Curved Surface Testing

CS-1

The interferogram shown below was obtained using the Twyman-Green interferometer to test a cheap camera lens in double pass. The camera lens is f/1.7 with a focal length of 50 mm.

a) Draw a schematic diagram and carefully explain the alignment procedure you would use to test the lens.

b) How good is the lens? What are the predominant aberrations? What is the approximate magnitude of the lens aberration? Comment upon whether you think the aberrations are in the design or fabrication errors. Be sure to give your reasons.

c) If the test arm of the interferometer is shortened, the fringes move up in the interferogram. What are the signs of the aberrations - i.e., for various zones is the optical path through the lens too large or too small?

d) Make a rough calculation as to the geometrical blur size for a point object.

e) What f/number should be used to obtain no more than 1/4 wave of aberration?

f) Is this an acceptable lens? Explain.

CS-2

In the optics shop we are making some aspheric collimating lenses. If we use a LUPI (Twyman-Green) to test these lenses in double pass we have to worry about off-axis aberrations introduced by tilting the lens during the test.

a) We claim that we can reduce the effect of misalignment by subtracting coma in the data reduction. However, if we subtract coma, we should also subtract some astigmatism. Why?

b) If we have a 30 cm diameter, 1.2 m focal length BK7 lens bent for minimum spherical aberration and we subtract 2 waves of coma, approximately how much astigmatism should we subtract? The wavelength is 633 nm.

c) What if only 0.2 waves of coma are present?

CS-3

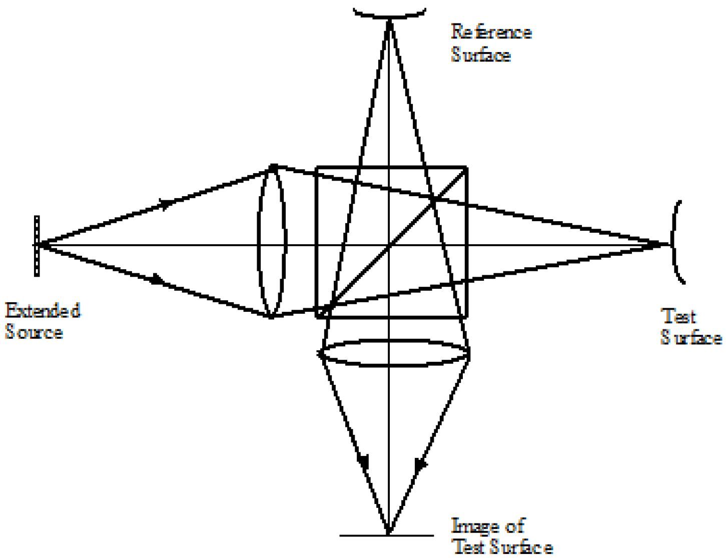
In the normal LUPI test of a convex spherical mirror the quality of the diverger lens is very important.

a) Why is the quality of the diverger lens less important if the arrangement shown below is used?

b) Why is the quality of the beamsplitter less important if we use an extended source and image the source onto the test surface?

c) How will aberrations in the beamsplitter influence the fringes obtained?

d) What additional requirements are imposed upon the beamsplitter if a white light source is used with the interferometer?



CS-4

A Fizeau interferometer having a HeNe laser as the light source is used to test flat surfaces. Let the reference surface in the Fizeau be perfect, but the 10 cm diameter collimator lens used in the interferometer has 2 waves of third-order spherical aberration. Give the approximate maximum error in the test results if the separation between the reference surface and the test surface is

a) 1 cm

b) 1 meter.

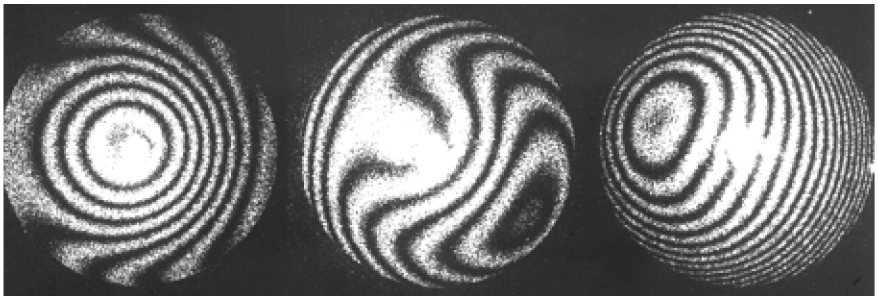
CS-5

The three scatterplate interferograms shown below were made of a 12 inch (30 cm) diameter parabolic mirror tested at the center of curvature.

a) How was the interferometer adjustment changed between the photographing of the three interferograms?

b) Obtain a plot (across one diameter) of the departure of the parabolic mirror relative to the sphere centered at the vertex center of curvature.

c) What is the focal length of the parabolic mirror?



CS-6

I am using a quasi-monochromatic spatially-incoherent circular source with a scatterplate interferometer. A 20 cm diameter, 200 cm radius of curvature spherical mirror is being tested. The lens used to image the source on the mirror has a 4 cm focal length. The interferometer is adjusted so as to produce fringes having a spacing of 2 cm when projected back onto the mirror being tested. How large can the diameter of the source be before a lack of spatial coherence causes the fringe contrast to go to zero? How does the result depend upon wavelength? State any simplifying assumptions you make.

CS-7

a) Sketch a diagram for using a scatterplate interferometer to test a flat mirror 2 cm in diameter. What limits the maximum size of the scatterplate? What limits the minimum size?

b) Assume the flat mirror is flat to within 5 fringes, how large a spectral bandwidth can be used for the source? State any assumptions.

CS-8

a) I am using a scatterplate interferometer to test an uncoated parabolic mirror using a null configuration. Sketch a suitable experimental setup.

b) In the answer to part a you should be reflecting off the parabolic mirror twice. I find that in doing the experiment I have so much light reflected back from the scatterplate that my fringe contrast is very low. Describe a "polarization technique" that would at least partially correct this problem.

c) Give at least 2 tradeoffs on the optimum ratio of scattered to unscattered light for a scatterplate. How does your answer depend upon whether a coated or an uncoated mirror is being tested?

d) Does the "hotspot" for a scatterplate interferogram fall on a dark or a bright fringe? Explain.

CS-9

a) Describe how you would use a single scatterplate to test a lens at 1:1 conjugates.

b) If it is possible, devise a way to use two identical scatterplates that do not have inversion symmetry to test a lens at 1:1 conjugates.

In both a) and b) explain how tilt and defocus are introduced.

CS-10

a) What is known about the fringe that passes through the "hot spot" in a scatterplate interferogram?
b) Give at least 2 tradeoffs on the optimum ratio of scattered to unscattered light for a scatterplate.

CS-11

A scatterplate interferometer is used to test a concave spherical mirror having a 9 mm diameter and 75 mm radius of curvature.

a) The interferometer is adjusted to give a 7 bright vertical tilt fringes across the interferogram with a bright fringe at both the left and right edges of the interferogram for a wavelength of 600 nm. In units of microns, how far was the scatterplate translated from the null fringe position to obtain these 7 tilt fringes?

b) The interferometer is adjusted to give 7 bright circular defocus fringes across the interferogram with a bright fringe at both the center of the interferogram and at the edge of the interferogram for a wavelength of 600 nm. In units of microns, how far was the scatterplate translated from the null fringe position to obtain these 7 circular defocus fringes?

c) In part a) above, what is the fringe order number for the fringe passing through the hot spot if the wavelength is changed to 700 nm?

CS-12

A Smartt PDI is used to test a lens. How will the interferogram change if
a) The PDI plate is translated laterally?
b) The PDI plate is translated longitudinally?

CS-13

I am using a Smartt point diffraction interferometer to test a lens that is essentially aberration free.

a) If I place the pinhole in the Smartt interferometer at the center of the 4th bright ring in the Airy disk, how many fringes do I see across the image of the lens I am testing? Be sure to list any assumptions you make.

b) If the diameter of the pinhole of part a) is equal to the Airy diameter/2.44, what should the density of the mask around the pinhole be to give maximum fringe contrast? I want only an approximate answer. You do not need to go through complicated numerical integration or diffraction calculations.

c) If the density calculated in part b) is off by 1 (i.e. transmittance off by an order of magnitude), how much will the fringe visibility suffer?

CS-14

A Smartt PDI can be modified to simultaneously give three interferograms with relative phase differences between adjacent interferograms of 90°. One way to accomplish this is to add a sinusoidal amplitude transmission grating in the plane containing the pinhole and partially transmitting filter. Once these three interferograms are detected, the phase of the wavefront can be calculated using the standard three-step equations given in the class notes.

a) What is the total amplitude transmittance of the interferometer in terms of the pinhole translation, and grating spacing?

b) To create interferograms in the ±1 diffraction orders which have phase shifts of ±90° relative to the zero order, where should the pinhole be placed with respect to the grating period?

CS-15

Question

A Smartt point diffraction interferometer is used to test an f/7.0 lens at a wavelength of 500 nm.

a) Sketch the setup.

b) What is the approximate maximum-size pinhole that would be acceptable?

c) What is the effect of having too large a pinhole?

d) Sketch the interferogram obtained testing a lens having 4 fringes of third-order spherical aberration and 6 fringes of tilt across the diameter. The lens is tested at paraxial focus.

CS-16

Design a self-referencing interferometer to test the wavefront quality of a laser beam. The wavelength is approximately 500 nm, the average power is 10 watts, the beam is 2 cm in diameter, the beam is pulsed at a rate of 1 MHz and the wavefront should be measured to an accuracy of approximately 1/100 wave rms. (Warning - there are at least 7 key points I am looking for.)

CS-17

I am using the star test to evaluate an optical system. How does the minimum blur diameter due to third-order spherical aberration compare to

a) the blur diameter due to astigmatism at the circle of least confusion?

b) the width of blur due to third-order coma which is twice the sagittal coma?

Assume equal amounts of third-order spherical, coma, and astigmatism as the maximum wavefront aberration.

CS-18

An 8 1/2 inch diameter, 48 inch focal length parabolic mirror tested at "center of curvature" using a Hartmann test. The Hartmann screen placed at the mirror surface has holes spaced 1 inch apart on a square grid. The coordinates of the Hartmann spots at paraxial focus are given below.

x coordinate of hole in Hartmann screen	x coordinate of Hartmann spot
-4 inch	-9.944 x 10-3 inch
-3	-4.930 x 10-3
-2	-1.268 x 10-3
-1	-2.085 x 10-4
0	0
1	1.085 x 10-4
2	9.681 x 10-4
3	3.930 x 10-3
4	1.194 x 10-2

Give the surface departure of the mirror from the desired parabolic mirror along the line tested. Is it practical to perform the Hartmann test at paraxial focus? Explain.

CS-19

State at least 3 important criteria for determining the spacing and size of the holes used in a classical Hartmann test.

CS-20

An 8 inch diameter. 24-inch focal length parabolic mirror is tested using a Foucault test. In the test the light source moves with the knife-edge. The mirror is found to be rotationally symmetric, however a surface error probably exists. The table gives the measured zone focus, relative to the paraxial center of curvature, as a function of zone radius.

a) How significant is the last decimal place in the data?

b) Determine the departure, in wavelengths (λ = 0.6328 μm), of the mirror surface relative to the desired parabolic surface.

ρ(in)	ϵ_z
0.5	0.001
1.0	0.008
1.5	0.015
2.0	0.030
2.5	0.045
3.0	0.087
3.5	0.130
4.0	0.182

CS-21

You are given the problem of analyzing the output of an AC radial Ronchi ruling interferometer. The spatial frequency of the grating is given by ν = (100 lines/mm)(25 mm/r), where r is the distance from the center of the grating. The grating is rotating at a rate of 1 revolution per second. We will consider only the interference between the 0 order and the +1 order and the 0 and the -1 order.

a) Why can we limit our discussion to only interference between 0 and +1 and 0 and -1 orders?

b) What is the modulation frequency of the signal? How does the frequency depend upon spectral wavelength, and r, the distance between the center of the grating and the position of the focused spot?

c) What is the angular shear as a function of r?

d) Show that the output signal can be written as

$$i_s = C_1 + C_2 \left(\text{Cos}\left[\Delta\,\phi^{i}[x, y] + \frac{\Delta^3}{6}\,\phi^{iii}[x, y] + \frac{\Delta^5}{120}\,\phi^{v}[x, y] - \omega\, t\right]\right)$$
$$\left(\text{Cos}\left[\frac{\Delta^2}{2}\,\phi^{ii}[x, y] + \frac{\Delta^4}{24}\,\phi^{iv}[x, y] + \cdots\right]\right)$$

where C_1 and C_2 are constants, Δ is the shear, ω is the modulation frequency, and ϕ(x,y) is the phase distribution we are measuring.

CS-22

The grating used in a Ronchi test can be either a density (amplitude) grating that has a 50% duty cycle (equal width transparent and opaque lines) or a phase grating where the entire grating is 100% transmitting, but every other line has a phase retardation of ϕ with respect to the adjacent lines. The 0 phase and the ϕ phase lines have equal width. Assume the spatial frequency of the grating is sufficient that at most only two orders overlap.

a) Show that for the phase grating the interference of the 0, +1 orders give a pattern that is complimentary to that of the 0, -1 orders. That is, a dark fringe in one pattern corresponds to a bright fringe in the other pattern. (See for example, Figure 9.19 of Malacara.) Is the situation the same for the density grating?

b) Comment upon conservation of energy for the use of phase and density (amplitude) gratings. That is, if I get a single black fringe in the interference pattern for a density or a phase grating, where has the energy gone?

CS-23

How are the number of fringes in a lateral shear interferogram related to the number of fringes in a Twyman-Green interferogram? Let S = shear distance / pupil semi-diameter.

a) By looking at the aberrations $A\left(x^2 + y^2\right)^2$ and $B\left(x^2 + y^2\right)$, and having the shear in the x direction, determine a rule valid for small shears which gives the ratio of the number of fringes in a lateral shear interferogram as a function of S and the maximum power of x in the aberration formula.

b) For the two aberrations in part a), give the results for a large amount of shear as well as a small amount of shear.

CS-24

A wedged plate lateral shear interferometer is used to check for collimation. The plate has an index of 1.5 and a wedge of 5 arc-seconds. The plate is oriented so the direction of the wedge is perpendicular to the direction of shear. The shear is set at 6 mm. A 50 mm diameter beam is being checked. Let the wavelength be 0.6328 microns.

a) How many bright fringes are there across the beam for perfect collimation?

b) If the beam is defocused such that at the edge of the pupil the OPD due to defocus is W, give the equation describing the shape and orientation of the bright fringes as a function of W.

c) If we claim we can measure fringe orientation to an accuracy of 1^{o}, how accurately can we measure defocus, i.e., how small of a defocus, W, can we detect?

CS-25

A lateral shear interferometer is used to perform a single pass test of a lens having 4 waves of spherical aberration. The shear is equal to 10% of the lens diameter. The resulting interferogram looks like a Twyman-Green interferogram having A fringes of coma and B fringes of tilt. What are A and B?

CS-26

What is the primary quantity the following instruments measure? (One word for each answer is sufficient.)

a) Shack cube interferometer

b) Hartmann Test

c) Shack-Hartmann test
d) Lateral shear interferometer
e) Radial shear interferometer
f) Wire test
g) Foucault test
h) Scatterplate interferometer
i) Nomarski Interferometer
j) Spherometer