Wavefront Distortion

Sometimes the best specification for an optical component is its effect on the emergent wavefront. This is particularly true for optical flats, collimation lenses, mirrors, and retroreflectors where the presumed effect of the element is to transmit or reflect the wavefront without changing its shape. Wavefront distortion is often characterized by the peak-to-valley deformation of the emergent wavefront from its intended shape. Specifications are normally quoted in fractions of a wavelength.

Consider a perfectly plane, monochromatic wavefront, incident at an angle normal to the face of a window. Deviation from perfect surface flatness, as well as inhomogeneity of the bulk material refractive index of the window, will cause a deformation of the transmitted wavefront away from the ideal plane wave. In a retroreflector, each of the faces plus the material will affect the emergent wavefront. Consequently, any reflecting or refracting element can be characterized by the distortions imparted to a perfect incident wavefront.

INTERFEROMETER MEASUREMENTS

CVI Melles Griot measures wavefront distortion with a laser interferometer. The wavefront from a helium neon laser (λ=632.8 nm) is expanded and then divided into a reference wavefront and test wavefronts by using a partially transmitting reference surface. The reference wavefront is reflected back to the interferometer, and the test wavefront is transmitted through the surfaces to the test element. The reference surface is a known flat or spherical surface whose surface error is on the order of $\lambda/20$.

When the test wavefront is reflected back to the interferometer, either from the surface being tested or from another $\lambda/20$ reference surface, the reference and test wavefronts recombine at the interferometer. Constructive and destructive interference occurs between the two wavefronts. A difference in the optical paths of the two wavefronts is caused by any error present in the test element and any tilt of one wavefront relative to the other. The fringe pattern is projected onto a viewing screen or camera system.

A slight tilt of the test wavefront to the reference wavefront produces a set of fringes whose parallelism and straightness depend on the element under test. The distance between successive fringes (usually measured from dark band to dark band) represents one wavelength difference in the optical path traveled by the two wavefronts. In surface and transmitted wavefront testing, the test wavefront travels through an error in the test piece twice. Therefore, one fringe spacing represents one-half wavelength of surface error or transmission error of the test element.

A determination of the convexity or concavity of the error in the test element can be made if the zero-order direction of the interference cavity (the space between the reference and test surfaces) is known. The zero-order direction is the direction of the center of tilt between the reference and test wavefronts.

Fringes that curve around the center of tilt (zero-order) are convex as a result of a high area on the test surface. Conversely, fringes that curve away from the center of tilt are concave as a result of a low area on the test surface.

By using a known tilt and zero-order direction, the amount and direction (convex or concave) of the error in the test element can be determined from the fringe pattern. Six fringes of tilt are introduced for typical examinations. CVI Melles Griot uses wavefront distortion measurements to characterize achromats, windows, filters, beamsplitters, prisms, and many other optical elements. This testing method is consistent with the way in which these components are normally used.

INTERFEROGRAM INTERPRETATION

CVI Melles Griot tests lenses with a noncontact phase-measuring interferometer. The interferometer has a zoom feature to increase resolution of the optic under test. The interferometric cavity length is modulated, and a computerized data analysis program is used to interpret the interferogram. This computerized analysis increases the accuracy and repeatability of each measurement and eliminates subjective operator interpretation.

Laser interferometer