Wavefront aberration measurement by the reverse Hartmann test

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Wavefront aberration (WFA) indicates the optical path difference between the actual and ideal wavefront. Although as a concept in physical optics, it can be expressed by the Zernike polynomial, and divided into geometric aberrations such as power, comet, astigmatism, etc. Thus, WFA is an important term in optical performance evaluation for optical systems. From the rough processing to the precise processing of optical systems, the WFA may vary from 100 microns to 100 nanometers. A measurement method with a high dynamic range is urgently needed for in-time evaluation and compensation during the manufacturing process. Nowadays the WFA measurement methods are primarily divided into two categories: interferometric measurements and non-interferometric measurements. Interferometric methods such as laser interferometry, have high accuracy but are limited in application due to their stringent environmental requirements, low dynamic range, and surface quality. Non-interferometric measurement methods utilize ray tracing to acquire normal vectors on the actual wavefront, integrating to form the actual wavefront, such as Ronchi grating and Shack-Hartmann test. These non-interferometric measurement methods have the advantages of strong vibration resistance and high dynamic range, their low accuracy and resolution are significant disadvantages. The methods above can't be used in whole stages of manufactured optical systems. The reverse Hartmann (RH) test, which traces light rays in the opposite propagation direction and calculates the wavefront direction vectors, is a burgeoning method for WFA measurement. To achieve light ray tracing, the RH test only needs a screen displaying a series of fringes and a camera to capture images. Based on the phase matrices calculated on pixels of the screen and camera, an accurate mapping model between pixels of the screen and camera is built, and light ray vectors are determined. Our research focuses on modeling the whole RH test system and analyzing the influence forms of different errors. A series of optical alignment methods are also put forward to enhance the accuracy of optical alignment in the RH test. For focal optical systems, a pinhole camera is used to avoid the influence of lens aberration, while for afocal systems, a measurement setup with a telecentric lens is used to meet the light propagation. Because of the high dynamic range and miniaturized size of the RH test, it is convenient to achieve in-time WFA measurements. We have used this technique in the ultra-precision machining of a monolithic double-surface workpiece. During this process, we measure the WFA of the workpiece after primary precision machining. Then several process improvements are proposed and used in precision machining compensation. Finally, the WFA of the workpiece is reduced. We will also use this technology to guide and improve the polishing process of monolithic multi-surface workpieces in the future.