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Noncontact alignment and spacing of optics

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Abstract

The performance of individual optics and of optical systems is sensitive to surface figure, to inter-element optic spacing and to the precise spatial location of figure defects. However, it is seldom practical during the manufacturing process to make detailed measurements each time one wants to test the optic. In this paper, we describe some simple, yet accurate tests which are appropriate to the constraints of a manufacturing environment. For testing surface figure and optical-element spacing, a test using a system of lenses is described. The problem of locating defects in a complicated piece, such as an aspheric, can be solved using an array of corner cubes. Since the intensity of the return beam from the corner cubes is much greater than that from the optic under test, there is no way to be confused by artifacts. Moreover, the accuracy of this method for surface mapping is good. Some problems with the practical implementation of these tests are also discussed.

Introduction

In the course of manufacturing a high quality, fast aspheric convex surface a Hindle type test, first used by Simpson-Oland and Meckel,[1] was used for testing the aspheric. The figure quality required for the aspheric is approximately the quality of the Hindle cavity. This requires a coherent subtraction of each optical surface of the Hindle tester from the final interferograms. Because of this, each surface of the Hindle test, including the aspheric, must be fiducialed so as to separate surface errors on the aspheric from errors in the test equipment. To solve this critical mapping problem a corner cube system for each surface in the test was designed. An unambiguous mapping of each surface was created using five cubes for each surface. We will discuss the tolerances required for the cubes manufacture and present photograph and interferograms of the system.

The requirements for spacing the aspheric being manufactured to the Hindle Shell are very tight- on the order of several microns. The spacing tolerance would normally require a calibrated spacer bar to be used for each test of the aspheric. This is quite clumsy and dangerous as in the final stages of manufacture the optician may require testing several times a day. To get around this difficulty a double lens was designed that sits on the Hindle Shell convex surface. The lens autofocuses at the aspheric surface and is adjusted such that the spacing is correct between shell and aspheric when straight fringes are seen across the spacer lens at the image plane of the interferometer. Tolerances on the lens will be presented with interferograms showing the lens in use.

Corner Cube System

The requirements for the fiducials are that they give an unambiguous reference to the surface being fiducialized. This means that the fiducials must be of different optical contrast to the rest of the surface being mapped. Corner cubes are perfect for this because they have the property that they return all the light that strikes them in the direction from which it came. Therefore in a multielement system the cubes will show up as small bright hot spots.

Because there are so many surfaces that need to be mapped in our test, each surface must be easily recognized with the fiducials. It was decided to do this in two ways. First each surface's corner cubes were mounted in a delrin ring with a unique radius (to the center of the cubes) for each surface. Secondly five corner cubes were used and they were arranged as follows. Four of the cubes were placed 90° to each other at the points of a compass. (N,S,E,W). The fifth cube was placed at unique angle for each surface, as measured from the compass point west towards the south. See the example in Figure 1. Also see the photograph of the ring in Figure 2.

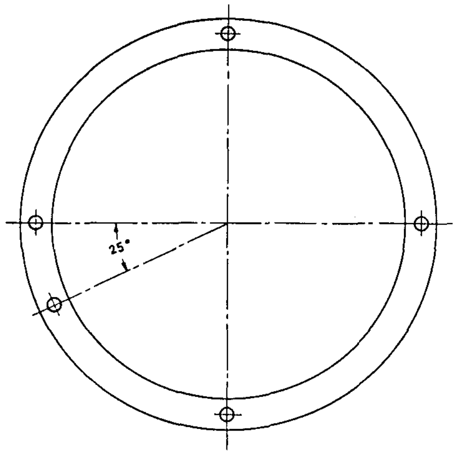

Figure 1. Hindle Shell Concave Surface Fiducial Ring

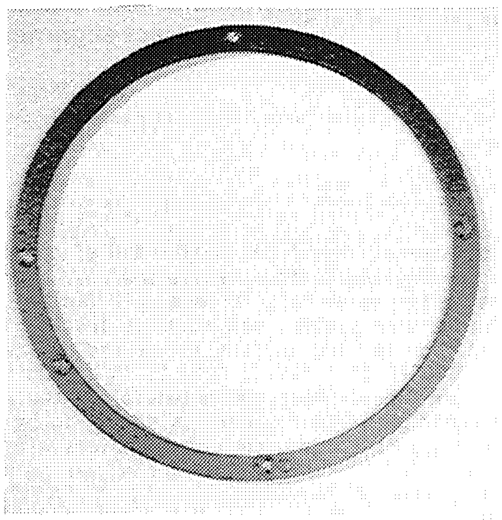

Figure 2. Fiducial Ring

The design feature of the retro-reflectors which allows this is the machining of a convex lens surface on a corner cube reflector. This surface collimates the light emanating from the CORI. Since the retro cube returns the collimated light with no perturbation in incidence angle the convex surface refocuses this beam to its original location. The CORI images the secondary's surface onto its internal reference surface and it will also image the retrocube apertures. Though the aperture of the cubes is 8mm. and the f/number is 750 their images are not diffracted in the interferogram but are crisp and round spots. If the cubes were not crowned the cone of light returning from them would be 16mm. wide at the CORI objective and the image of them would not be as bright since it would not contain all the energy originally delivered to the cube. Moreover, since the virtual source being reimaged is located at twice the distance of the secondary clear aperture, it is not imaged properly but appears as a diffraction pattern, slightly misfocused. These facts are especially important for those cubes on the underside of the beamsplitter. In this case the source for the cubes is only 700mm. away and virtually no light would make its way back to the CORI. See Figure 3 and 4.

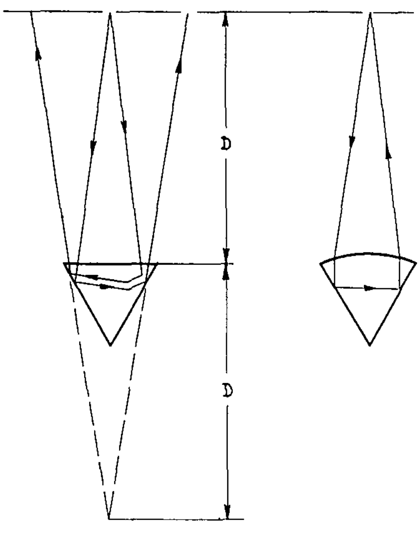

Figure 3. Ray Diagrams of Cubes

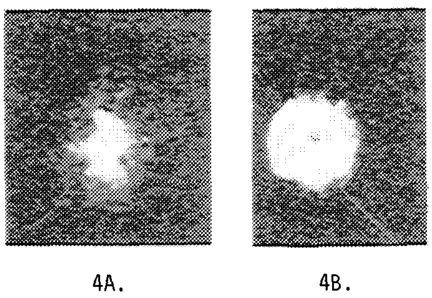

Figure 4A. Image Of Normal Cube   4B. Image of Cube with Radius

In specifying the manufacturing tolerances for these cubes, use is made of work done by P. Yoder.[2] In this paper the deviation angles of the exiting beams of a retro-prism are expressed as a function of the deviation angles of the back faces of the prism. For the worst case, where all three faces deviate by a angle θ the deviation of the beam at each exit facit is n3.26 θ. Due to the CORI's imaging of the retro reflector aperture onto its film plane, any deviation in the beam from the cubes are refocused without lateral mishaping of the image. The only uncorrectable beam distortion is vignetting. This will reduce the intensity of the image of the reflector and the images resolution in the meridian of the vignetting (due to reduced apparent aperture). In the system mentioned above the central ray for the reflectors at the edge of the system aperture was imaged one millimeter from the edge of the interferogram (the same as the interferometer aperture). The system distance was 6m. and the vignetting angle was 1/1600 = 35 sec. Using formula (1) this means the prism faces must be true to 7 sec. They were made to 5 sec. or better and are well resolved in the interferogram.

$$\theta = 0.307\ ^{\delta}/n \text{ where } \delta = 35 \text{ sec and } n = 1.472. \qquad 1)$$

The advantage of these optics, in this situation are:

1) Being retro optics they always return light to its source and are always visible inspite of source misalignment.

2) They are imaged in the same plane on the tested surface and hence their images are located to the precision of the fixtures which hold them.

3) Due to the crown on the surface of the reflectors light flux is conserved on return to the source.

Spacing lens

As discussed in the introduction there was a very stringent spacing requirement between the Hindle Shell and the aspheric. For inprocess testing a spacer bar would have been slow and dangerous. The aspheric being made had a small central obscuration in the central region. Therefore a small well corrected lens was designed to be placed on the center of the convex side of the Hindle Shell. See Figure 5.

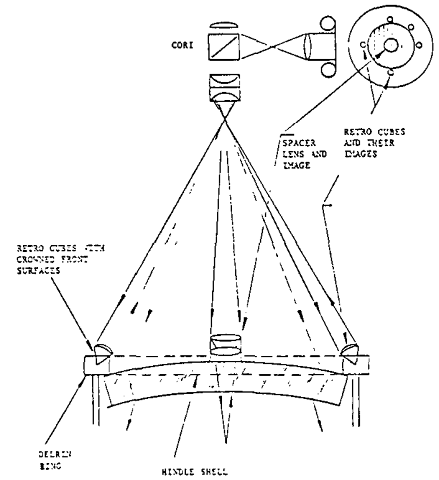

Figure 5. Hindle Shell And Alignment Fixturing

The spacing must be done to better than 12 microns. The lens was designed to autofocus off the surface of the aspheric. The focus of the lens is the correct spacing plus the axial thickness of the shell. The f number of the lens is approximately f/4.5. This means that the defocus error for $\lambda/4$ is 12 microns, this meets the requirement especially if the power is controlled to say, $\lambda/10$ or better. The lens system is a two element aplanatic lens with each surface required to be smooth to $\lambda/10$ or better. This insures that the non straightness of fringes is due to incorrect spacing, not aberration of the lens. This spacing is first adjusted with a spacer bar and the lens is adjusted to remove all power and spherical. Adjusting the spacing until the power is better than $\lambda/10$ will insure correct spacing of the aspheric from the Hindle Shell. The lens as seen through the interferometer has straight fringes when the shell spacing is at the correct distance from the aspheric. See Figure 6.

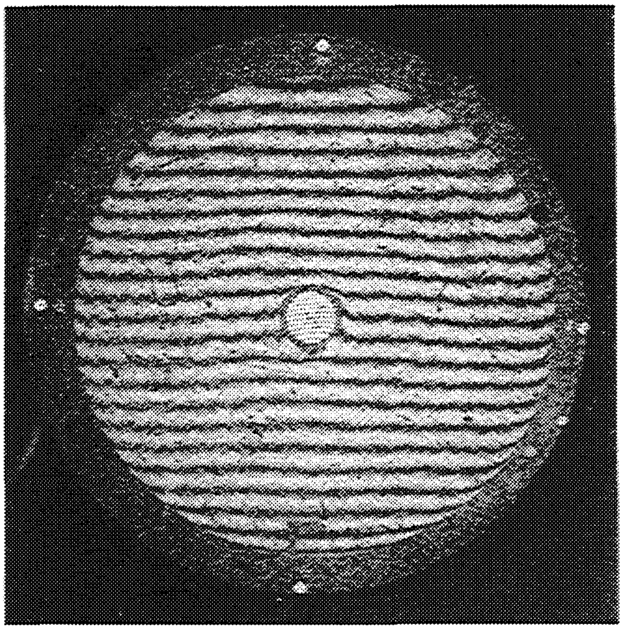

Figure 6. Interferogram Showing Spacer Lens And Fiducials

Conclusion

We have found the systems described above as useful for fiducializing and spacing an actual optical system. The format of the system is presented so that all the information of the test is viewed simultaneously - spacing, fiducials and surface quality of the test piece are all on the same interferogram.

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References

1. Simpson, F.A., B.H. Oland, and J. Meckel, "Testing Convex Aspheric Lens Surfaces with a Modified Hindle Arrangement", Opt. Eng. 13, G101 (1974)
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