Optimize This Lens

Optimization

Optimization is the process of improving a lens, subject to boundary conditions called "constraints." CODE V has a feature called Automatic Design that can take a starting point lens model and vary some of its parameters to reduce the size of its "error function." The error function is a measure of image quality, defined such that smaller is better. CODE V's default error function is based on geometrical RMS spot size derived from a grid of rays similar to the spot diagram you just made. A perfect lens would have a zero spot size. Aberrations will increase the size of the error function. Optimization seeks to minimize and balance aberrations to produce the best possible image quality. For the first example, you will use the default error function and a constraint on focal length.

Setting Default Variables

Before you can optimize, you need a starting point lens, and you need to designate the parameters that are allowed to change. These are variables. Typical variables are radius of curvature, air space or glass thickness, and index of refraction, although there are many other possible variables (for example, aspheric coefficients, decenters, etc.).

A common starting set of variables includes all non-dummy curvatures and all air spaces. You can set these for the triplet by selecting surfaces 1 through 7 (image) to define the range of interest.

1. Click on the Lens Data Manager window to bring it to the foreground (or click its title in the Navigation Window).

2. Click surface number 1 in the first column, and drag down to Image. This will select the range of surfaces from surface 1 to 7 (image).

3. Choose the Edit > Default Variables menu.

You will see a small $v$ symbol appear next to each radius of curvature and each non-glass thickness. Although their values have not changed, these items are now variables for any subsequent optimization.
Add Thickness Variables

One of the problems with the f/3 lens is the edge thickness of the front and rear positive lens elements. To fix this, you will need to allow the glass thickness of these elements to vary. These are not default variables, so you will have to add them explicitly.

1. Left-click anywhere in the **Lens Data Manager** window to de-select the cells used in the last procedure.

2. Right-click the thickness value for surface 1 (2.0000).

3. On the shortcut menu, choose **Vary**.

![Thickness Table]

4. Repeat this step for surface 5: go to the thickness value of surface 5 in the Lens Data Manager window, right-click, and choose **Vary** from the shortcut menu.

Running AUTO for Optimization

You are now ready to optimize this lens with the AUTO option.

1. Choose the **Optimization > Automatic Design** menu to open the **Automatic Design** dialog box.

You can see that there are many tabs in this dialog box. AUTO has many features, allowing great flexibility for optimizing even the most complex of optical systems. But in this example, you will use just two of its features, taking advantage of the many intelligent default values built into the program. Later you will learn how to make modifications to the error function and other features. In this case, you will define a single “specific constraint” to require
AUTO to keep the effective focal length (EFL) of 50 mm. You will request that a picture of the lens be drawn on each cycle, so that you can track its progress.

2. Click the **Specific Constraints** tab.

3. Click the **Insert Specific Constraint** button.
The Edit Constraint dialog box is displayed.

4. Click the drop-down list in the Category field and choose Optical Definitions (this is the first item and may be selected by default).

5. Click the drop-down list in the Constraint field and choose Effective Focal Length (this is the first item and may be selected by default).

Note that there are a number of grayed-out fields in this dialog box. This is because there are many types of constraints available in AUTO, and only certain parameters apply to each one. Effective Focal Length (EFL) only requires a zoom position parameter (which defaults to zoom position 1, since this is not a zoom lens).

Each constraint has a target value and a constraint mode that tells the program how you wish to control this constraint (for example, hold it to a specific value or between upper and lower bounds). In this case, you want the equality constraint (=). You also want to hold this lens to the current EFL value, so you will ask CODE V to get this value for you.

6. Choose the = value in the Constraint Mode field.

7. Click the Calculate Default Target button.

This current EFL is very close to 50 mm; this is good enough.
8. Click OK to enter this constraint.

The Effective Focal Length constraint has been entered (drag the first column wider to see more of the name, if you like). You could enter other constraints in this way—complex lenses may require many constraints, but this is all you need for the moment.

9. Click the Output Controls tab.

You will accept the defaults for most of the settings on this tab, but you want to see a picture of the lens as it is changed during AUTO.

10. Click the Draw System at each cycle checkbox and select surface 1 for Start and Image for End (these may be selected by default).

Since there are so many tabs in the AUTO dialog, how can you keep track of which ones you have changed? There is a special symbol (a red star) that appears on tabs where changes have been made.
This allows you to go back and check your inputs (tabs with no change symbols will contain only default values, or parameters that are only used when requested by the user).

11. Click **OK** to start AUTO.

The following progress dialog displays. You can click the **Stop** button any time, or allow AUTO to determine when improvement has stopped.

You will also see pictures appearing in separate graphics tabs in the AUTO output window. Note the 8 graphics tabs, one picture for each cycle, so you can review how the design form changed during optimization. Note the nice edges on the positive lenses.
You will also see extensive text output in both the Text tab of the AUTO window, as well as in the Command Window (same data). Here is part of the output for the final iteration cycle (ERR.F is the error function value, which is related to spot size in the default error function - smaller is better - it starts at about 14,000 for the f/3 triplet):

**CYCLE NUMBER 8:**

<table>
<thead>
<tr>
<th></th>
<th>ERR. F. = 343.25460373</th>
<th>(change = -10.41085787)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>92.60111555</td>
<td>142.03770667</td>
</tr>
<tr>
<td>Y</td>
<td>92.60111555</td>
<td>355.09066986</td>
</tr>
</tbody>
</table>

Normal AUTO Completion - System improvement less than IMP

The optimization should run for about 8 cycles.
Analysis and Comparison

Before and After Comparison

Now you can re-do the analysis steps done on the starting lens and compare these plots with the “torn off” plots you saved for the non-optimized f/3 lens. From the AUTO drawings above, you have already seen that your edge thicknesses have been fixed.

Ray Aberration Curves

You can re-run the quick ray aberration curve in one of two ways. If the original quick ray aberration window is still open, you can update the plot by clicking on its “execute” button to re-run it. You can tell if it's still open by checking the Navigation Window—you will see Quick Ray Aberration Plot listed under Analysis Windows.

1. Click Quick Ray Aberration Plot in the Navigation Window to bring it to the front.
2. Click the button to re-run the rim ray plot for the optimized lens.

Notice that the transverse aberrations are considerably smaller than those of the f/3 starting point lens, but still not extremely well corrected. Chromatic aberration is quite noticeable. If the Quick Ray Aberration Plot window is not listed under Analysis Windows, you probably closed the window, and you can simply make a new one.
3. Click the Quick Ray Aberration Plot button:

By default, ray aberration plots use 0.05 mm as their default scale; however, the quick ray aberration plot auto-scales to the size of the aberration.

**Spot Diagram**

You could do another quick spot diagram, but in that case, the program will find a new automatic scale factor, so it will be harder to compare. So you will instead use the standard Spot Diagram option, which will allow you to set the scale factor to 0.0875 mm, the value used in the pre-optimization plot.

1. Choose the **Analysis > Geometrical > Spot Diagram** menu.

The **Spot Diagram** dialog box will display. There are a number of settings you can modify, but you only need to change the scale factor, which is located on the **Display** tab.

2. Click the **Aberration Scaling** radio button and enter 0.0875 in the **Scale** field.
3. Click OK to run the spot diagram.

Comparing the “before” and “after” spot diagrams, you can see that the rays are now contained in a much smaller spot size.

Save Your Work

If you have not done so by now, you should save your newly optimized lens in a file.

1. Choose the File > Save Lens As menu.

   Note that there is also a Save Window As menu item, which is only used to save the contents of graphics and text windows.

2. Navigate to the desired directory, and enter a name for the file (e.g., cookef3_optimized.len).

3. Click the Save button.

   CODE V saves the lens in a binary format (.len file). This file contains only the descriptive data for the lens (radii, thicknesses, glass, variables, f/number, etc.). It does not contain any of the analysis results you have done. However, the program also saves an additional “environment” file (same name but with extender .env). This file contains information on the windows you had open when you saved the lens, so when you later restore the lens using the File > Open menu, its “environment” (such as the configuration of other windows) is also restored.
Tip: If you ever want to restore a lens without its associated environment, you can do this at the CODE V> prompt in the Command Window by typing the RES (restore) command, followed by the lens file name. If the file is not in your local directory (default is C:\CVUSER), you will have to include the directory path to the file. For example:

RES "c:\mylenses\triplet.len"

Exit or Continue?

If you want a break before the next session, you can exit from CODE V now.

* Choose the File > Exit menu to leave CODE V.