

Scanning Pupil Tolerancing

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Abstract: The tolerancing of lens systems has become more complex as system requirements tighten. The tolerancing of just the center thicknesses, surface radii, and surface irregularity are no longer sufficient for optical elements. This paper focuses on a new method to tolerance optical surfaces. There have been many papers written about different methods to tolerance optical surfaces which look to limit the artifacts left by different fabrication processes. The method proposed in this paper focuses on tolerancing to meet system performance, not the fight against the surface fingerprint of a particular fabrication process.
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1. Introduction

There have been many excellent papers on how to tolerance optical surfaces. As different methods of generating optical surfaces have developed, fabricators have created different residual artifacts. The optical designers often sought perfect surfaces by tolerancing whatever residuals the fabricator created. Many papers discuss tolerancing the peak-to-valley of the errors, power spectral density, and surface slope errors [1-4].

All methods of manufacturing optical elements produce some type of surface figure errors [5]. Using optical design programs, one may easily model these surface errors. Such surface errors are often low frequency. This paper discusses a method of surface tolerancing which addresses these common manufacturing errors. The tolerancing is based upon system level performance parameters set by the end user. The ideal tolerances are ones which limit manufacturing errors that would cause unacceptable system performance, not ones that place unnecessary burdens on the optical fabricators.

Localized slope errors on surfaces can impact performance in small parts of the field. Localized errors can cause problems not evident in some testing. Consequently, localized errors may be very costly. Examining and understanding the impact of these types of defects may prevent significant problems. Through the modeling outlined in this paper, we are able to develop methods to evaluate the performance degradation for local surface errors.

The problem with having tolerances which do not have a direct correlation to a system parameter is that they will often need to be overly tight. We have seen this with tolerances which allow various surface defects which pass a certain tolerance, but have various impacts to the system parameters [6]. The tolerancing method proposed here focuses more on tolerancing for the system performance, and does not focus on any specific manufacturing errors that result from a certain process of fabrication.

2. Scanning instantaneous pupil

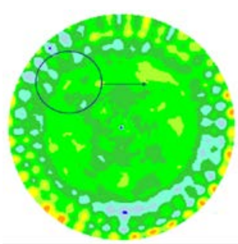

Fig. 2 Instantaneous pupil scanned over interferogram covering the clear aperture

The instantaneous pupil is defined as the pupil size at the surface of the optic for a given field point. Often this pupil size is a constant over the entire surface. The designer achieves the tolerancing by fitting the surface error over the instantaneous pupil to a polynomial set. Certain coefficients of this polynominal can then be directly correlated to a system level parameter, i.e. distortion or field flatness. The designer then can tolerance these coefficients to control the system's performance. This instantaneous pupil and the associated fitting/tolerancing are then scanned over the entire surface.

As an example of how to fit and tolerance over the instantaneous pupil we can look at two common system parameters, distortion and image flatness. High performance systems require tight control over these parameters. The distortion of a small area of the field is controlled by the surface slope errors over the instantaneous pupils that correspond to just that field point. More specifically, if the surface over just the instantaneous pupil is tilted, a localized distortion will result.

If we wish to limit localized focus shifts in the field, we must look at changes of power in the corresponding instantaneous pupils. Figure 3 depicts such changes of power. A small bump or hole in the center of an optic with a diameter that nearly matches the size of the instantaneous pupil will have an effect on the focus of the center field point, and an effect on the distortion around this field point.

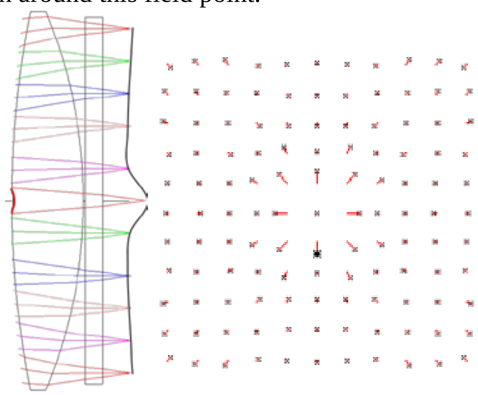

Fig. 3 Illustration of a defect and its result on the image plane

3. Limitations

Although we have found this method of tolerancing to be beneficial, it does have limitations. Because it is tied to the instantaneous pupil on the surface, there is not significant benefit to surfaces which are near the aperture stop or a conjugate to the stop. The polynominal fit of the surface departure in the scanning instantaneous pupil will help with some mid spatial frequencies. It will not cover some of the higher frequency errors. These errors are more likely to cause scatter problems in an optical system.

4. Summary

The tolerancing method presented has been found to be beneficial in the tolerance of optical surfaces of high precision optical systems. Because of the instantaneous pupil being tied to the specifications placed on the surfaces, the method is most useful for surfaces away from the aperture stop. By finding a direct relationship between a surface specification and a critical system parameter, we are able to apply tolerances which help produce good systems, without placing needlessly tight tolerances on a surface.

5. References

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