Part 5
Testing of Aspheric Surfaces

- Description of aspheric surfaces
- Techniques for testing aspheric surfaces
- Requirements for use of optical analysis software in optical testing
- Limitations of current aspheric testing techniques

Aspheric Surfaces

Aspheric surfaces are of much interest because they can provide

- Improved performance
- Reduced number of optical components
- Reduced weight
- Lower cost

Conics

A conic is a surface of revolution defined by means of the equation

$$s^2 - 2rz + (k+1)z^2 = 0$$

Z axis is the axis of revolution. k is called conic constant. r is the vertex curvature.

$$s^2 = x^2 + y^2$$

Sag for Conic

$$z = \frac{s^2 / r}{1 + [1 - (k+1)(s/r)^2]^{1/2}}$$

$$s^2 = x^2 + y^2$$

Sag for Asphere

$$z = \frac{s^2 / r}{1 + [1 - (k+1)(s/r)^2]^{1/2}} + A_4 s^4 + A_6 s^6 + \ldots$$

$$s^2 = x^2 + y^2$$

k is the conic constant

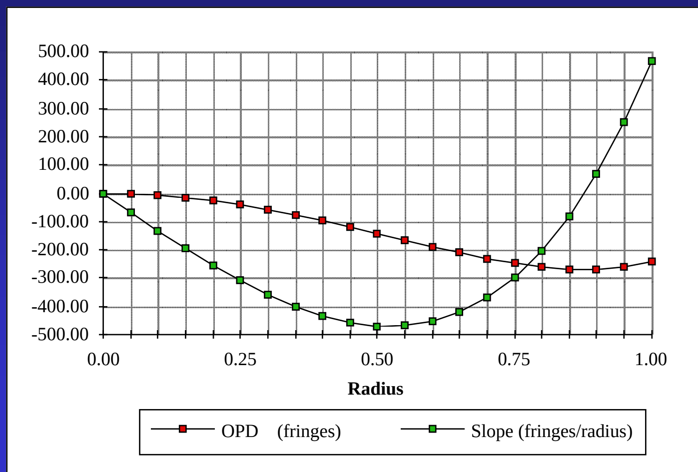
r is the vertex radius of curvature

A's are aspheric coefficients

Difficulty of Aspheric Test

Slope of aspheric departure determines difficulty of test

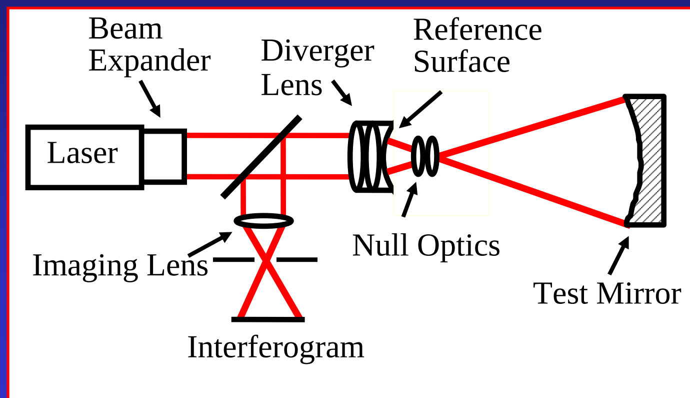
Wavefront Departure and Slope versus Radius



Aspheric Testing Techniques

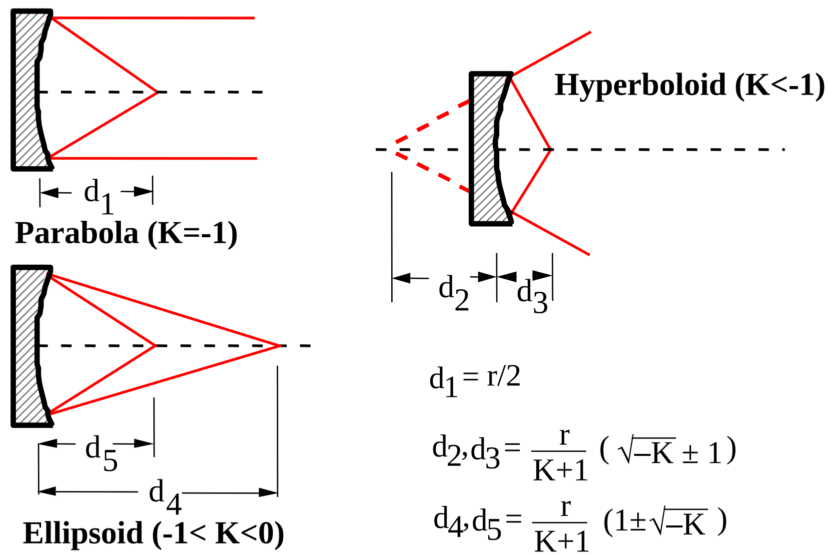
- **Null Tests - Perfect optics give straight fringes**
  - **Conventional null optics**
  - **Holographic null optics**
  - **Computer generated holograms**
- **Non-null Tests - Even perfect optics do not give straight fringes**
  - **Lateral shear interferometry**
  - **Radial shear interferometry**
  - **High-density detector arrays**
  - **Sub-Nyquist interferometry**
  - **Long-wavelength interferometry**
  - **Two-wavelength holography**
  - **Two-wavelength interferometry**

Conventional Null Optics



Hubble Pictures (Before and After the Fix)

Null Tests for Conics

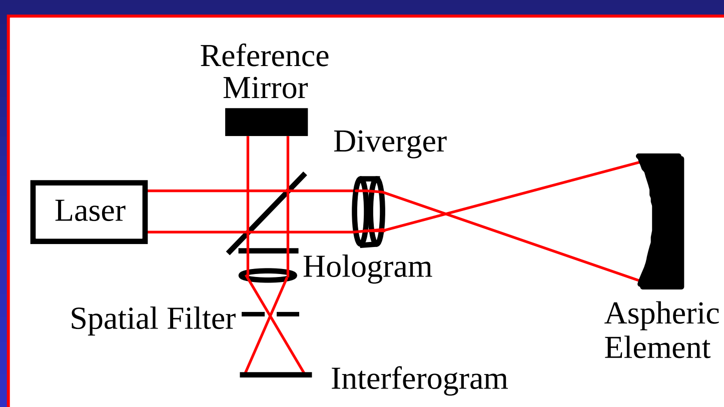


$$d_1 = r/2$$

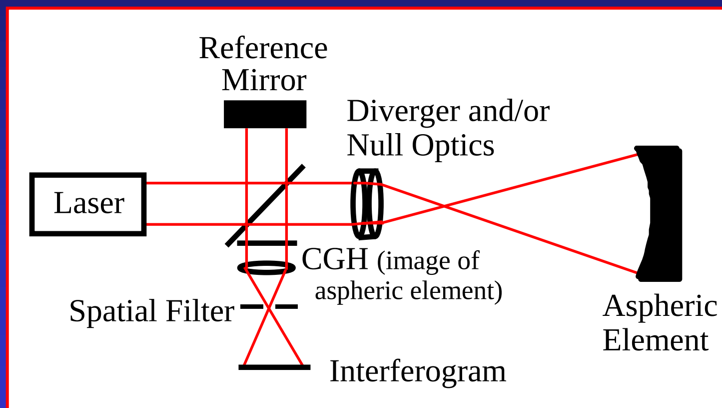
$$d_2, d_3 = \frac{r}{K+1}\left(\sqrt{-K} \pm 1\right)$$

$$d_4, d_5 = \frac{r}{K+1}\left(1 \pm \sqrt{-K}\right)$$

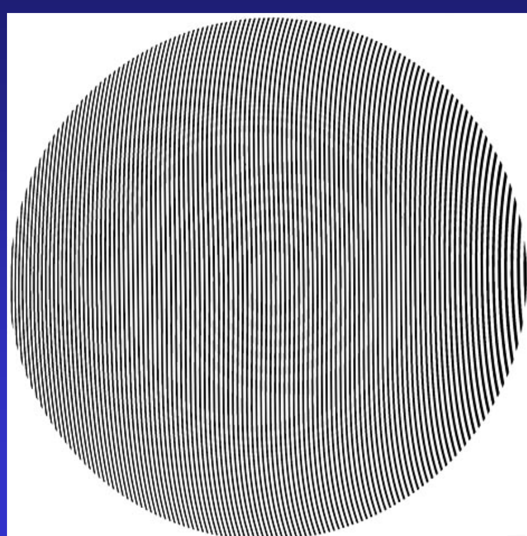
Holographic Null Optics



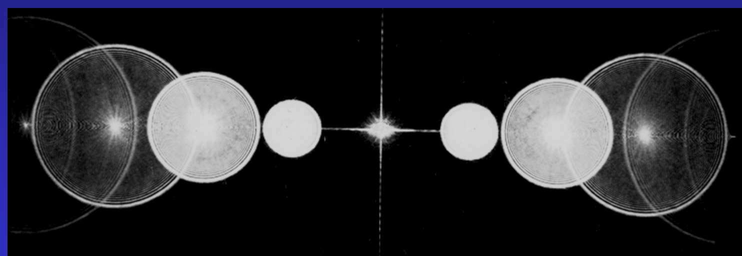
CGH Interferometer



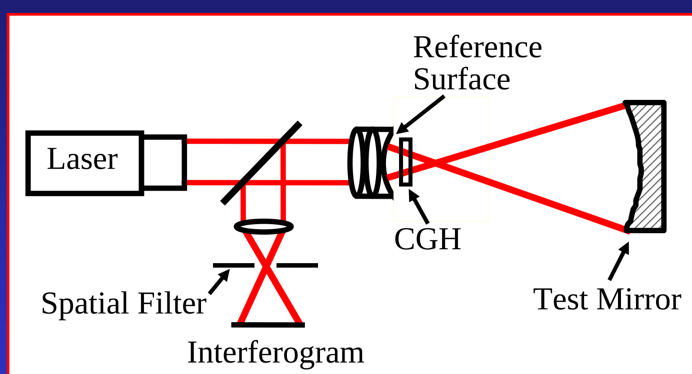
Computer Generated Hologram



Light in Spatial Filter Plane



CGH Used as Null Lens



- Can use existing commercial interferometer
- Double pass through CGH, must be phase etched for testing bare glass optics
- Requires highly accurate substrate

Error Source

- Pattern distortion (Plotter errors)
- Alignment Errors
- Substrate surface figure

Pattern Distortion

- The hologram used at *m*th order adds *m* waves per line;
- CGH pattern distortions produce wavefront phase error:

$$\Delta W(x,y) = -m\lambda \frac{\varepsilon(x,y)}{S(x,y)}$$

$\varepsilon(x,y)$ = grating position error in direction perpendicular to the fringes;

$S(x,y)$ = localized fringe spacing;

For m = 1, phase error in waves = distortion/spacing

0.1 µm distortion / 20 µm spacing -> λ/200 wavefront

Plotters

- E-beam
  - Critical dimension – 1 micron
  - Position accuracy – 50 nm
  - Max dimensions – 150 mm
- Laser scanner
  - Similar specs for circular holograms

Calibration of Plotter Errors

- Put either orthogonal straight line gratings or circular zone plates on CGH along with grating used to produce the aspheric wavefront
- Straight line gratings produce plane waves which can be interfered with reference plane wave to determine plotter errors
- Circular zone plates produce spherical wave which can be interfered with reference spherical wave to determine plotter errors

Solving Substrate Distortion Problems

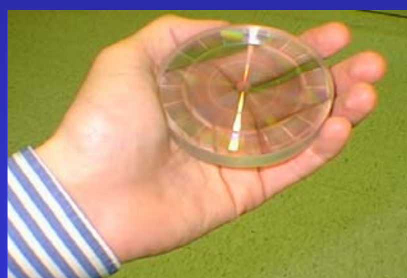
- Use direct laser writing onto custom substrates
- Measure and back out substrate
- Use an optical test setup where reference and test beams go through substrate

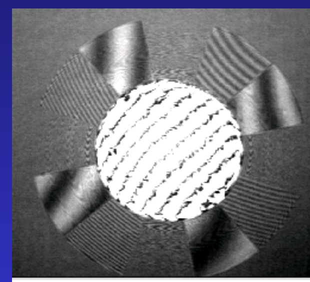
Alignment Errors

- Lateral misalignment gives errors proportional to slope of wavefront
- Errors due to longitudinal misalignment less sensitive if hologram placed in collimated light
- Alignment marks (crosshairs) often placed on CGH to aid in alignment
- Additional holographic structures can be placed on CGH to aid in alignment of CGH and optical system under test

Use of CGH for Alignment

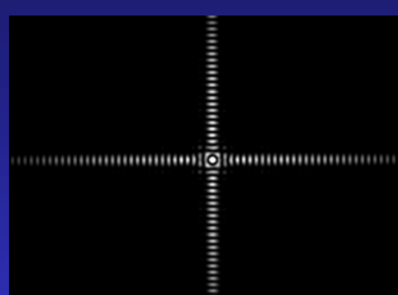
- Commonly CGH's have patterns that are used for aligning the CGH to the incident wavefront.





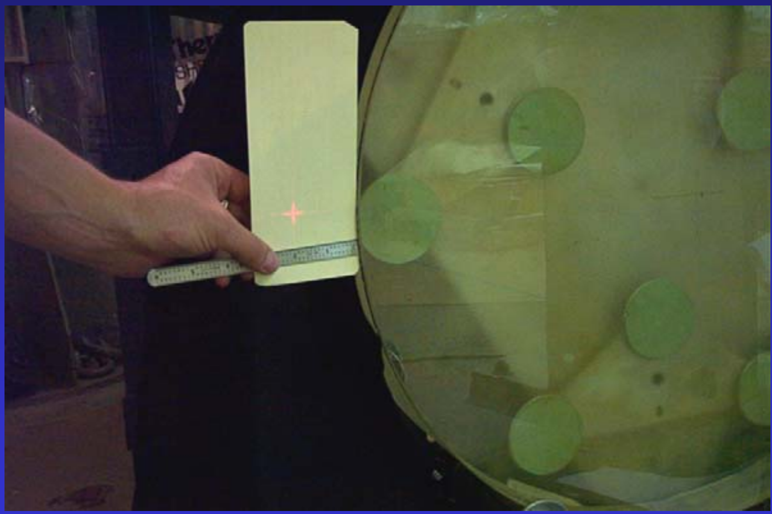
Using multiple patterns outside the clear aperture, many degrees of freedom can be constrained using the CGH reference.

Projection of Fiducial Marks

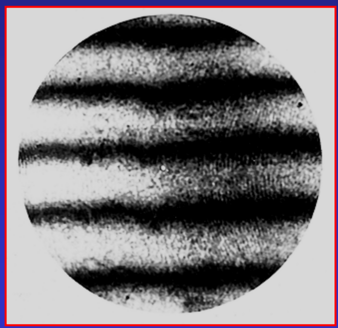


- The positions of the crosshairs can be controlled to micron accuracy
- The patterns are well defined and can be found using a CCD
- Measured pattern at 15 meters from CGH. Central lobe is only 100 μm FWHM

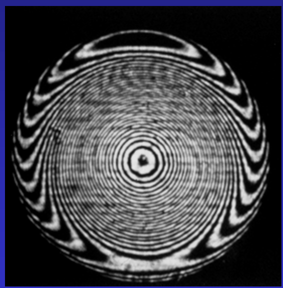
CGH Alignment for Testing Off-Axis Parabola



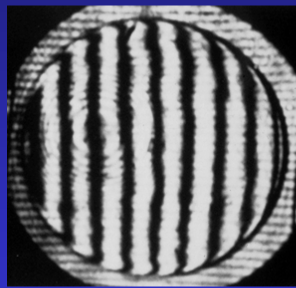
Holographic test of refractive element having 50 waves of third and fifth order spherical aberration



CGH test of parabolic mirror



No CGH



CGH

Lens Analysis Software

- Must know precisely how optics in test setup change aspheric wavefront.
- Must know effects of misalignments, so errors due to misalignments can be removed.

Basic Limitations of Aspheric Testing

- Must get light back into the interferometer
- Must be able to resolve the fringes
- Must know precisely the optical test setup

This is the most serious problem