Optics 513 Exam #1

October 21, 2008
Closed Book Exam
Calculate the quantities asked for, don't just give equations.

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1) (10 Pts)

A focal collimator with an Fo/A of 1000 is used to measure the focal length of a lens. The image of the reticle is measured to be 2± 0.01 mm.

a) What is the focal length of the lens?

b) Briefly describe how you would use the focal collimator to measure all the cardinal points of the lens.

Solution

a)

$$f = A' \left(\frac{F_o}{A}\right) = 2\ m \pm 10\ mm$$

b)

The image is formed at one focal point and one principal point and one nodal point are a distance equal to the focal length away from the focal point. The lens must be turned around to determine the second focal point position and consequently the second principal point and the second nodal point.

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2) (5 Pts)

Give two factors which limit the maximum refractive index that can be measured using the Abbe refractometer.

Solution

The refractive index of the reference prism and the refractive index of the index matching fluid limit the refractive index that can be measured using the Abbe refractometer. In particular, the refractive index must be less than or equal to the lower of the refractive index of the index matching fluid or the reference prism.

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3) (20 Pts)

A 50 mm diameter, f/8 lens has 2 waves of third-order spherical when it is illuminated with a collimated beam of HeNe light (λ = 633 nm).

a) What is the diameter of the geometrical image of a collimated beam at paraxial focus?
b) How many waves of defocus should be added to give the minimum geometrical spot image?
c) How many waves of defocus should be added to maximize the Strehl Ratio?
d) What is the minimum diameter of the geometrical spot image?

Solution

a)

$\Delta w = w_{040}\,\rho^4;\quad w_{040} = 2\,\lambda;\quad \lambda = 0.633\ \text{microns};$

$\epsilon_\rho = -\frac{R}{h}\frac{\partial \Delta w}{\partial \rho};\ R = 400\ \text{mm};\ h = 25\ \text{mm};$

$\epsilon_{\rho max} = \text{Abs}\left[-\frac{400\ \text{mm}}{25\ \text{mm}}\,4\,(2)\,(0.633\ \mu\text{m})\right] = 81.024\ \mu\text{m}$

geometricalSpotDiameter = 162.05 μm

b)

For every wave of third-order spherical we should add -1.5 waves of defocus. Therefore, we need -3 waves of defocus to get minimum spot size.

c)

-2 waves of defocus

d)

$\Delta w = w_{040}\left(\rho^4 - 1.5\,\rho^2\right)$

Therefore the spot size will be $\frac{1}{4}$the spot size at paraxial focus.

geometricalSpotDiameter = 40.51 μm

4) (25 Pts)

A computer was used to simulate the four interferograms shown below.

a) (5 Pts) For interferogram #1, the aberration is of the form $A\rho^4 + B\rho^2$. If A is equal to 8, what is B? (It may be hard to see from the figure, but there is a bright fringe at the edge of the pupil.)

b) (15 Pts) For Figures 2, 3, and 4 the aberration is of the form $Ay\rho^2 + By + Cx$, where $\rho = \sqrt{x^2 + y^2}$ and $0 \le \rho \le 1$. A is the same for the three interferograms. What are A, B, and C for the three figures? (It may be hard to see from the figures, but there is a bright fringe at the top and bottom of Figure 2 and there is a bright fringe at the edge of Figure 4.)

c) (5 Pts) What aberrations do the four figures represent?

Figure 1

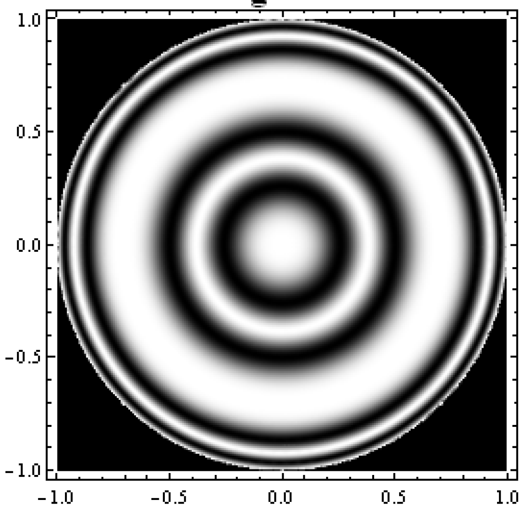
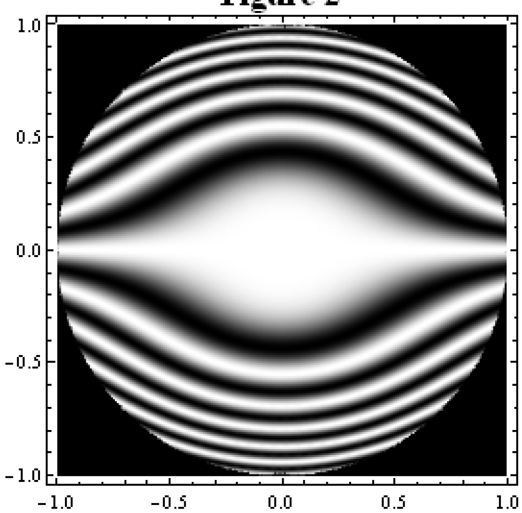
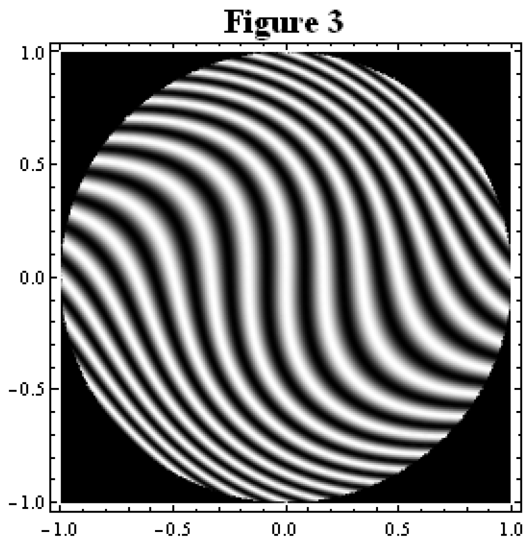
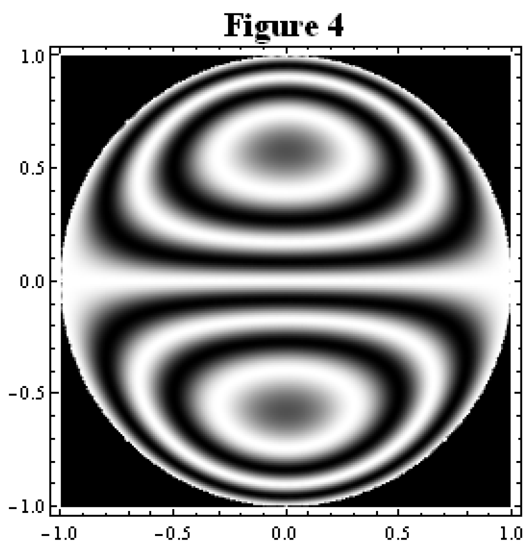


Figure 2







Solution

a)

To have the wide fringe region A and B must have opposite signs. Since the OPD at the edge is the same as at the center, A and B must be equal in amplitude, but opposite in sign.

B = −8

b)

Fig. 2 No tilt in x or y.

A = 6, B = 0, C = 0

Fig. 3. No tilt in y. 6 fringes of tilt across the radius for x.

A = 6, B = 0, C = 6

Fig. 4. No tilt in x. OPD same at edge as center so there must be -6 fringes of tilt in y.

Fig. 4 A = 6, B = -6, C = 0

c)

Fig. 1 Spherical and focus

Fig. 2 Coma

Fig. 3 Coma and x tilt

Fig. 4 Coma and -y tilt

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5) (20 Pts)

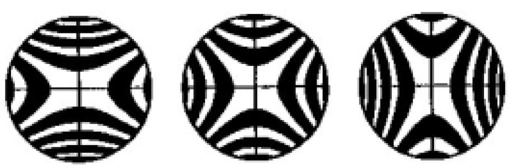
The following three interferograms were obtained testing a nearly spherical mirror in a laser-based Fizeau interferometer using a 633 nm light source. (It may be hard to see from the figures, but there is a dark fringe at the edge along the x and y axes for all three interferograms.)

a) What is the name of the aberration present?

b) What is the peak-valley surface height error in units of microns? Give any assumptions you are making.

c) How was the interferometer adjusted in going from the interferogram on the left to the interferogram on the right?

d) Describe the motion of the fringes in the middle interferogram as you push in on the mirror to move the mirror closer to the reference surface. State any assumptions being made.



Solution

a)

Astigmatism

b)

Wavefront P-V = 5 fringes = 3.15 microns. Surface height error P-V = 1.58 microns.

c)

Distance between transmission sphere in Fizeau interferometer and spherical mirror changes.

d)

Saddle point so if fringes in x direction move toward center of interferogram then fringes in y direction move away from center of interferogram, and vice versa.

6) (20 Pts)

A concave spherical mirror is measured in a phase-shifting laser-based Fizeau interferometer made for the testing of flats. The diameter of the spherical mirror is 10 cm. A 1024 x 1024 element CCD array having a 5 micron pixel separation is used in the interferometer. The wavelength is 633 nm.

a) Assuming we want to test the entire mirror surface, what is the shortest radius of curvature mirror that we can measure? State any assumptions you are making.

b) Repeat part a) for an 8 micron pixel separation.

Solution

a)

Assume the image of the mirror fills the detector. We must have at least two detector elements per fringe so the maximum wavefront slope is 256 waves/radius.

$$\text{opd} = 2\,\frac{x^2}{2\,r};\quad \text{slope} = 2\,\frac{x}{r};\quad r = 2\,\frac{x}{\text{slope}}$$

$$r = 2\,\frac{5\times 10^{-2}\,\text{m}}{256\,\frac{0.6328\times 10^{-6}\,\text{m}}{5\times 10^{-2}\,\text{m}}} = 30.8648\,\text{m}$$

b)

As long as the image of the mirror fills the detector the answer is independent of the pixel separation.

Exam Grades

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   84, 83, 82, 81, 80, 80, 78, 72, 71, 69, 66, 58, 53, 52, 48};

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Print["Minimum = ", Min[examGrades]];
Print["Standard Deviation = ", N[StandardDeviation[examGrades]]];
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Mean = 78.6087

Maximum = 100

Median = 81.

Minimum = 48

Standard Deviation = 15.2248
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