

Specifying More Than Peak to Valley

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Abstract: This paper is an introduction to specifications and tolerances intended to more thoroughly define figure and form of precision optical elements. Specifications that will be outlined here include Mid-Spatial Frequency Wavefront Error, Slope, and PVR.

1. Mid-Spatial Frequency Error

Most models of optical systems presume ideal surfaces however; surface preparation and metrology methods lead to non ideal surfaces. Such departures from ideal form can be characterized as undulations across the surface. Sub-aperture and deterministic polishing techniques are more prone to periodic surface undulations commonly referred to as ripple or mid spatial frequency (MSF) error.

Figure 1-1 depicts one surface fabricated using sub-aperture deterministic polishing techniques. The path taken by the sub-aperture polisher is clearly visible.

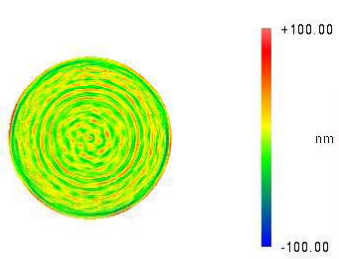


Figure 1-1 Surface fabricated using sub-aperture deterministic polishing technique.

Three key questions should be asked when specifying MSF:

- A) Is the application or design sensitive to these errors?
- B) What errors are expected for a given fabrication process?
- C) How do the errors of a given spatial frequency domain effect performance?

For most systems, these errors should not pose any significant difficulties. In cases where MSF does pose issues, bounds on the allowable error in those spatial frequency regimes should be added to optical prints. [1]

2. Slope:

Slope error specification is constructed in the following manner. For a given horizontal length, the increase or decrease in form error at the end point relative to the starting point is measured. The two values form a line, the angle it forms relative to horizontal (no form error) defines a slope: the larger the slope angle the larger the slope error. Figure 2-1 and 2-2 show how slope is measured using a small portion of the lens relative to its overall size.

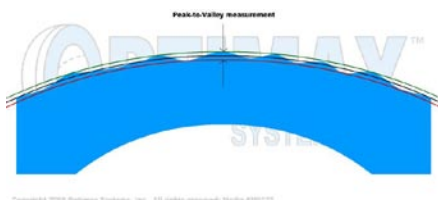


Figure 2-1 Lens cross section, peak to valley measurement.

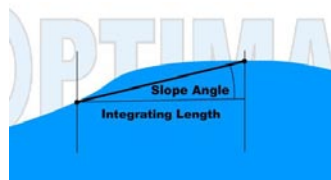


Figure 2-2 Enlarged detail

At a minimum a slope specification must contain at least an integrating length and the slope error, and sampling length is included only when needed. The metrology device must provide coverage and resolution to meet the specified integrating length. Using a table of 2-D or 3-D form error information slope error can be measured. Interferometric fringe analysis software can often perform the calculations directly. Measurements can always be made graphically, plotting the data using appropriate scale. Figure 2-3 shows the geometrical representation of a slope specification. [2]

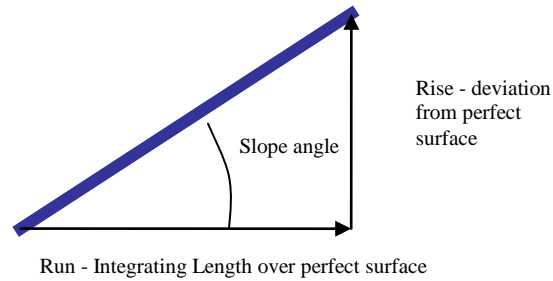


Figure 2-3 Rise to run of slope specification

3. PVR:

Peak to valley (PV) is entrenched in optics design and manufacture as a characterization of optical figure. Many modern interferometers utilize 1k X 1k detectors, the output of which may not be well represented by two points. PVR is a robust amplitude parameter that combines the PV of a 36-term Zernike fit and the root mean square (RMS) of the residual surface error. This provides automatic filtering, is insensitive to system resolution, relates directly to system performance, and maintains the “ideal” 5:1 PV to RMS ratio.

Dramatic improvements in optical fabrication and metrology have rendered PV a troublesome parameter to use when specifying form and figure. Sub-aperture deterministic polishing methods, computer controlled polishing and diamond turning produces surfaces that do not necessarily approximate the 5:1 PV to RMS rule. High resolution interferometers “see everything” such that small defects may be resolved that may not have an impact on imaging performance. Correlation among different interferometers is difficult to obtain and is dependent upon instrument resolution and the frequency content of the surface. [3]

Traditional metrology methods necessitate masking small defects thereby significantly reducing the number of data points obtained by the instrument. By using PVR, the number of points removed from the data set is greatly reduced resulting in a robust measurement. Table 3-1 shows data from a sample surface measured on four interferometers with varying resolution. As one would suspect PV among the instruments decreases as resolution becomes more course. PVR data however remains virtually unchanged.

Detector Resolution	PV, nm	PVR, nm
1024x1024	53.81	39.46
512x512	38.27	39.41
256x256	36.88	39.33
128x128	33.9	39.19

Table 3-1 Sample surface data from four instruments

While not the “cure all” for all interferometric metrology, PVR does capture the detailed aspects of optical function needed when specifying form and figure of optical surfaces.

[1] David M. Aikens, Jessica E. DeGroot-Nelson, Richard N. Youngworth “*Specification and Control of Mid-Spatial Frequency Wavefront Errors in Optical Systems*”

[2] Brandon Light, Optimax Systems Inc. “*Specifying and Measuring Slope Error of Optical Surfaces*”

[3] Chris J. Evens, Zygo Corporation “*PVR-A Robust Amplitude Parameter for Optical Surface Specification*”