OPTI340, Spring 2009
Design Project 5

Due: February 27, 2009

Design Project 5: The Landscape Lens

Introduction

The landscape lens was used as one of the earliest forms of photographic lenses. It was initially used in a "camera obscura," basically a dark room with a small hole in one wall wherein an image is formed of the outside world on the opposite wall. This concept was improved upon in the 16th century with the addition of a simple convex lens into the aperture. It was also used in early photographic cameras for its ability to produce images over moderate fields-of-view. As you'll see, stop position relative to the lens can affect certain aberrations. The landscape lens also provides us with an example with the concept of a "local minima" in a simple merit function and how typical lens design optimization (damped least-squares) arrives at these solutions.

Our previous design projects demonstrated that spherical aberration changes as a function of pupil size. The current design project will focus on coma and astigmatism, field dependent aberrations to demonstrate how aperture stop position affects these aberrations. As such we'll use a very "slow" lens so that spherical aberration will not be the dominate aberration.

The landscape lens will satisfy the following conditions:

- Focal length: 150mm
- F/number: 16
- Wavelength: 633nm
- FOV: ± 10°
- Glass: Schott, NK-5
- **Thickness: 4 mm**
- Object: at infinity
- Distortion: < 2% (goal)
- Evaluate at best RMS spot focus

For each of these designs, you'll want to provide the following analyses:

Lens layout
Ray fan plot
Spot diagram plot
Field curve plot
Third order aberration contribution list

You may want to create a macro to produce these analyses.

A) Aperture in front of landscape lens

Construct a plano-convex lens (plano side toward object) to satisfy the design parameters above. Insert a surface between the object and lens and make this the aperture stop. Use a marginal ray angle solve to set the rear surface radius of curvature. Use a paraxial image solve to set the image distance and specify the required entrance pupil diameter to produce an F/16 lens.

- Provide a layout and lens prescription for this lens
- Generate a ray fan diagram, spot diagram, and field curve plot
- List the third-order transverse ray aberration.
- What is/are the dominate aberration(s) of this lens?

Optimize the lens to minimize spherical aberration and coma with the following parameters as variables:

Front lens radius of curvature
Aperture stop thickness
Image thickness

Solves
Marginal ray angle solve on rear lens surface to maintain f/16, 150mm efl
Paraxial image distance

<u>Construct a simple optimization macro:</u>
Define the following optimization constraints using the GUI Optimization window:

- Error Function Definitions and Controls Tab
    - Error Function Content: CODE V error function only
- Specific Constraints Tab
  (Insert Specific Constraint)
    - Third order spherical aberration
        - Minimize
          Target = 0; weight = 0.001
    - Third-order tangential coma
        - Minimize
          Target = 0; weight = 0.001
- User Constraints/ray definitions
  Define a balanced astigmatism constraint
  Ast = (tas)- (sas)
  Now go to Specific Constraints Tab and add a User Defined Constraint
    - @ast
        - Minimize
          Target = 0; weight = 0.001
- Optimize your system

Now evaluate this design and compare it to the starting lens performance.

- How has the aberration content of the lens changed?
- What is the shape factor of the lens?
- Where is the aperture stop in relation to the lens?

B) Aperture stop behind landscape lens
Construct a lens to satisfy the design parameters above. Insert a surface between the image and lens and make this the aperture stop

Use the same optimization constraints as in Part A and re-optimize the lens. Now evaluate this design and compare it to the Part A optimized lens performance.

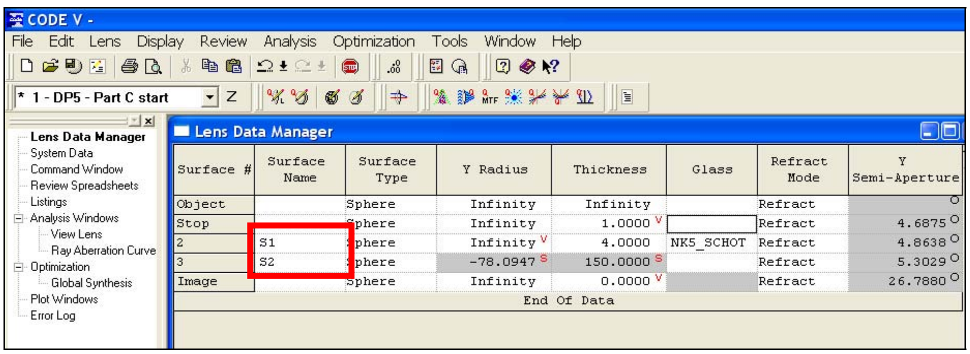
- How has the aberration content of the lens changed?
- Which lens has better optical performance?

What you've just found are two local minima for the landscape lens to minimize spherical aberration and astigmatism. Depending on the starting conditions of lens, the position of the aperture stop relative to the lens, one or the other local minima was found. Can CODE V find both of these solutions?

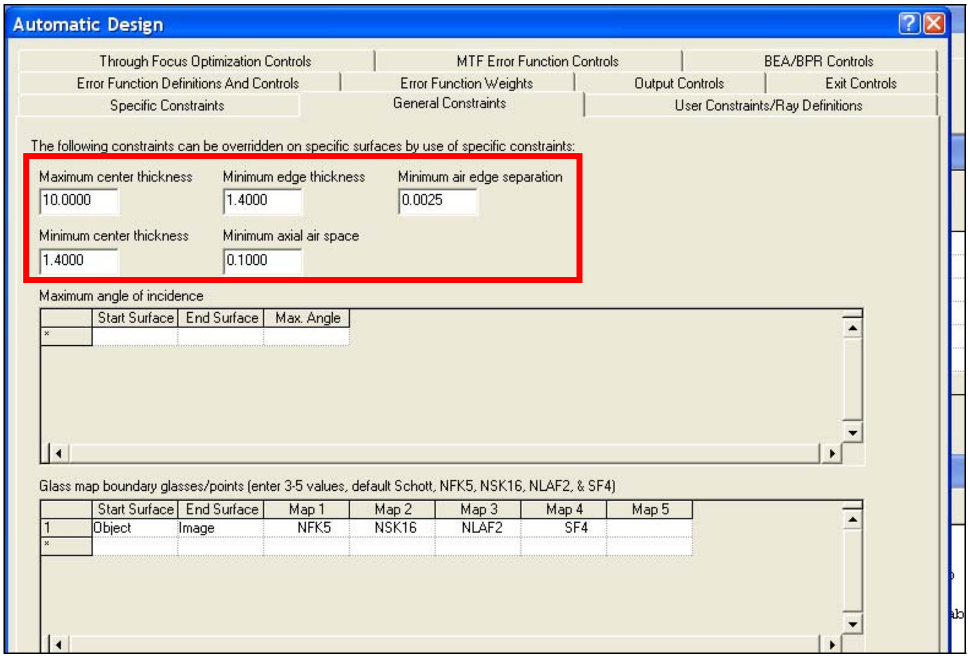
C) Global synthesis

Next, we'll use the **Global Synthesis** option during optimization. Without getting into much detail, Global Synthesis was developed by ORA to allow a damped least-squares optimization routine to "search" further beyond a local minima with the goal of finding global minima (or at least additional local minima" for a specific error function. See the CODE V Help documentation for a more complete description of Global Synthesis.

Restore the starting lens from Part A, but now assign "Surface Names" to the front and back lens surfaces (S1 and S2—note capital letters). Surface names allow your macro additional flexibility in specifying surfaces:



In order to create optimized lenses that remain realistic, the default CODE V optimization function employs a number of "smart" defaults. These defaults have been implemented to prevent the designer from created unrealistic lenses. These "General constraints" constrain the center and edge thicknesses of lenses to prevent 'negative' thicknesses during the optimization process and in most cases keep the designer out of trouble. See below for the general constraints described in the GUI:



However, at other times, these constrains prevent us from discovering potential solutions. If we start with the stop in front of the lens can we allow CODE V to find the second solution with the stop located behind the lens? Remembering that CODE V normally traces rays *sequentially*, if the stop that's defined in *front* of the lens wanted to move *behind* the lens, a *negative* distance from the stop to the lens would be required. In most cases, negative thicknesses are physically impossible and the general constraints prevent these occurrences. However, in our landscape lens example, we've just found that another solution exists with the aperture stop located behind the lens; in order for CODE V to find this solution, we need to somehow override the default constraints that prevent this from happening.

General constraints are overridden by constraints that control the specific parameter. In our case, we want to override the general constraint that does not allow the stop surface to "move through" the lens surface (ie. negative thickness). A constraint such as:

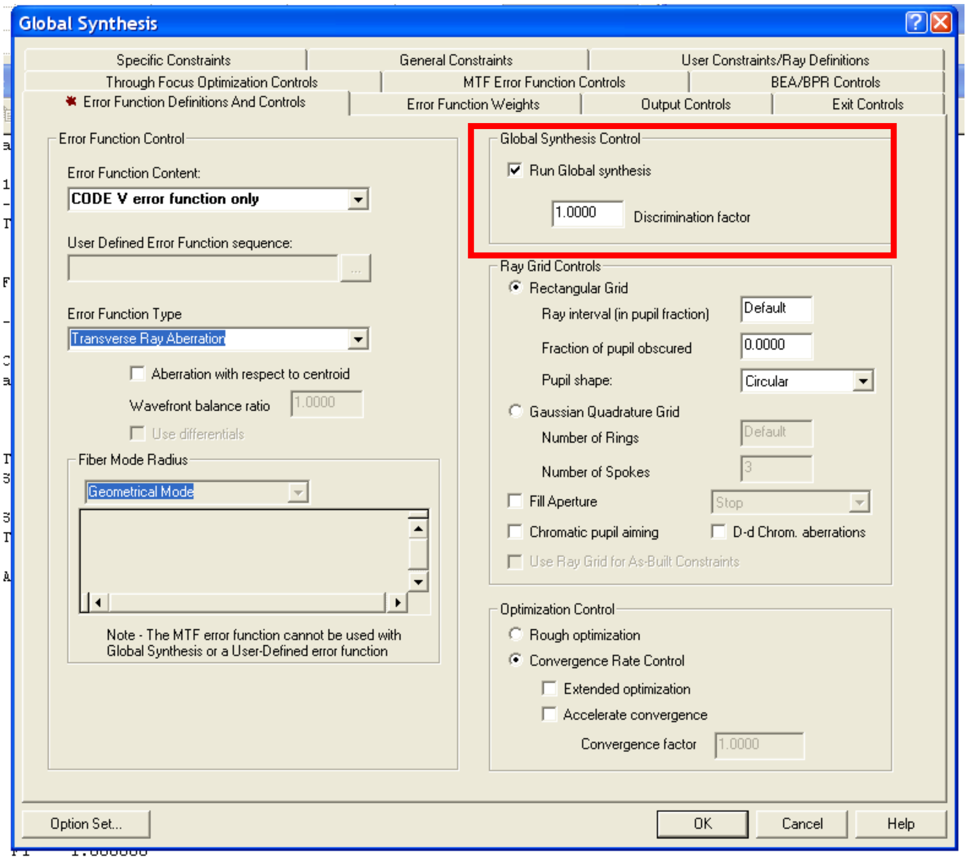
> **CT SS > -100** ! center thickness Surace S (stop surface) greater than -100 mm

will allow the aperture stop thickness to be any value greater than -100mm.

Open your Automatic Design Window and modify the specific constraints:

- Specific Constraints Tab
  (Insert Specific Constraint)
  - Manufacturing and Packaging→Center Thickness (Stop surface)
    - > Lower bound
      Target = -100

Return to the *Error Function Definitions and Controls Tab* to change your optimization run for Global Synthesis operation by checking the Global Synthesis box:



Now optimize your lens.

Two lens files, ‘lens1’ and ‘lens2’ should be created with different error function values. Restore each of these lenses and compare them to the solutions you found in Parts A and B.

Global synthesis is an extremely powerful tool available to the lens designer that enable him/her to explore large solution space regions and synthesize solutions that may not have been found with traditional lens designs methods.