APPLICATION NOTE

PVr – A Robust Amplitude Parameter

Introduction

It is a well-established practice in optics manufacturing to specify optical surfaces based on the peak-to-valley(PV) departure from nominal surface shape. PV is defined as the height difference between the highest and lowest points on the surface after removal of piston and tilt for flats, after a best-fit sphere for spherical surfaces, and after removing the nominal asphere in aspheric metrology.

The increase in spatial resolution in interferometers has resulted in more artifacts being visible in a measurement. In addition, the difference in resolution from system to system results in a wide range of noise characteristics across metrology equipment. In an effort to generate a "realistic result," the metrologist will often attempt to manually remove pixels of data that incorrectly drive the PV. This usually results in the potential for a large variation in the reported PV of a surface across operators and instruments.

To counter these issues, PVr – A Robust Amplitude Parameter, has been developed. This application note provides an overview of PVr and describes the benefits in using PVr to specify optical surfaces.

The Problem with PV and Modern Optical Manufacturing

The PV result is driven by the highest and lowest pixels and is biased by noise, often producing a result that is not representative of actual surface form. When selectable filtering is used to modify artifacts or noise, it is not easy to ensure measurement reproducibility.

In addition to the above conditions, dramatic changes in optical fabrication and metrology methods over the past two decades have made PV a troublesome parameter to use when buying and selling optics. Small tool fabrication processes such as MRF, computer controlled polishers, diamond turning, etc., do not necessarily produce surfaces that approximate the 5:1 rule for PV/rms.

Small artifacts in the measured surface have little or no impact on the imaging performance of an optical system can be resolved with interferometers that utilize high resolution cameras.

The lack of standards for frequency cut-offs, filters, and outlier rejection, techniques often used to remove questionable pixels of data, make it nearly impossible to achieve acceptable measurement reproducibility. Differences in instrument resolution and the frequency content of the test surface can also contribute to measurement variations from one interferometer to another.

The Advantages of PVr

The major advantage of PVr over PV is that it provides a repeatable result that is independent of instrument resolution and user variability. This is achievable because PVr is largely insensitive to differences in detector sensitivty making it possible to characterize high resolution data from modern instruments and correlate it to metrology from older systems that have low resolution cameras. Since PVr has low sensitivity, "standardized" filtering is not required.

Fitting Zernike polynomials to optics with circular apertures is extremely robust even on relatively sparse data sets. When a fit to the 36 term set is performed, it efficiently captures the

PVr – A Robust Amplitude Parameter

- A repeatable method for specifying optical surfaces
- Low sensitivity to noise and detector resolution
- PVr application available in MetroPro™ 8.3
- Reduces instrument to instrument variability

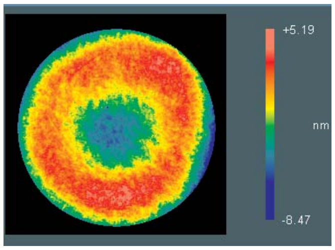
low order aberrations – the very aberrations that tend to dominate the figure of most optics. The rms of the residual after the fit to 36 terms is equally robust, and this adds a characterization of the mid-spatial frequencies in the surface. Therefore, PVr for circular apertures is defined as:

$$PVr = PV_{36Zernikes} + 3 \times \sigma_{36\ ZernikeResid}$$

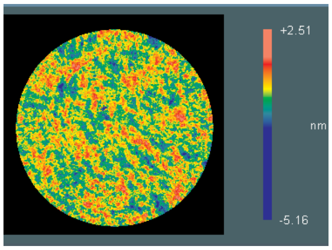
The first term in the above equation is the PV of the surface generated using the 36 term Zernike fit to the data. The second term is 3 times the rms of the residual after fitting and removing the 36 terms.

Data from a 150 mm reference flat shown below was measured with a ZYGO VeriFire™ AT interferometer, with a 1K x1K detector. The PV of the surface generated from the 36 term Zernike fit is 10.0 nm and the rms of the residual is 0.5 nm, hence:

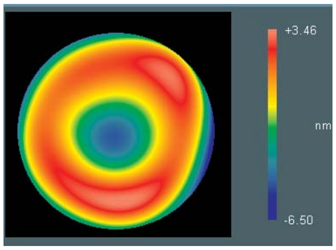
$$PVr = 10.0 + 3 \times (0.5) = 11.5\ nm$$



Original Raw Data
PV = 13.7 nm, rms = 2.1 nm



Residual after 36 Term Fit
PV = 7.7 nm, rms = 0.5 nm



Generated Surface from Fit
PV = 10.0 nm, rms =2.1 nm

What Makes PRv Robust?

PVr is detector independant and reasonably insensitive to noise, specifically from small defects. By describing the surface via its Power Spectral Density function and then applying a 36 term Zernike fit, the underlying, low order, optical surface figure is captured. This represents the bulk of the surface amplitude.

The table shows the relationship of detector resolution to PV and PVr for a 300 mm flat optic. It shows the effect of reducing pixel resolution computationally on PV and PVr. Note the stability of the PVr as the detector resolution is changed.

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

PVr as a Surface Specification Standard

For circular apertures, PVr is easily computed using functions readily available in commercial interferometer software. It is currently under review to be included in the ISO Standard.

When using PVr as a surface specification parameter, along with the basic definition of PVr described in this application note, two constraints should be kept in mind. PVr should be less than PV. There are cases in which large and spatially varying noise gives a large residual rms without affecting the PV. And in the limiting case of extremely good optics, the calculation of 3 times the residual may have to be readjusted to 6 times the residual; otherwise there may be an unacceptably large number of data points falling outside the range characterized by PVr.

Conclusion

PVr is a robust, repeatable amplitude specification for optical surfaces. It eliminates the need to manually intervene in a traditional PV result. PVr simplifies specification of mainstream optical surfaces and can reduce disagreements about surface characterizations made on different instruments.

PVr will not solve all optical specification requirements as it does not capture detailed aspects of optical functions for particular applications. Other functional specifications (rms, slope, PSD, structure function, etc.) are likely to have better correlation with specific surface functionality.

For more information on PVr, or a copy of ZYGO's technical paper on PVr, contact your ZYGO representative.

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