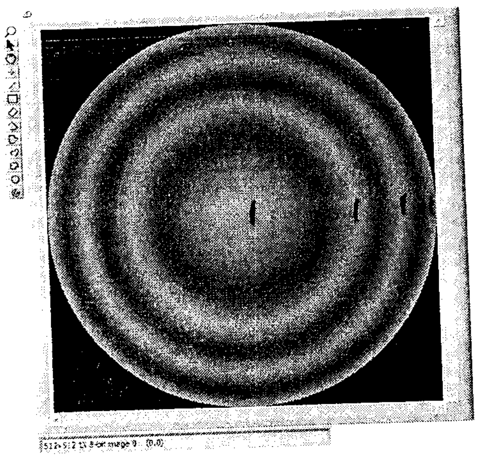
OPTI 415/515 Optical Specifications, Fabrication, and Testing Burge

Midterm #1

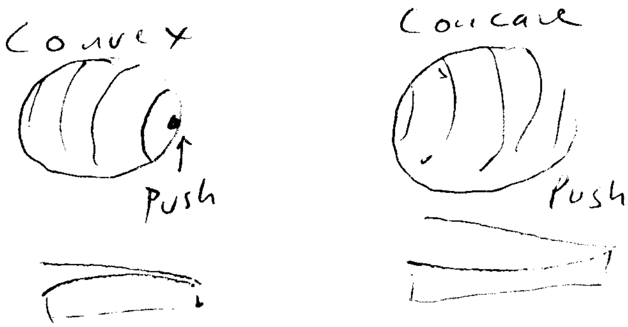
1) (15) A light box (with green mercury lamp) is used to compare the shape of an unknown surface against a flat reference surface. The interferogram below is produced. The diameter of the optical component is 50 mm.



A) Can you determine if the part is convex or concave from this single image? If not, describe specifically how to determine if the unknown part is concave or convex.

Cannot tell from static fringes.

Push on one side



B) Calculate the sag of the surface in nm

3 ring; $\lambda: 546$ nm

$S = \frac{3}{2} \cdot 546 = 819\text{ nm}$

C) Determine the radius-of-curvature in mm.

~~Ro~~ Flat surface

$$S = \frac{r^2}{2R}$$

$$R = \frac{(D/2)^2}{2S} = \frac{D^2}{8S}$$

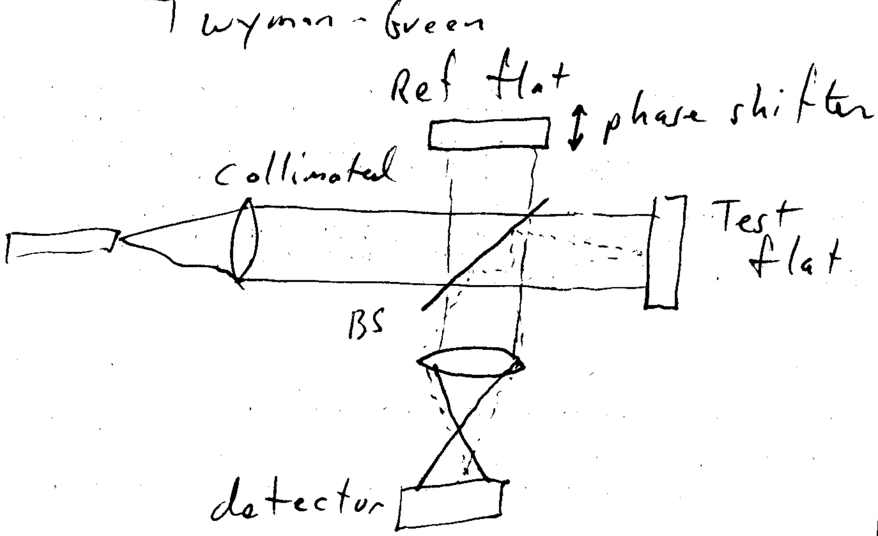
$S = 819 \times 10^{-6}$ mm

$D = 50$ mm

$R = 382$ m

[redacted]

2) (10) Sketch a schematic layout for a temporal phase shifting Twyman-Green and Fizeau interferometer using a laser source for testing a flat mirror. You do not need to sketch the details of how the collimated beam is produced. Identify the key components including test and reference surfaces, phase shifter, and digital camera where the interferogram is located. What surface should be imaged onto the detector array?



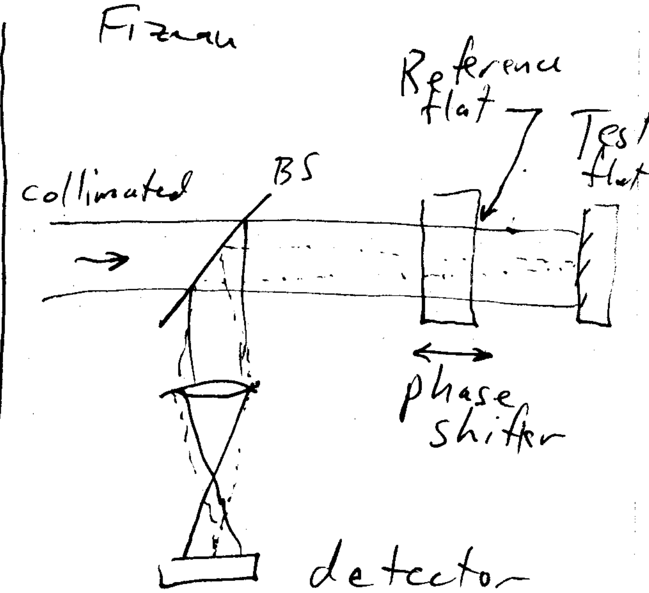


Image the test flat onto the detector for both

3) (5) Compare the relative advantages of a Twyman-Green and Fizeau interferometer. Assume a temporal phase shifting system, not instantaneous phase shifting.

Fizeau: + Most optics are common path, so they do not degrade accuracy

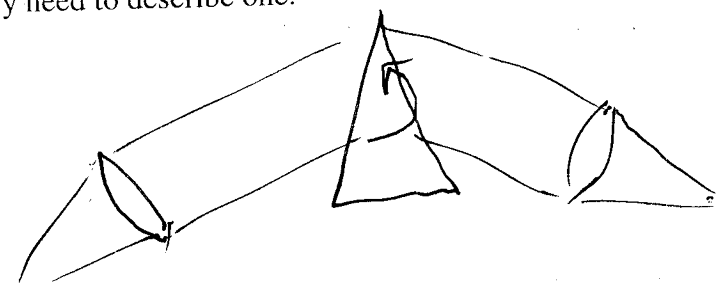
- Requires phase shifting by pushing large reference surface.

T-G + Allows adjustment of reference mirror, enabling use of multimode lasers

+ easy to phase shift

+ can easily accommodate different reflectivities

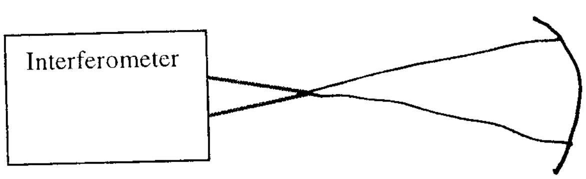
4) (10) Sketch the layout and describe the process for measuring the index of refraction of a glass using a prism. Identify the required components. There are at least two possible ways of doing this, you only need to describe one.



Use a goniometer, measure deviation of prism. Adjust prism angle for minimum deviation. Measure wedge angle

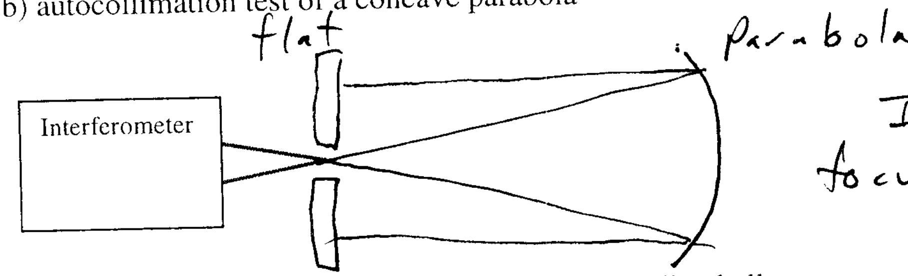
5) (15) Sketch the optical setup to test the following components using an interferometer with converging spherical wavefront as shown below. Details of the interferometer are not required. Identify the components, center-of-curvature, etc. for each setup.

a) concave spherical surface



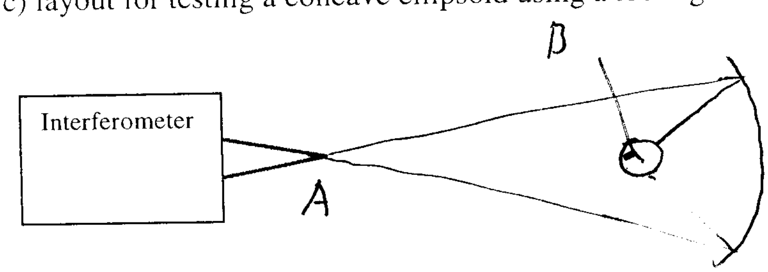
Interferometer focus at sphere center of curvature

b) autocollimation test of a concave parabola



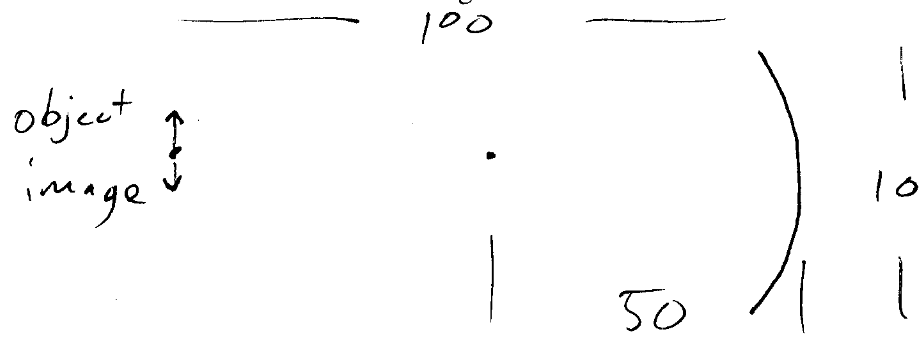
Interferometer focus at parabola focus

c) layout for testing a concave ellipsoid using a tooling ball



Ellipse foci A, B

6) (10) A spherical mirror has a radius-of-curvature of 100 mm and a diameter of 10 mm
a) Sketch the mirror and indicate its center-of-curvature and focal point locations. A 1 mm tall object (arrow) is placed at the center-of-curvature pointing up with its base on the axis. Show the object and image. What is the transverse magnification?



$M = -1$

b) What is the "diffraction limited" depth-of-focus of the mirror according to the Rayleigh criterion for the image of an object placed at the center-of-curvature?

$\lambda/4$ P-V Wavefront error

$\delta z = \pm 2 \lambda F^2$

F is working $F^{\#} = 10$

$\delta z = \pm 2(.5\mu m)10^2 = \pm 100\,\mu m$

7) (5) Zernike polynomials are orthogonal over a <u>Unit circle</u>.

What would happen if Zernike polynomials were used to fit data over a triangular aperture?

Not orthogonal!

Values for coefficients will depend on how many coefficients are included in the fit.

[redacted]

8) (15) Phase shifting interferometry is used to measure the phase of a wavefront and thereby determine errors in a surface.

A) Write an equation describing two-beam interference including a term for phase-shifting.

$$\cancel{I = I_0 + I_1 \cos(\phi}$$

$$I(x,y) = I_0(x,y) + I_1(x,y)\cos(\phi(x,y) + \Delta)$$

Δ is the phase shift term

B) How far must the reference mirror in a Twyman-Green interferometer be moved to cause a ¼ wavelength (90 degree) phase shift with a 633 nm HeNe source?

$$90^\circ \Rightarrow \lambda/4 = 633/4 = 158 \text{ nm WF}$$

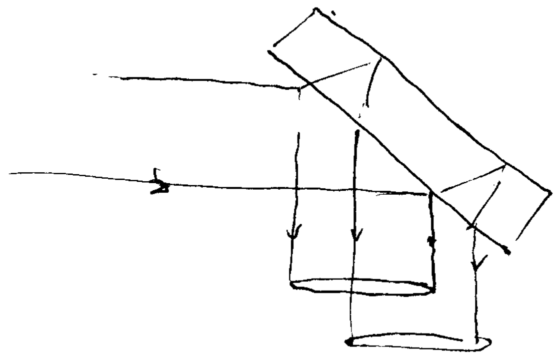
Mirror moves ½ as much 79 nm for each $\lambda/4$ step.

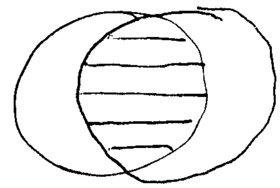
C) Phase shifting interferometers are sensitive to a variety of effects. List at least three items that can adversely affect the quality of measured data.

Vibration
Atmospheric effects
phase shift calibration error
phase shift linearity
detector non-linearity

9) (15) Shear plate interferometer.

a) Sketch a shear plate interferometer used for testing collimation of a beam. The interferometer is designed to have 5 horizontal fringes when the beam is collimated.





Wedge
$\perp$ shear

b) What happens to the fringes if the beam is not perfectly collimated?

Fringe pattern will tilt

c) How can you use a shear plate to test for astigmatism in a nearly collimated beam?

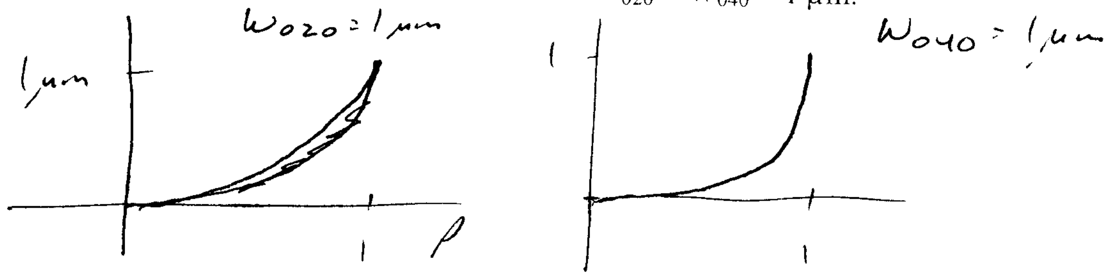
Rotate shear plate.

Look at components at 0° + 90°

Question for 515 students (20 points)
(Extra credit for 415 students)

The Seidel aberrations for power and spherical aberration take the form $W_{020}\rho^2$ and $W_{040}\rho^4$ where ρ is the normalized pupil radius.

a) Sketch the profile of these two functions for $W_{020} = W_{040} = 1\ \mu m$.



b) Show mathematically that these functions are not mutually orthogonal over a unit circle.

Functions f and g are orthogonal when $\iint f \cdot g\, dA = 0$

$$\int_0^1 (\rho^2)(\rho^4)\cdot(\rho \cdot 2\pi\, d\rho) \qquad dA = 2\pi\rho\, d\rho \qquad \rho: (0,1)$$

$$2\pi \int_0^1 \rho^7 d\rho = 2\pi\, \frac{1}{8}\rho^8 \Big|_0^1 = \frac{\pi}{4} \neq 0$$

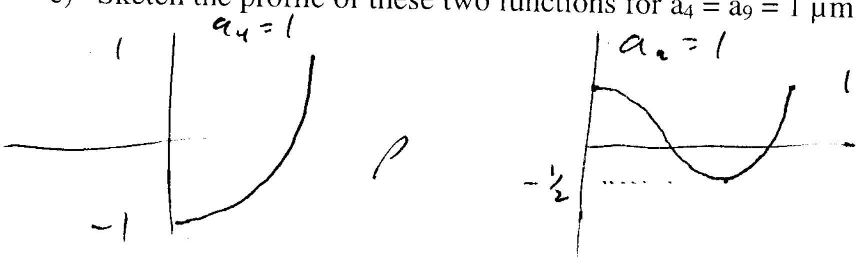
ρ	Z_4	Z_9
0	-1	1
.7	0	$-\frac{1}{2}$
1	1	1

The orthogonal forms are represented in Zernike polynomials

Power: $a_4\,(2\rho^2 - 1)$

Spherical: $a_9\,(6\rho^4 - 6\rho^2 + 1)$

c) Sketch the profile of these two functions for $a_4 = a_9 = 1\ \mu m$



$$\frac{6}{4} - \frac{6}{2} + 1$$

$$1\tfrac{1}{2} - 2 = -\tfrac{1}{2}$$

d) For 1 µm Zernike spherical aberration ($a_9 = 1\ \mu m$), re-write the function in terms of Seidels. Find the values for W_{020} and W_{040}.

$$a_9 = 1\,\mu m \qquad 1\,\mu m\,[6\rho^4 - 6\rho^2 + 1]$$

$$= W_{040}\rho^4 + W_{020}\rho^2 + W_{000}$$

$$W_{040} = 6\,\mu m$$

$$W_{020} = -6\,\mu m$$