OPTI340, Spring 2009
Design Project 4

Due: February 20, 2009

<u>Design Problem 4:</u> Spherical Aberration

In a rotationally symmetric monochromatic optical system, the only on-axis aberration (other than defocus) is spherical aberration. The wavefront coefficient for third order spherical aberration is W_{040}. Thus this aberration varies with the 4^{th} power (ρ^4) of the aperture. To study or understand spherical aberration, one need only examine the lower left hand ray fan plot. Defocus which varies with the square (ρ^2) of the aperture can be introduced to reduce the magnitude of spherical aberration. Lens designers often examine the surface-by-surface aberration contribution to understand and ultimately reduce the aberration content of a lens assembly. CODE V has several built-in methods to analyze the aberration content of an optical system. To better understand spherical aberration, we'll be investigation how aperture size, refractive index, shape factor, lens splitting, and non-spherical surfaces affect spherical aberration.

Lens Parameters:

Focal length:	75mm
F/number:	3
Center thickness:	8mm
Wavelength:	633nm
Object distance:	infinity
On-axis only	

A. Aperture

For this example define a plano-convex (with the convex side toward the infinite conjugate) lens using H-K9L CDGM glass. Define the lens radius of curvature to achieve the specified effective focal length. Use CODE V to calculate the third order transverse SA at different lens apertures. What is the relationship between lens aperture and SA? Show mathematically and graphically.

B. Refractive index

Reset the plano-convex lens in Part A to F/3 and change the glass types to the following:

H-BaK3, H-ZK11, H-LaF2, Z-F6, and H-ZF52A

Re-optimize the lens radii of curvature to maintain the 75mm focal length and calculate the SA of the lens for each of these glass types. How does the SA change with these glasses? How does the refractive index of these glasses change?

C. Shape factor

Using the lens defined in Part A working at F/3, bend the lens (change the shape factor) while holding the focal length (a paraxial marginal ray angle solve may be useful) constant at 75mm. Plot the transverse 3^{rd} and 5^{th} order SA (from **Fifth order aberrations**) versus shape factor (*<u>Shape factor is defined on page 35 of Dr. Dereniak's Lecture notes</u>*) and fit it to a curve. What is the dependence of 3^{rd} order SA on the shape factor? At what shape factor is the transverse 3^{rd} order spherical minimized? How far/close is the plano-convex lens shape from the minimum shape factor for 3^{rd} order SA?

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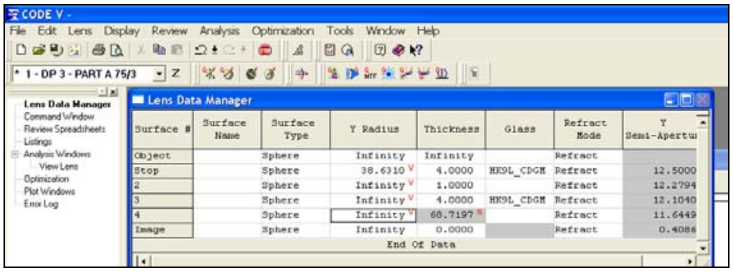
D. Lens splitting

Restore the original lens from Part A again, but this time set the F/number to 2. Thus far, you've investigated the effect aperture, refractive index and shape factor have on the generation of spherical aberration. Another often used technique to reduce the magnitude of spherical aberration in a lens design is to split lenses. Insert two additional surfaces between the front and rear lens surfaces:



Make both lenses 4 mm thick using H-K9L glass. Define all four lens surfaces as variables, but freeze the lens thicknesses and separation between the lenses. Adjust the radii of curvature to make the lenses roughly equal in power. Re-optimize the lens to maintain f=75mm and minimize third-order spherical aberration while also keeping the optical power of each lens positive.

- How has the magnitude of the third-order spherical aberration changed compared to the singlet?
- How has the surface-by-surface contribution changed compared to the singlet?

E. Conic Surface

Restore the lens from Part A and flip the lens such that the plano surface is toward the object. Define a marginal ray exit angle solve on the rear lens surface to produce an F/3 lens (remember marginal ray exit angle on surface before image == -1/[2*(F/number)].) Make the rear lens surface a conic and let both the radius and conic constant on this surface be variables. Include the image distance also as a variable. Since a marginal ray solve has been defined to control the F/number, a focal length constraint is unnecessary during optimization to maintain a 75 mm focal length. Let the first surface remain plano (infinite radius of curvature). Also, include a 1° semi-field in addition to the on-axis field position.

a. Optimize and report the *type* of conic surface that has been generated on the rear lens surface after optimization.
b. Determine and report the maximum sag departure of the conic surface in fringes at 633nm.
c. Compare the results of this conic lens with those obtained for the optimized lens in Part C above.

There is a very important observation to be made here. Because we setup our lens with a field-of-view, we can now observe a critical point. In this example we used a 1° semi-field. With the lens in the earlier Part C, where we correctly minimized the angles of incidence across both surfaces, the field dependent aberration (coma) was quite small. However, in this plano-convex lens the coma is very large. This implies that this configuration will be more sensitive to alignment. So, even though on-axis both solutions are equally effective in providing good image quality, in the real world the former solution is preferable.