

SX_Pc_L	**Stylus X Pc Low**	Smallest number of local peaks which project through a selectable band centered about the mean line for each valid line in the X direction, over the assessment length.
SX_Pc_RMS	**Stylus X Pc RMS**	Standard deviation of the number of local peaks which project through a selectable band centered about the mean line for each valid line in the X direction, over the assessment length.
SX_Ra	**Stylus X Ra**	Arithmetic average roughness height for lines in the X direction.
SX_Ra_H	**Stylus X Ra High**	Largest arithmetic average roughness height value for valid lines in the X direction.
SX_Ra_L	**Stylus X Ra Low**	Smallest arithmetic average roughness height value for valid lines in the X direction.
SX_Ra_RMS	**Stylus X Ra RMS**	Standard deviation of the arithmetic average roughness height value for valid lines in the X direction.
SX_Rk	**Stylus X Rk**	Core roughness depth for lines in the X direction.
SX_Rk_H	**Stylus X Rk High**	Largest core roughness depth for lines in the X direction.
SX_Rk_L	**Stylus X Rk Low**	Smallest core roughness depth for lines in the X direction.
SX_Rk_RMS	**Stylus X Rk RMS**	Standard deviation of the core roughness depth for lines in the X direction.
SX_Rku	**Stylus X Rku**	Kurtosis (a measure of the sharpness) of lines in the X direction.
SX_Rku_H	**Stylus X Rku High**	Largest kurtosis (a measure of the sharpness) of lines in the X direction.
SX_Rku_L	**Stylus X Rku Low**	Smallest kurtosis (a measure of the sharpness) of lines in the X direction.
SX_Rku_RMS	**Stylus X Rku RMS**	Standard deviation of the kurtosis (a measure of the sharpness) of lines in the X direction.
SX_Rmax	**Stylus X Rmax**	Maximum of all peak-to-valley (Rt) values for lines in the X direction, measured over the assessment length.
SX_Rmax_H	**Stylus X Rmax High**	Largest maximum of all peak-to-valley (Rt) values for valid lines in the X direction, measured over the assessment length.
SX_Rmax_L	**Stylus X Rmax Low**	Smallest maximum of all peak-to-valley (Rt) values for valid lines in the X direction, measured over the assessment length.
SX_Rmax_RMS	**Stylus X Rmax RMS**	Standard deviation of the maximum of all peak-to-valley (Rt) values for valid lines in the X direction, measured over the assessment length.
SX_Rp	**Stylus X Rp**	Maximum peak height for lines in the X direction over the assessment length.
SX_Rp_H	**Stylus X Rp High**	Largest maximum peak height for lines in the X direction over the assessment length.
SX_Rp_L	**Stylus X Rp Low**	Smallest maximum peak height for lines in the X direction over the assessment length.
SX_Rp_RMS	**Stylus X Rp RMS**	Standard deviation of the maximum peak height for lines in the X direction over the assessment length.

SX_Rpk	**Stylus X Rpk**	Reduced peak height for lines in the X direction over the assessment length.
SX_Rpk_H	**Stylus X Rpk High**	Largest reduced peak height for lines in the X direction over the assessment length.
SX_Rpk_L	**Stylus X Rpk Low**	Smallest reduced peak height for lines in the X direction over the assessment length.
SX_Rpk_RMS	**Stylus X Rpk RMS**	Standard deviation of the reduced peak height for lines in the X direction over the assessment length.
SX_Rpm	**Stylus X Rpm**	Mean of all maximum peak heights for lines in the X direction over the assessment length.
SX_Rpm_H	**Stylus X Rpm High**	Largest mean of all maximum peak heights for lines in the X direction over the assessment length.
SX_Rpm_L	**Stylus X Rpm Low**	Smallest mean of all maximum peak heights for lines in the X direction over the assessment length.
SX_Rpm_RMS	**Stylus X Rpm RMS**	Standard deviation of the mean of all maximum peak heights for lines in the X direction over the assessment length.
SX_Rq	**Stylus X Rq**	Rms average roughness height for lines in the X direction over the assessment length.
SX_Rq_H	**Stylus X Rq High**	Largest rms average roughness height for lines in the X direction over the assessment length.
SX_Rq_L	**Stylus X Rq Low**	Smallest rms average roughness height for lines in the X direction over the assessment length.
SX_Rq_RMS	**Stylus X Rq RMS**	Standard deviation of the rms average roughness height for lines in the X direction over the assessment length.
SX_Rsk	**Stylus X Rsk**	Skewness (a measure of asymmetry) of lines in the X direction over the assessment length.
SX_Rsk_H	**Stylus X Rsk High**	Largest skewness (a measure of asymmetry) of lines in the X direction over the assessment length.
SX_Rsk_L	**Stylus X Rsk Low**	Smallest skewness (a measure of asymmetry) of lines in the X direction over the assessment length.
SX_Rsk_RMS	**Stylus X Rsk RMS**	Standard deviation of the skewness (a measure of asymmetry) of lines in the X direction over the assessment length.
SX_Rt	**Stylus X Rt**	Vertical distance between the highest peak and the lowest valley for lines in the X direction over the assessment length.
SX_Rt_H	**Stylus X Rt High**	Largest vertical distance between the highest peak and the lowest valley for lines in the X direction over the assessment length.
SX_Rt_L	**Stylus X Rt Low**	Smallest vertical distance between the highest peak and the lowest valley for lines in the X direction over the assessment length.
SX_Rt_RMS	**Stylus X Rt RMS**	Standard deviation of the vertical distance between the highest peak and the lowest valley for lines in the X direction over the assessment length.
SX_Rv	**Stylus X Rv**	Maximum valley depth for lines in the X direction over the assessment length.

SX_Rv_H	**Stylus X Rv High**	Largest maximum valley depth for lines in the X direction over the assessment length.
SX_Rv_L	**Stylus X Rv Low**	Smallest maximum valley depth for lines in the X direction over the assessment length.
SX_Rv_RMS	**Stylus X Rv RMS**	Standard deviation of the maximum valley depth for lines in the X direction over the assessment length.
SX_Rvk	**Stylus X Rvk**	Reduced valley depth for lines in the X direction over the assessment length.
SX_Rvk_H	**Stylus X Rvk High**	Largest reduced valley depth for lines in the X direction over the assessment length.
SX_Rvk_L	**Stylus X Rvk Low**	Smallest reduced valley depth for lines in the X direction over the assessment length.
SX_Rvk_RMS	**Stylus X Rvk RMS**	Standard deviation of the reduced valley depth for lines in the X direction over the assessment length.
SX_Rvm	**Stylus X Rvm**	Mean value of the ten lowest points for lines in the X direction over the assessment length.
SX_Rvm_H	**Stylus X Rvm High**	Largest mean value of the ten lowest points for lines in the X direction over the assessment length.
SX_Rvm_L	**Stylus X Rvm Low**	Smallest mean value of the ten lowest points for lines in the X direction over the assessment length.
SX_Rvm_RMS	**Stylus X Rvm RMS**	Standard deviation of the mean value of the ten lowest points for lines in the X direction over the assessment length.
SX_Rz	**Stylus X Rz**	Difference between Stylus X Rpm and Stylus X Rvm.
SX_Rz_H	**Stylus X Rz High**	Largest difference between Stylus X Rpm and Stylus X Rvm.
SX_Rz_L	**Stylus X Rz Low**	Smallest difference between Stylus X Rpm and Stylus X Rvm.
SX_Rz_RMS	**Stylus X Rz RMS**	Standard deviation of the difference between Stylus X Rpm and Stylus X Rvm.
SX_S	**Stylus X S**	Mean spacing between adjacent local peaks for lines in the X direction measured over the assessment length.
SX_S_H	**Stylus X S High**	Largest mean spacing between adjacent local peaks for lines in the X direction measured over the assessment length.
SX_S_L	**Stylus X S Low**	Smallest mean spacing between adjacent local peaks for lines in the X direction measured over the assessment length.
SX_S_RMS	**Stylus X S RMS**	Standard deviation of the mean spacing between adjacent local peaks for lines in the X direction measured over the assessment length.
SX_Sm	**Stylus X Sm**	Mean spacing between profile peaks at the mean line for lines in the X direction, measured over the assessment length.
SX_Sm_H	**Stylus X Sm High**	Largest mean spacing between profile peaks at the mean line for lines in the X direction, measured over the assessment length.
SX_Sm_L	**Stylus X Sm Low**	Smallest mean spacing between profile peaks at the mean line for lines in the X direction, measured over the assessment length.

SX_Sm_RMS	**Stylus X Sm RMS**	Standard deviation of the mean spacing between profile peaks at the mean line for lines in the X direction, measured over the assessment length.
SY_asm_1	**Stylus Y Assessment Length**	Total length of the area in the Y direction.
SY_D_a_RMS	**Stylus Y Delta_a RMS**	Standard deviation of the arithmetic mean of the slopes at all points along lines in the Y direction, within the assessment length.
SY_D_q_RMS	**Stylus Y Delta_q RMS**	Standard deviation of the RMS mean of the slopes at all points along lines in the Y direction, within the assessment length.
SY_Del_a	**Stylus Y Delta_a**	Arithmetic mean of the slopes at all points along lines in the Y direction, within the assessment length.
SY_Del_a_H	**Stylus Y Delta_a High**	Largest arithmetic mean value of the slopes at all points found along each valid line in the Y direction, within the assessment length.
SY_Del_a_L	**Stylus Y Delta_a Low**	Smallest arithmetic mean value of the slopes at all points found along each valid line in the Y direction, within the assessment length.
SY_Del_q	**Stylus Y Delta_q**	RMS mean of the slopes at all the points along lines in the Y direction, within the assessment length.
SY_Del_q_H	**Stylus Y Delta_q High**	Largest RMS mean value of the slopes at all points found along each valid line in the Y direction, within the assessment length.
SY_Del_q_L	**Stylus Y Delta_q Low**	Smallest RMS mean value of the slopes at all points found along each valid line in the Y direction, within the assessment length.
SY_Htp	**Stylus Y Htp**	Difference between bearing ratios for lines in the Y direction, calculated at bearing ratio tp1 and bearing ratio tp2.
SY_Htp_H	**Stylus Y Htp High**	Largest difference between bearing ratios for lines in the Y direction, calculated at bearing ratio tp1 and bearing ratio tp2.
SY_Htp_L	**Stylus Y Htp Low**	Smallest difference between bearing ratios for lines in the Y direction, calculated at bearing ratio tp1 and bearing ratio tp2.
SY_Htp_RMS	**Stylus Y Htp RMS**	Standard deviation of the difference between bearing ratios for lines in the Y direction, calculated at bearing ratio tp1 and bearing ratio tp2.
SY_Lam_a	**Stylus Y Lambda_a**	Arithmetic average wavelength. A measure of the spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SY_Lam_a_H	**Stylus Y Lambda_a High**	Largest arithmetic average wavelength. A measure of the largest spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SY_Lam_a_L	**Stylus Y Lambda_a Low**	Smallest arithmetic average wavelength. A measure of the smallest spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.

SY_Lam_a_RMS	**Stylus Y Lambda_a RMS**	Standard deviation of the arithmetic average wavelength. A measure of the standard deviation spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SY_Lam_q	**Stylus Y Lambda_q**	RMS average wavelength. A measure of the spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SY_Lam_q_H	**Stylus Y Lambda_q High**	Largest RMS average wavelength. A measure of the largest spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SY_Lam_q_L	**Stylus Y Lambda_q Low**	Smallest RMS average wavelength. A measure of the smallest spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SY_Lam_q_RMS	**Stylus Y Lambda_q RMS**	Standard deviation of the RMS average wavelength. A measure of the standard deviation spacing between local peaks and valleys, taking into account their relative amplitudes and individual spatial frequencies.
SY_lines	**Stylus Y Num Valid Lines**	Number of valid lines assessed in the Y direction.
SY_Mr1	**Stylus Y Mr1**	Material component relative to peaks for valid lines in the Y direction.
SY_Mr1_H	**Stylus Y Mr1 High**	Largest material component relative to peaks for each valid line found in the Y direction.
SY_Mr1_L	**Stylus Y Mr1 Low**	Smallest material component relative to peaks for each valid line found in the Y direction.
SY_Mr1_RMS	**Stylus Y Mr1 RMS**	Standard deviation of the material component relative to peaks for each valid line found in the Y direction.
SY_Mr2	**Stylus Y Mr2**	Material component relative to valleys for lines in the Y direction.
SY_Mr2_H	**Stylus Y Mr2 High**	Largest material component relative to valleys for each valid line found in the Y direction.
SY_Mr2_L	**Stylus Y Mr2 Low**	Smallest material component relative to valleys for each valid line found in the Y direction.
SY_Mr2_RMS	**Stylus Y Mr2 RMS**	Standard deviation of the material component relative to valleys for each valid line found in the Y direction.
SY_num_1	**Stylus Y Num Sample Lengths**	Number of sample lengths used for lines in the Y direction.
SY_Pc	**Stylus Y Pc**	Number of local peaks which project through a selectable band centered about the mean line for lines in the Y direction, over the assessment length .
SY_Pc_H	**Stylus Y Pc High**	Largest number of local peaks which project through a selectable band centered about the mean line for each valid line in the Y direction, over the assessment length.
SY_Pc_L	**Stylus Y Pc Low**	Smallest number of local peaks which project through a selectable band centered about the mean line for each valid line in the Y direction, over the assessment length.

SY_Pc_RMS	**Stylus Y Pc RMS**	Standard deviation of the number of local peaks which project through a selectable band centered about the mean line for each valid line in the Y direction, over the assessment length.
SY_Ra	**Stylus Y Ra**	Arithmetic average roughness height for lines in the Y direction.
SY_Ra_H	**Stylus Y Ra High**	Largest arithmetic average roughness height value for valid lines in the Y direction.
SY_Ra_L	**Stylus Y Ra Low**	Smallest arithmetic average roughness height value for valid lines in the Y direction.
SY_Ra_RMS	**Stylus Y Ra RMS**	Standard deviation of the arithmetic average roughness height value for valid lines in the Y direction.
SY_Rk	**Stylus Y Rk**	Core roughness depth for lines in the Y direction.
SY_Rk_H	**Stylus Y Rk High**	Largest core roughness depth for lines in the Y direction.
SY_Rk_L	**Stylus Y Rk Low**	Smallest core roughness depth for lines in the Y direction.
SY_Rk_RMS	**Stylus Y Rk RMS**	Standard deviation of the core roughness depth for lines in the Y direction.
SY_Rku	**Stylus Y Rku**	Kurtosis (a measure of the sharpness) of lines in the Y direction.
SY_Rku_H	**Stylus Y Rku High**	Largest kurtosis (a measure of the sharpness) of lines in the Y direction.
SY_Rku_L	**Stylus Y Rku Low**	Smallest kurtosis (a measure of the sharpness) of lines in the Y direction.
SY_Rku_RMS	**Stylus Y Rku RMS**	Standard deviation of the kurtosis (a measure of the sharpness) of lines in the Y direction.
SY_Rmax	**Stylus Y Rmax**	Maximum of all peak-to-valley (Rt) values for lines in the Y direction, measured over the assessment length.
SY_Rmax_H	**Stylus Y Rmax High**	Largest maximum of all peak-to-valley (Rt) values for valid lines in the Y direction, measured over the assessment length.
SY_Rmax_L	**Stylus Y Rmax Low**	Smallest maximum of all peak-to-valley (Rt) values for valid lines in the Y direction, measured over the assessment length.
SY_Rmax_RMS	**Stylus Y Rmax RMS**	Standard deviation of the maximum of all peak-to-valley (Rt) values for valid lines in the Y direction, measured over the assessment length.
SY_Rp	**Stylus Y Rp**	Maximum peak height for lines in the Y direction over the assessment length.
SY_Rp_H	**Stylus Y Rp High**	Largest maximum peak height for lines in the Y direction over the assessment length.
SY_Rp_L	**Stylus Y Rp Low**	Smallest maximum peak height for lines in the Y direction over the assessment length.
SY_Rp_RMS	**Stylus Y Rp RMS**	Standard deviation of the maximum peak height for lines in the Y direction over the assessment length.
SY_Rpk	**Stylus Y Rpk**	Reduced peak height for lines in the Y direction over the assessment length.
SY_Rpk_H	**Stylus Y Rpk High**	Largest reduced peak height for lines in the Y direction over the assessment length.

SY_Rpk_L	**Stylus Y Rpk Low**	Smallest reduced peak height for lines in the Y direction over the assessment length.
SY_Rpk_RMS	**Stylus Y Rpk RMS**	Standard deviation of the reduced peak height for lines in the Y direction over the assessment length.
SY_Rpm	**Stylus Y Rpm**	Mean of all maximum peak heights for lines in the Y direction over the assessment length.
SY_Rpm_H	**Stylus Y Rpm High**	Largest mean of all maximum peak heights for lines in the Y direction over the assessment length.
SY_Rpm_L	**Stylus Y Rpm Low**	Smallest mean of all maximum peak heights for lines in the Y direction over the assessment length.
SY_Rpm_RMS	**Stylus Y Rpm RMS**	Standard deviation of the mean of all maximum peak heights for lines in the Y direction over the assessment length.
SY_Rq	**Stylus Y Rq**	Rms average roughness height for lines in the Y direction over the assessment length.
SY_Rq_H	**Stylus Y Rq High**	Largest rms average roughness height for lines in the Y direction over the assessment length.
SY_Rq_L	**Stylus Y Rq Low**	Smallest rms average roughness height for lines in the Y direction over the assessment length.
SY_Rq_RMS	**Stylus Y Rq RMS**	Standard deviation of the rms average roughness height for lines in the Y direction over the assessment length.
SY_Rsk	**Stylus Y Rsk**	Skewness (a measure of asymmetry) of lines in the Y direction over the assessment length.
SY_Rsk_H	**Stylus Y Rsk High**	Largest skewness (a measure of asymmetry) of lines in the Y direction over the assessment length.
SY_Rsk_L	**Stylus Y Rsk Low**	Smallest skewness (a measure of asymmetry) of lines in the Y direction over the assessment length.
SY_Rsk_RMS	**Stylus Y Rsk RMS**	Standard deviation of the skewness (a measure of asymmetry) of lines in the Y direction over the assessment length.
SY_Rt	**Stylus Y Rt**	Vertical distance between the highest peak and the lowest valley for lines in the Y direction over the assessment length.
SY_Rt_H	**Stylus Y Rt High**	Largest vertical distance between the highest peak and the lowest valley for lines in the Y direction over the assessment length.
SY_Rt_L	**Stylus Y Rt Low**	Smallest vertical distance between the highest peak and the lowest valley for lines in the Y direction over the assessment length.
SY_Rt_RMS	**Stylus Y Rt RMS**	Standard deviation of the vertical distance between the highest peak and the lowest valley for lines in the Y direction over the assessment length.
SY_Rv	**Stylus Y Rv**	Maximum valley depth for lines in the Y direction over the assessment length.
SY_Rv_H	**Stylus Y Rv High**	Largest maximum valley depth for lines in the Y direction over the assessment length.
SY_Rv_L	**Stylus Y Rv Low**	Smallest maximum valley depth for lines in the Y direction over the assessment length.

SY_Rv_RMS	**Stylus Y Rv RMS**	Standard deviation of the maximum valley depth for lines in the Y direction over the assessment length.
SY_Rvk	**Stylus Y Rvk**	Reduced valley depth for lines in the Y direction over the assessment length.
SY_Rvk_H	**Stylus Y Rvk High**	Largest reduced valley depth for lines in the Y direction over the assessment length.
SY_Rvk_L	**Stylus Y Rvk Low**	Smallest reduced valley depth for lines in the Y direction over the assessment length.
SY_Rvk_RMS	**Stylus Y Rvk RMS**	Standard deviation of the reduced valley depth for lines in the Y direction over the assessment length.
SY_Rvm	**Stylus Y Rvm**	Mean value of the ten lowest points for lines in the Y direction over the assessment length.
SY_Rvm_H	**Stylus Y Rvm High**	Largest mean value of the ten lowest points for lines in the Y direction over the assessment length.
SY_Rvm_L	**Stylus Y Rvm Low**	Smallest mean value of the ten lowest points for lines in the Y direction over the assessment length.
SY_Rvm_RMS	**Stylus Y Rvm RMS**	Standard deviation of the mean value of the ten lowest points for lines in the Y direction over the assessment length.
SY_Rz	**Stylus Y Rz**	Difference between Stylus Y Rpm and Stylus Y Rvm.
SY_Rz_H	**Stylus Y Rz High**	Largest difference between Stylus Y Rpm and Stylus Y Rvm.
SY_Rz_L	**Stylus Y Rz Low**	Smallest difference between Stylus Y Rpm and Stylus Y Rvm.
SY_Rz_RMS	**Stylus Y Rz RMS**	Standard deviation of the difference between Stylus Y Rpm and Stylus Y Rvm.
SY_S	**Stylus Y S**	Mean spacing between adjacent local peaks for lines in the Y direction measured over the assessment length.
SY_S_H	**Stylus Y S High**	Largest mean spacing between adjacent local peaks for lines in the Y direction measured over the assessment length.
SY_S_L	**Stylus Y S Low**	Smallest mean spacing between adjacent local peaks for lines in the Y direction measured over the assessment length.
SY_S_RMS	**Stylus Y S RMS**	Standard deviation of the mean spacing between adjacent local peaks for lines in the Y direction measured over the assessment length.
SY_Sm	**Stylus Y Sm**	Mean spacing between profile peaks at the mean line for lines in the Y direction, measured over the assessment length.
SY_Sm_H	**Stylus Y Sm High**	Largest mean spacing between profile peaks at the mean line for lines in the Y direction, measured over the assessment length.
SY_Sm_L	**Stylus Y Sm Low**	Smallest mean spacing between profile peaks at the mean line for lines in the Y direction, measured over the assessment length.
SY_Sm_RMS	**Stylus Y Sm RMS**	Standard deviation of the mean spacing between profile peaks at the mean line for lines in the Y direction, measured over the assessment length.
Terms_String	**Terms Removed**	Text description of terms removed from the analyzed surface (e.g., tilt, curvature, cylinder).

Time	**Time**	Time stamp indicating when surface data is acquired.
Title	**Title**	User generated title that is appended to the measurement data.
tp1	**Bearing Ratio tp1**	Left bearing ratio percentage used in the calculation of bearing ratio Htp.
tp2	**Bearing Ratio tp2**	Right bearing ratio percentage used in the calculation of bearing ratio Htp.
UserNote1 - UserNote12		User appended note into field 1 - field 12.
V1	**Bearing Ratio V1**	Material filled profile peak volume.
V2	**Bearing Ratio V2**	Lubricant filled profile valley volume.
Valid	**Valid Points**	A count of the valid points in the measurement.
Vol_opt_String	**Volume Options**	Indicates the options used in volume calculation (e.g., inversion of data, top threshold, etc.).
Wavelength	**Wavelength**	Wavelength of the filter used for the phase shift (PSI) measurement.
Wedge	**Wedge**	Wedge factor used in the interferometric measurement. Typically used only with large aperture interferometers.
WRa	**Waviness Ra**	Arithmetic average roughness height over the entire 3D surface after a low pass filter is applied.
WRp	**Waviness Rp**	Maximum peak height after a low pass filter is applied.
WRq	**Waviness Rq**	Rms average roughness height over the entire 3D surface (same as RMS) after a low pass filter is applied.
WRt	**Waviness Rt**	Arithmetic average roughness height over the entire 3D surface after a low pass filter is applied.
WRv	**Waviness Rv**	Arithmetic average roughness height over the entire 3D surface after a low pass filter is applied.
XCrossings	**X Crossings**	X-crossings is a count of the average number of times the data (profile) crosses the zero height line from positive to negative and negative to positive in the x-direction of the profile. This count value is then divided by the length of one x-profile.
XPSD_A	**X Avg PSD A**	Constant in Fractal Roughness/PSD equation.
XPSD_B	**X Avg PSD B**	Constant in Fractal Roughness/PSD equation.
XPSD_HCO	**X Avg PSD High Cutoff (1/C)**	User-specified high cutoff frequency value for X Average PSD analysis.
XPSD_LCO	**X Avg PSD Low Cutoff (1/D)**	User-specified low cutoff frequency value for X Average PSD analysis.
XPSD_Rf	**X Avg PSD Rf**	Fractal roughness, calculated using a linear least-squares fit of X Average PSD data.
XPSD_Rms	**X Avg PSD RMS**	RMS calculated from X Average PSD data. Provides a roughness value similar to Rq.
XSize	**X Size**	Number of pixels in the x-direction for the selected array (e.g., 119, 238, etc.).
XSlopeRa	**XSlope Ra**	Arithmetic average (Ra) of the surface X-slopes.
XSlopeRp	**XSlope Rp**	Maximum value (Rp) of the surface X-slopes.
XSlopeRq	**XSlope Rq**	The RMS of the surface X-slopes.

XSlopeRt	**XSlope Rt**	Maximum value (Rp) minus the minimum (Rv) of the surface X-slopes.
XSlopeRv	**XSlope Rv**	Minimum value (Rv) of the surface X-slopes.
XYSize	**X/Y Size**	Composite size of the array specified for the measurement (e.g., 119 x 184, 140 x 700, etc.).
YCrossings	**Y Crossings**	Y-crossings is a count of the average number of times the data (profile) crosses the zero height line from positive to negative and negative to positive in the y-direction of the profile. This count value is then divided by the length of one y-profile.
YPSD_A	**Y Avg PSD A**	Constant in fractal roughness/PSD equation.
YPSD_B	**Y Avg PSD B**	Constant in fractal roughness/PSD equation.
YPSD_HCO	**Y Avg PSD High Cutoff (1/C)**	User-specified high cutoff frequency value for Y Average PSD analysis.
YPSD_LCO	**Y Avg PSD Low Cutoff (1/D)**	User-specified low cutoff frequency value for Y Average PSD analysis.
YPSD_Rf	**Y Avg PSD Rf**	Fractal roughness, calculated using a linear least-squares fit of Y average PSD data.
YPSD_Rms	**Y Avg PSD RMS**	RMS calculated from Y Average PSD data. Provides a roughness value similar to Rq.
YSize	**YSize**	Number of pixels in the y-direction for the selected array (e.g., 184, 368, 700, etc.).
YSlopeRa	**YSlope Ra**	Arithmetic average (Ra) of the Y-slopes.
YSlopeRp	**YSlope Rp**	Maximum value (Rp) of the surface Y-slopes.
YSlopeRq	**YSlope Rq**	The RMS of the Y-slopes.
YSlopeRt	**YSlope Rt**	Maximum value (Rp) minus the minimum value (Rv) of the Y-slopes.
YSlopeRv	**YSlope Rv**	Minimum value (Rv) of the Y-slopes.

Appendix C

Exporting Data and Graphics from Vision™

Data files and graphics can be exported from Vision™ into other applications, and output data files from Vision™ can be converted for use in DOS and other applications via ASCII data format. Graphics and screen captures can be copied from Vision™ and pasted into other Windows™ applications via the Clipboard.

Converting OPD and ASCII Data Formats

The WYKO Vision™ program analyzes and stores data in OPD (optical path difference) format. This OPD format may be converted to ASCII format via a program named BLK2ASC (block to ASCII). After conversion to ASCII format, the file may be manipulated via a DOS text editor. When file manipulations are complete, the ASC2BLK (ASCII to block) program can be used to turn the ASCII file back into an OPD format file.

BLK2ASC Syntax

Use the program BLK2ASC to turn an OPD file into an ASCII file. The syntax for BLK2ASC is:

BLK2ASC   input OPD filename   output ASCII filename

For example, if the input OPD filename was `disk.opd`, at the DOS prompt you would type:

```
BLK2ASC     disk.opd   disk.txt
```

The output ASCII file would then be found in `disk.txt`.

ASC2BLK Syntax

Use the program ASC2BLK to turn an ASCII file into an OPD file. The syntax for ASC2BLK is:

ASC2BLK   input ASCII filename   output OPD filename

For example, if the input ASCII filename was `disk.txt`, at the DOS prompt you would type:

```
ASC2BLK       disk.txt            disk.opd
```

The output OPD file would then be found in `disk.opd`.

OPD Data Array Format

Part of a sample OPD to ASCII output file is shown in Table C-1. For both integer and floating point data types, invalid pixels (data points) are list as "BAD".

Header Information

Important information on measurement parameter settings is listed in the ASCII file in front of the measured output data. As shown in Table C-1, this ASCII "header" information is listed in the following format:

blockname   blocktype   elements   attribute
parameter value

- The **blockname** field specifies the name utilized for a particular parameter.
- The **blocktype** field specifies the type of ARRAY_2D block.
- The **elements** field specifies whether the item is floating point or integer format.
- The **attribute** field is used by WYKO OPD analysis programs.
- The **parameter value** field is the assigned value for the given parameter.

Table C-1. Sample OPD Output Converted to ASCII

```
            Directory            Directory          25         FFFF
            Wavelength           Float_Array_2D     1          0010
              632.8
            F_number             Float_Array_2D     1          0010
              0
            Pupil_diam           Float_Array_2D     1          0010
              95
            Gauss_apo_wx         Float_Array_2D     1          0010
              0
            Gauss_apo_wy         Float_Array_2D     1          0010
              0
            Wedge                Float_Array_2D     1          0010
              0.5
            Ref_index            Float_Array_2D     1          0010
              0
            New_modulation       Float_Array_2D     1          0010
              10
            Time                 Byte_Array_2D      8          0008
              10:05:26
            Date                 Byte_Array_2D      8          0008
              03/23/93
            Title                Byte_Array_2D      20         0001
              3.5" DISK
            Note                 Byte_Array_2D      60         0001
              WYKO MODEL 400
            Aspect               Float_Array_2D     1          0001
              0.83
            Mult                 Short_Array_2D     1          0001
              1024
            Mod_threshold        Float_Array_2D     1          0001
              7
            Window_size          Short_Array_2D     1          0001
              0
            Step                 Short_Array_2D     1          0001
              0
            RAW DATA             Array_3D           1          0001
              256       240         2
BAD     BAD     BAD     BAD     BAD     BAD     BAD     BAD     BAD     BAD
434     451     466     479     492     503     513     521     528     534
539     542     544     545     544     542     538     534     528     520
511     501     490     477     462     BAD     BAD     BAD     BAD     BAD
-347    -290    -235    -181    -128    -76     -26     22      70      117
162     206     249     291     331     370     408     445     480     514
547     579     610     639     667     694     719     744     767     789
etc...
```

For example, as shown in Table C-1, a wavelength parameter assigned a value of 632.8 nm would be listed as follows:

```
Wavelength  Float_Array_2D   1    0010
   632.8
```

OPD Data

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

```
RAW DATA          Array_3D   1     0001
 256        240         2
```

This line tells us that the array size (in pixels) is 256x240. Thus, there are 256 columns of pixels in the X direction, and 240 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 top leftmost pixel, moving down and to the right. As shown in Figure C-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 C-1, where the array size is 256x240, we have 256 columns, and 240 rows of data. Therefore, max X would be equal to 255 and max Y would be equal to 239, since we start at (0,0).

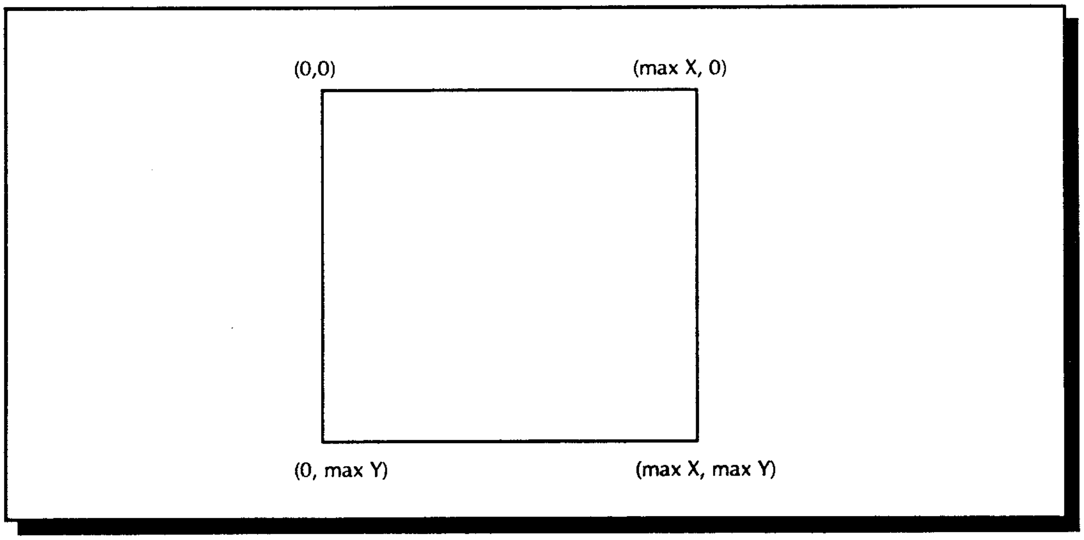


Figure C-1. Measured OPD Data Orientation

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 columns of ten, as shown in Table C-2. Thus, for our example of a 256x240 array, the first 240 data points listed in the ASCII file are the first column of pixels, (0, 0) to (0, 239). The second 240 data points stored are the second column of pixels, (1, 0) to (1, 239), etc., for a total of 61,440 data points. Thus, for this example, the first 24 rows of data in the ASCII file are the first column of measured data.

Table C-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)	(0,238)	(0,239)
(1,0)	(1,1)	(1,2)	(1,3)	(1,4)	(1,5)	(1,6)	(1,7)	(1,8)	(1,9)
.									
.									
.									
(255, 0)	(255,1)	(255,2)	(255,3)	(255,4)	(255,5)	(255,6)	(255,7)	(255,8)	(255,9)
(255,10)	(255,11)	(256,12)	(256,13)	(255,14)	(255,15)	(255,16)	(255,17)	(255,18)	(256,19)
.									
.									
.									
(255,230)	(255,231)	(255,232)	(255,233)	(256,234)	(255,235)	(255,236)	(255,237)	(255,238)	(255,239)

Converting Integer and Floating Point Data

To convert OPD integer data 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.

Exporting Graphics Via the Clipboard

Because Vision™ is a Windows™ application and is connected to the Clipboard, you can use the Clipboard to transport analysis screens in graphic format between Vision™ 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 As** and **Paste** commands, and using the PRINT SCREEN key.

☞ Graphics can also be exported from Vision™ using the **Edit » Copy To Metafile** command. This command copies the currently selected window into a file in metafile format.

Exporting Graphics Using Edit » Cut 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 doesn't matter, as long as the screen you wish to copy is the selected (highlighted) screen.

2. Select **Edit » Copy As Metafile** or **Copy As Bitmap**. Choose *Bitmap* format for Microsoft Works™ or Microsoft Draw™. *Metafile* format works best with Microsoft Write™ or Microsoft Word™.

3. Switch to your other application. If the other application is not open, start the other application. If the other application is already open, press CTRL+ESC, and then choose the application from the Task List.

4. Position the cursor where you want to insert the screen graphic.

5. 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.

Exporting Graphics Using the PRINT SCREEN Key

1. Select ALT+PRINT SCREEN, to copy the currently selected *window* to the Clipboard. Select 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. If the other application is already open, press CTRL+ESC, and then choose the application from the Task List.
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 Graphics Using Microsoft Paintbrush™

If you would like to save your analysis screen in a graphics file for importation into another application at a later time, you may do so using Microsoft Paintbrush™ or any other drawing program of your choice.

1. Copy your analysis screen using one of the two methods outlined above.
2. Open Microsoft Paintbrush™, or your drawing program of choice.
3. Select **Edit » Paste** or CTRL+V, to paste the Clipboard contents into your drawing program.
4. Select **File » Save As** to bring up the Save As dialogue box.
5. Type in the filename you want to give your graphics file, and select the file type under the Save File as Type list box.

☞ The filename you give your output file must have the correct extension associated with it. For example, if you save your file as a PCX file, it must have the extension `.pcx`. If you do not give it the correct extension, your Windows™ application will not recognize it as a graphics file.

6. Select **OK** to save your graphics file. Your file can now be imported into any compatible Windows™ program.

Appendix D

System Specifications

System

Measurement technique	Optical phase-shifting and vertical-scanning interferometry
Measurement capability	Three-dimensional surface profile measurements
Objectives	1.5X, 2.5X, 10X, 20X, 40X, and five-objective turret
Field of view	Variable, up to 8 mm (see Table D-1)
Measurement array size	Selectable (128 x 128 to 739 x 484)
Light source	Tungsten halogen lamp (user replaceable)
Stage	± 6° tip/tilt, ± 90° rotation; ± 2° in. X/Y translation
Video display	9 in. black and white monitor
Computer system	PC with Pentium™ processor, 17 in. monitor (21 in. optional), and printer
Signal output	Standard RS-170, 2:1 interlaced TV output, or CCIR
Active pixels	739 (H) by 484 (V)
Alignment system	Fringe viewing and twin spot alignment
Software	WYKO Vision™ software running under Microsoft Windows™

Performance

Vertical measurement range	0.1 nm to 500 µm
Vertical resolution	PSI: <1 Å Ra multiple, averaged measurements; 3 Å single measurement VSI: < 1 nm multiple, averaged measurements; 3 nm single measurement
Scan speed	2.4 µm/sec

Environment

Temperature range	Between 15° and 30° C
Humidity range	≤ 80%, non-condensing

Dimensions

Total system, including isolation table	60 in. W x 34 in. D x 57 in. H
Weight	230 lb; table, 400 lb

Power Requirements

Input voltages	110/220 VAC, 50/60 Hz
Power consumption	300 W
Compressed air	Range 40 to 80 psi

U.S. Patents

4,931,630; 5,133,601; 5,204,734

Table D-1. Magnification Objective Specifications

Magnification objective	1.5X	2.5X	10X	20X	40X
Interferometer type	Michelson	Michelson	Mirau	Mirau	Mirau
Numerical aperture	0.036	0.075	0.25	0.40	0.50
Working distance (mm)	18	2.0	4.0	1.9	3.9
Field of view [with magnification selector (mm)]					
0.5X	8.2 x 6.1	4.9 x 3.7	1.2 x 0.9	0.6 x 0.5	0.3 x 0.2
1.0X	4.3 x 3.2	2.6 x 1.9	0.6 x 0.5	0.3 x 0.2	0.2 x 0.1
2.0X	2.1 x 1.6	1.3 x 1.0	0.3 x 0.2	0.2 x 0.1	0.02 x 0.06
Spatial sampling limit [with magnification selector (μm)]					
0.5X	12.7	7.6	1.9	1.0	0.5
1.0X	6.6	4.0	1.0	0.5	0.2
2.0X	3.3	2.0	0.5	0.2	0.1
Surface slope limit[1] [with magnification selector (deg)]					
0.5X	0.7	1.2	4.8	9.6	19.5
1.0X	1.4	2.3	9.4	15.3	19.5
2.0X	1.5	2.8	9.4	15.3	19.5

---

[1] Assumes a theoretically smooth surface. In practice, steeper slopes may be measured because of reflections from surface microroughness.

IRQ and Address Settings

When boards are added to a computer, the board settings must be set so that no conflicts with the existing hardware settings exist. If hardware conflicts exist, inconsistent hardware performance or lock-up will occur. The DAC boards' I/O register addresses listed in Table D-2 are the default values. These can be changed via the board dip switches.

Table D-2. IRQ and Address Settings

Function/Device	Interrupt Level	Memory Address (Hex)	I/O Register Address (Hex)
System Timer	0		
Keyboard	1		060 - 06F
Cascade	2		
Serial Port 2	3		3F8 - 3FF
Serial Port 1	4		2F8 - 2FF
Parallel Port 2	5		278 - 27F
Floppy Controller	6		3F0 - 3F7, 1F0 - 1F8
Parallel Port 1	7		378 - 37F
Clock	8		070 - 07F
Reserved	9 - 12		
Math Coprocessor	13		0F8 - 0FF
Hard Disk Drive	14		1F0 - 1F8, 170 - 177
MM-96 DSP	15 (12 for IBUS)		140 - 147
PC Hydra DSP	15 (12 for IBUS)		140 - 147
VGA Board / BIOS		A0000 - BFFFF	3B4 - 3DE
Super VGA Board / BIOS (Paradise & S3)		C0000 - C7FFF	
WYKO DAC Board			380 - 387
WYKO Camera Interface			300 - 33F
WYKO Translator Control			340 - 37F
PC23 X-Y Stage Motor Control			3E0
AT6400 X-Y Stage (with tip-tilt) Motor Control			300 - 310
Video Pre-Processor		Plug and Play	Plug and Play

Note: Your system may or may not have all of the above boards installed, depending on its configuration. If you have questions, contact WYKO Customer Services at (520) 741-1297.

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

See 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 t_{p1} and t_{p2}, 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

See 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

See Summit Mean Height.

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

See Phase Shifting Interferometer.

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

See Mean Line/Surface.

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. Rmax 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_{vk}

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_{vi} 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

See Vertical Scanning Interferometer.

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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