Optical Design with Zemax

Lecture 9: Advanced handling
2014-06-13
Herbert Gross
## Preliminary Schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Topic</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.04</td>
<td>Introduction</td>
<td>Introduction, Zemax interface, menus, file handling, preferences, Editors, updates, windows, coordinates, System description, Component reversal, system insertion, scaling, 3D geometry, aperture, field, wavelength</td>
</tr>
<tr>
<td>2</td>
<td>25.04</td>
<td>Properties of optical systems I</td>
<td>Diameters, stop and pupil, vignetting, Layouts, Materials, Glass catalogs, Raytrace, Ray fans and sampling, Footprints</td>
</tr>
<tr>
<td>3</td>
<td>02.05</td>
<td>Properties of optical systems II</td>
<td>Types of surfaces, Aspheres, Gratings and diffractive surfaces, Gradient media, Cardinal elements, Lens properties, Imaging, magnification, paraxial approximation and modelling</td>
</tr>
<tr>
<td>4</td>
<td>09.05</td>
<td>Aberrations I</td>
<td>Representation of geometrical aberrations, Spot diagram, Transverse aberration diagrams, Aberration expansions, Primary aberrations,</td>
</tr>
<tr>
<td>5</td>
<td>16.05</td>
<td>Aberrations II</td>
<td>Wave aberrations, Zernike polynomials</td>
</tr>
<tr>
<td>6</td>
<td>23.05</td>
<td>Aberrations III</td>
<td>Point spread function, Optical transfer function</td>
</tr>
<tr>
<td>7</td>
<td>30.05</td>
<td>Optimization I</td>
<td>Principles of nonlinear optimization, Optimization in optical design, Global optimization methods, Solves and pickups, variables, Sensitivity of variables in optical systems</td>
</tr>
<tr>
<td>8</td>
<td>06.06</td>
<td>Optimization II</td>
<td>Systematic methods and optimization process, Starting points, Optimization in Zemax</td>
</tr>
<tr>
<td>9</td>
<td>13.06</td>
<td>Advanced handling I</td>
<td>Telecentricity, infinity object distance and afocal image, Local/global coordinates, Add fold mirror, Scale system, Make double pass, Vignetting, Diameter types, Ray aiming, Material index fit</td>
</tr>
<tr>
<td>10</td>
<td>20.06</td>
<td>Advanced handling II</td>
<td>Report graphics, Universal plot, Slider, Visual optimization, IO of data, Multiconfiguration, Fiber coupling, Macro language, Lens catalogs</td>
</tr>
<tr>
<td>11</td>
<td>27.06</td>
<td>Imaging</td>
<td>Fundamentals of Fourier optics, Physical optical image formation, Imaging in Zemax</td>
</tr>
<tr>
<td>12</td>
<td>04.07</td>
<td>Correction I</td>
<td>Symmetry principle, Lens bending, Correcting spherical aberration, Coma, stop position, Astigmatism, Field flattening, Chromatical correction, Retrofocus and telephoto setup, Design method</td>
</tr>
<tr>
<td>13</td>
<td>11.07</td>
<td>Correction II</td>
<td>Field lenses, Stop position influence, Aspheres and higher orders, Principles of glass selection, Sensitivity of a system correction</td>
</tr>
</tbody>
</table>
Contents

1. Miscellaneous
2. Index fit
3. Universal plots
4. Slider and visual optimization
5. Multi configuration
6. Lens catalogs
7. Macro language
8. Data IO
9. Coupling of Zemax with Matlab
Quick Focus Option

- In the menu TOOLS – DESIGN – QUICK FOCUS we have the opportunity to adjust the image location according to the criteria:
  1. Spot diameter
  2. Wavefront rms
  3. Angle radius

- IN principle, this option is a simplified optimization

- Example: find the best image plane of a single lens

Spot before and after performing the optimal focusing
Quick Adjust Option

- In the menu TOOLS – DESIGN – QUICK ADJUST we have the opportunity to adjust:
  1. one thickness
  2. one radius
   similar to the quick focus function somewhere in the system

- Special application: adjust the air distance before a collimation lens to get the best collimation

- As criteria, wavefront, spot diameter of angular radius are possible

- Example: Move a lens in between a system to focus the image

  Spots before and after the adjustment.
Lens catalogs:
Data of commercial lens vendors

Searching machine for one vendor

Components can be loaded or inserted

Preview and data prescription possible

Special code of components in brackets according to search criteria
- Some system with more than one lens available
- Sometimes:
  - aspherical constants wrong
  - hidden data with diameters, wavelengths, ...
  - problems with old glasses
- Data stored in binary .ZMF format
- Search over all catalogs not possible
- Catalogs changes dynamically with every release
- Private catalog can be generated
Stock Lens Matching

- This tool swaps out lenses in a design to the nearest equivalent candidate out of a vendor catalogue
- It works together with the merit function requirements (with constraints)
- Aspheric, GRIN and toroidal surfaces not supported; only spherical
- Works for single lenses and achromates
- Compensation due to thickness adjustments is optional
- Reverting a lens to optimize (?)
- Top results are listed
- Combination of best single lens substitutions is possible. Overall optimization with nonlinear interaction?

Ref.: D. Lokanathan
Stock Lens Matching

- Selection of some vendors by CNTR SHIFT marking

Ref.: D. Lokanathan
## Stock Lens Matching

### Output

<table>
<thead>
<tr>
<th>Surfaces : Variables</th>
<th>Vendors</th>
<th>Show Matches</th>
<th>EFL Tolerance (%)</th>
<th>EPD Tolerance (%)</th>
<th>Air Thickness Comp.</th>
<th>Nominal Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.003094</td>
</tr>
</tbody>
</table>

**Component 1 (Surfaces 10-11)**

1. 014-3470 (OPTOSIGMA)  
2. 013-2460 (OPTOSIGMA)  
3. LDX-30.0-155.0-C (CVI MELLES GRIOT)  
4. L-BCX148 (ROSS OPTICAL)  
5. GCL010223 (DaHeng Optics)

<table>
<thead>
<tr>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003102</td>
<td>0.000008</td>
</tr>
<tr>
<td>0.003109</td>
<td>0.000015</td>
</tr>
<tr>
<td>0.003109</td>
<td>0.000015</td>
</tr>
<tr>
<td>0.003109</td>
<td>0.000015</td>
</tr>
<tr>
<td>0.003118</td>
<td>0.000024</td>
</tr>
</tbody>
</table>

**Component 2 (Surfaces 13-14)**

1. 313338000 (LINOS PHOTONICS)  
2. LDK-30.0-104.1-C (CVI MELLES GRIOT)  
3. 114-0214 (EKSMA OPTICS)  
4. GCL010407 (DaHeng Optics)  
5. SLB-30B-100N (Sigma Koki)

<table>
<thead>
<tr>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>0.003102</td>
<td>0.000000</td>
</tr>
<tr>
<td>0.003102</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

**Best Combinations**

1. 1: 014-3470 (OPTOSIGMA)  
   2: 313338000 (LINOS PHOTONICS)  

<table>
<thead>
<tr>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003107</td>
<td>0.000012</td>
</tr>
</tbody>
</table>

2. 1: 014-3470 (OPTOSIGMA)  
   2: LDK-30.0-104.1-C (CVI MELLES GRIOT)  

<table>
<thead>
<tr>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003107</td>
<td>0.000012</td>
</tr>
</tbody>
</table>

3. 1: 014-3470 (OPTOSIGMA)  
   2: SLB-30B-100N (Sigma Koki)  

<table>
<thead>
<tr>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003107</td>
<td>0.000013</td>
</tr>
</tbody>
</table>

Ref.: D. Lokanathan
Establishing a special own material

Select menu: Tools / Catalogs / Glass catalogs

Options:
1. Fit index data
2. Fit melt data

Input of data for wavelengths and indices

It is possible to establish own material catalogs with additional glasses as an individual library
Material Index Fit

- Melt data:
  - for small differences of real materials
  - no advantage for new materials

- Menue option:
  - 'Glass Fitting Tool' don't works (data input?)
Material Index Fit

- **Menue: Fit Index Data**
- **Input of data: 2 options:**
  1. explicite entering wavelengths and indices
  2. load file xxx.dat with two columns:
     - wavelength in μm and index
- **Choice of 4 different dispersion formulas**
- **After fit:**
  - pv and rms of approximation visible
  - no individual errors seen
  - new material can be added to catalog
  - data input can be saved to file
- Compact window with 4 or 6 output options can be summarized and defined individually
In the menu of output windows the option OVERLAY allows for superposing of two or more variations of the output.

This gives the opportunity to compare various versions.

Examples:
1. Layout for x- and y-cross section
2. Universal plot for different parameters
3. Delano diagram for different field sizes
- Possibility to generate individual plots for special properties during changing one or two parameters
- Usually the criteria of the merit function are shown
- Demonstration: aspherical lens, change of Strehl ratio with values of constants
- The sensitivity of the correction can be estimated
- It is seen, that the aspherical constants on one side are enough to correct the system
- One-dimensional: change of 4th order coefficient at first surface

- Two-dimensional case: dependence on the coefficients on both sides
Universal plot configurations can be saved and called later

Useful example: spot diameter as a function of a variable: operator RSCH
Slider

- Slider option in menu: Tools / Miscellaneous / Slider
- Dependence of chosen window output as a function of a varying parameter
- Automatic scan or manual adjustment possible
- Example 1: spot for changing the aspherical constant of 4th order of a lens

Example 2: Optical compensated zoom system
Visual optimization

- Menu Tools / Design / Visual optimization
- Change of variable quantities by slider and instantaneous change of all windows
- 'Optimization' under visual control of the consequences

![Visual Optimization Table]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Min</th>
<th>Max</th>
<th>± Δ</th>
<th>Slider Control</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface 1 Curvature</td>
<td>0.020216</td>
<td>0.020616</td>
<td></td>
<td></td>
<td>0.020416</td>
</tr>
<tr>
<td>Surface 2 Curvature</td>
<td>0.0086026</td>
<td>0.0087026</td>
<td></td>
<td></td>
<td>0.0086526</td>
</tr>
<tr>
<td>Surface 2 Thickness</td>
<td>-7.1264e-007</td>
<td>-7.0264e-007</td>
<td></td>
<td></td>
<td>-7.0764e-007</td>
</tr>
<tr>
<td>Surface 3 Curvature</td>
<td>0.02711</td>
<td>0.02751</td>
<td></td>
<td></td>
<td>0.02731</td>
</tr>
<tr>
<td>Surface 5 Curvature</td>
<td>0.043338</td>
<td>0.044338</td>
<td></td>
<td></td>
<td>0.043838</td>
</tr>
<tr>
<td>Surface 5 Thickness</td>
<td>4.1655</td>
<td>4.2655</td>
<td></td>
<td></td>
<td>4.2155</td>
</tr>
<tr>
<td>Surface 6 Thickness</td>
<td>22.181</td>
<td>22.581</td>
<td></td>
<td></td>
<td>22.381</td>
</tr>
<tr>
<td>Surface 7 Curvature</td>
<td>-0.043484</td>
<td>-0.042484</td>
<td></td>
<td></td>
<td>-0.042984</td>
</tr>
</tbody>
</table>
- Output of numerical data of results:
  Text option with save: generation of ASCII file
Data IO

- Export of IGES / STEP files, for CAD data transfer
Multi Configuration

- Multi configuration editor
- Establishment of different system paths or configurations
- Toggle between configurations with CNTR A
- Examples:
  1. Zoom systems, lenses moved
  2. Scan systems, mirror rotated
  3. Switchable optics, components considered / not taken into account
  4. Interferometer, test and reference arm
  5. Camera with different object distances
  6. Microscope tube system for several objective lenses
  7. ...
- In the multi configuration editor, the parameters / differences must be defined
- Many output options and the optimization can take all configurations into account
- Special option: show all configuration in the 3D layout drawing simultaneously
  1. shifted, for comparison
  2. with same reference, overlayed
Multi Configuration

- Demonstrational example: Twyman-Green interferometer
There is a macro language for Zemax to allow for individual problem solving. Some provided example files are distributed. Editing and running can be done from Zemax interface. Necessary: xxx.ZMX-file. Debugging of macro-language errors is cumbersome. Not all of the output data is provided by the commands. Coding of parameters is in many cases a bit tricky. Graphical options rather limited. Possibilities:
1. special and individual analysis
2. change of system data and case studies
3. optimization
4. print export of data
- Code Example: Incidence angles at all surfaces for 3 field positions
- Online output
Important Macro Commands

- ! comment line follows
- variables, declarations, simple operations, strings, basic mathematical functions
- IF THEN ELSE, GOTO, LABEL, FOR NEXT

- \( a = \text{AQVAL}() \) numerical aperture
- \( r_o = \text{CURV}(j) \) surface curvature of surface no. \( j \)
- \( y = \text{FLDY}(j) \) field size no. \( j \)
- \( u = \text{RAYL}(j) \) direction cosine of real ray at surface no. \( j \)
- \( y = \text{RAYY}(j) \) \( y \)-value of real ray at surface no. \( j \)
- \( t = \text{THIC}(j) \) thickness at surface \( j \)

PRINT ,text', x,y print text
FORMAT 5.3 numerical format of output: 5 places, 3 digits
OUTPUT ,fname.txt' declaration of output file for results
GETSYSTEMDATA n get special coded (n) data of the system
GETZERNIKE maxorder, wave, field, sampling, vector, zerntype, epsilon, reference
PWAV n set primary wavelength
RAYTRACE hx, hy, px, py, wavelength
SURP surface, code, value1, value2 set surface properties
SYSP code, value1, value2 set system properties
Example - 1

! 2013-05-12 H.Gross
!
! Calculation of the 2nd moments in x- and y-direction of a system spots for all field points
! A circular pupil shape is assumed
! number of field positions in the data
nfld = nfld()
!
! number of pupil sampling points (fix), arbitrary choice, determines accuracy and run time
!
npup = 21
! look for main wavelength in the data
!
jwave = pwav()
!
initialization of increments in field and pupil
!
dw = 2/(nfld-1)
dp = 2/(npup-1)
!
! determine the index of image surface
nsur = nsur()
!
! header row in output: nfld npup jwave
print " "
print "Spot 2nd order moments in my"
print " "
FORMAT 10.5
print " "
Example - 2

!------------------------------------------------------------
! loop over field points in y-direction: index jy
! for jy = 1, nfield, 1

   hx = 0
   hy = sqrt((jy-1)/(nfield-1))
!
!------------------------------------------------------------
! first loop to calculate the centroid
! initialization of centroids and moments
!
   xc  = 0
   yc  = 0
   Mx2 = 0
   My2 = 0
   Nray = 0
!
! loop over pupil points: indices kx, ky
!
   for ky = 1, npup, 1
      for kx = 1, npup, 1
         px = -1+(kx-1)*dp
         py = -1+(ky-1)*dp
! raytrace
    raytrace hx, hy, px, py, jwave
    xp = rayx(n)
    yp = rayy(n)

! error case for rays outside circular pupil
    ierr = raye()
    pr = sqrt(px*px+py*py)
    if ( pr > 1) then ierr = 1

! summation of 1st order moment to calculate the centroid in x and y
    if (ierr == 0)
        Nray = Nray+1
        xc = xc + xp
        yc = yc + yp
    endif

! end of pupil loop
    next
    next

! final calculation of centroid coordinates xc,yc
    xc = xc / Nray
    yc = yc / Nray

! second loop over pupil for calculation of moments M2 and M3
! indices kx, ky

    for ky=1, npup, 1
        for kx = 1, npup, 1
Example - 4

\[ px = -1 + (kx - 1) \times dp \]
\[ py = -1 + (ky - 1) \times dp \]

! raytrace
  raytrace hx, hy, px, py, jwave
  xp = rayx(n)
  yp = rayy(n)

! error case
  ierr = raye()
  pr = sqrt(px*px + py*py)
  if (pr > 1) then ierr = 1

! summation of moments, scaling from mm into my
  if (ierr == 0)
    Mx2 = Mx2 + (xp-xc)*(xp-xc)*1.e6
    My2 = My2 + (yp-yc)*(yp-yc)*1.e6
  endif

! end of pupil loops
  next
  next

! final calculation of moments for present field location and print of results
  Mx2 = Mx2 / Nray / 3.14159
  My2 = My2 / Nray / 3.14159

! determine field size
  Hy = fldy(jy)
  FORMAT 8.4
  PRINT " ",",",", "," centroid yc = ",yc," My2 = ",My2
  print " 

! end of field loop
  next