Aberrations

A-1

I have an optical system with +4 waves ($\lambda = 0.5\ \mu$m) of third order spherical aberration. If the pupil diameter is 4 cm and the distance between the exit pupil and the paraxial image plane is 10 cm, find

a) Geometrical spot size at paraxial focus.

b) Longitudinal aberration, LA.

c) Show that the focal shift required to make the OPD zero at the edge of the pupil is 0.5 LA.

d) What focal shift is required to make the transverse aberration equal to zero at the edge of the pupil?

e) Show that the minimum geometrical spot size due to third-order spherical aberration occurs at a focus three quarters the distance from the paraxial focus to the marginal focus. What is the minimum geometrical spot size? If $\Delta w = W_{040}\ (\rho^4 - a\,\rho^2)$, what is a?

f) What is the maximum wavefront slope in units of waves/radius and arc-seconds?

A-2

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.

A-3

A 20 cm diameter, 80 cm radius of curvature spherical mirror is illuminated with a collimated beam of light with wavelength 633 nm. Describe the on-axis wavefront aberrations in terms of Zernike polynomials. Do not worry about terms for which the aberration corresponds to less than 1/20 wave.

A-4

I want to maximize the Strehl ratio by balancing third-order and fifth-order spherical aberrations with defocus. What are the optimum amounts of third-order spherical and defocus if I have 8 λ of fifth-order spherical?

A-5

Derive the relationship between Zernike polynomials and the Seidel aberrations shown in Table V (page 37) in Volume XI of Applied Optics and Optical Engineering.

A-6

If the coefficients for the first 8 Zernike polynomials are 5.9568, -0.5239, 0.0753, -0.1537, 0.1290, 0.0275, 0.0226, and -1.0185, determine the tilt, focus, astigmatism, coma, and fourth order spherical. Give both magnitude (including sign) and angle.

A-7

Starting with Eq. (3), derive Eq. (4) (page 5) in Volume XI of Applied Optics and Optical Engineering.

A-8

Derive Eqs. (68) (page 41), (70), and the exact version of Eq. (72) in Volume XI of Applied Optics and Optical Engineering.

A-9

The coefficients for Zernike #8, Zernike #6, and Zernike #3 are 2, 3, and 4, respectively. All other Zernike polynomials have zero coefficients. How many waves of tilt, defocus, astigmatism, coma, and spherical aberration are present?

A-10

Compare the relative maximum dimension in the geometrical spot image at

a) paraxial focus for a system having 2 waves of spherical aberration and

b) sagittal focus for a system having 4 waves of astigmatism.

A-11

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) What is the minimum diameter of the geometrical spot image?

A-12

I have a special optical system where the only aberration is third-order coma. The Strehl ratio for the system must be greater than 0.7. Which one or two Zernike polynomials are we interested in for this system? How large can the coefficient be before the optical system is unacceptable?

A-13

Use the table of Zernike polynomials provided in class to help answer the following.

a) What is the smallest number of waves of defocus that will introduce zero irradiance on axis for an aberration free image of a point source?

b) As the obscuration ratio of a circular aperture increases, does the size of the central core of the diffraction pattern increase or decrease?

c) We have 4 waves of third-order spherical aberration. How many waves of defocus should be added to maximize the Strehl ratio?

d) We have 4 waves of third-order spherical aberration. How many waves of defocus should be added to minimize the geometrical spot size?

A-14

I have a conic having a conic constant k = -0.5, a radius of curvature of 40 cm, and a semi-diameter of 5 cm. If I place a point source of wavelength 0.5 microns on axis a distance of 30 cm away from the conic, how many waves of aberration (peak-valley) are present in the reflected beam?

A-15

I have a system having an aberration of the form $(7\lambda)\ \rho^3\ \mathrm{Cos}[\phi] - (7\ \lambda)\ \rho^3 \mathrm{Sin}[\phi]$ where $0 \leq \rho \leq 1$. Linear tilt of the form A x + B y is introduced to minimize the rms wavefront variation over the circular aperture of unit radius. What should A and B be equal to?

A-16

The coefficient of the Zernike polynomial for which n = 2 and m = 0 is equal to 5λ. How many waves of third-order spherical aberration are present?

A-17

I am given the job of measuring the position of the first zero of the image of the point source formed using an optical system having a central obscuration. As part of the job, I need to calculate the theoretical position of the first zero. Let ϵ = diameter of central obscuration divided by diameter of optical system and let β = diameter of central maximum of diffraction pattern for system having the central obscuration divided by the diameter of central maximum of diffraction pattern for system if it did not have a central obscuration. Derive an expression in terms of J_1, the first order Bessel function, relating β and ϵ.

A-18

The first nine Zernike polynomials can be written as

#0 1

#1 $\rho\ \mathrm{Cos}[\phi]$

#2 $\rho\ \mathrm{Sin}[\phi]$

#3 $2\rho^2 - 1$

#4 $\rho^2\ \mathrm{Cos}[2\phi]$

#5 $\rho^2\ \mathrm{Sin}[2\phi]$

#6 $\left(3\,\rho^2 - 2\right)\rho\ \mathrm{Cos}[\phi]$

#7 $\left(3\,\rho^2 - 2\right)\rho\ \mathrm{Sin}[\phi]$

#8 $6\,\rho^4 - 6\,\rho^2 + 1$

a) What are the names of the aberrations we associate with each term?

b) Give the Zernike coefficients for an aberration of the form $6\,\rho^3\cos[\phi] + 4\,\rho^4 + 6\,\rho^2$.

c) I have a system having an aberration of the form $(7\lambda)\,\rho^3\cos[\phi]$ - $(5\lambda)\,\rho^3\sin[\phi]$ where $0 \le \rho \le 1$. Linear tilt of the form Ax + By is introduced to minimize the rms wavefront variation over the circular aperture of unit radius. What should A and B be equal to?