Optical Design with Zemax

Lecture 10: Advanced handling
2013-06-28
Herbert Gross
<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.04</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>19.04</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>26.04</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>03.05</td>
<td>Aberrations I</td>
<td>Representation of geometrical aberrations, Spot diagram, Transverse aberration diagrams, Aberration expansions, Primary aberrations,</td>
</tr>
<tr>
<td>17.05</td>
<td>Aberrations II</td>
<td>Wave aberrations, Zernike polynomials, Point spread function, Optical transfer function</td>
</tr>
<tr>
<td>24.05</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>31.05</td>
<td>Optimization II</td>
<td>Systematic methods and optimization process, Starting points, Optimization in Zemax</td>
</tr>
<tr>
<td>07.06</td>
<td>Imaging</td>
<td>Fundamentals of Fourier optics, Physical optical image formation, Imaging in Zemax</td>
</tr>
<tr>
<td>14.06</td>
<td>Illumination</td>
<td>Introduction in illumination, Simple photometry of optical systems, Non-sequential raytrace, Illumination in Zemax</td>
</tr>
<tr>
<td>21.06</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>28.06</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>05.07</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>12.07</td>
<td>Correction II</td>
<td>Field lenses, Stop position influence, Aspheres and higher orders, Principles of glass selection, Sensitivity of a system correction, Microscopic objective lens, Zoom system</td>
</tr>
<tr>
<td>12.07</td>
<td>Physical optical modelling</td>
<td>Gaussian beams, POP propagation, polarization raytrace, polarization transmission, polarization aberrations</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.
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

- 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
Lens Catalogs

- 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
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

- Menu option:
  - 'Glass Fitting Tool' doesn't work (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 $\mu$m 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 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

![Slider example](image1)

- Example 2: Optical compensated zoom system

![Slider example](image2)
- Menu Tools / Design / Visual optimization
- Change of variable quantities by slider and instantaneous change of all windows
- 'Optimization' under visual control of the consequences
- Output of numerical data of results:
  Text option with save: generation of ASCII file
- 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.
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

- \( a = AQVAL() \) numerical aperture
- \( ro = CURV(j) \) surface curvature of surface no. \( j \)
- \( y = FLDY(j) \) field size no. \( j \)
- \( u = RAYL(j) \) direction cosine of real ray at surface no. \( j \)
- \( y = RAYY(j) \) \( y \)-value of real ray at surface no. \( j \)
- \( t = THIC(j) \) 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
! 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
nfield = 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/(nfield - 1)
dp = 2/(npup - 1)
!
! determine the index of image surface
n = nsur()
!
! header row in output: nfield 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

\[
\text{raytrace} \ hx, \ hy, \ px, \ py, \ jwave \\
\text{xp} = \text{rayx}(n) \\
\text{yp} = \text{rayy}(n) \\
\]

! error case

\[
\text{ierr} = \text{raye}() \\
\text{pr} = \sqrt{px^2 + py^2} \\
\text{if ( pr > 1) then ierr = 1} \\
\]

! summation of moments, scaling from mm into my

\[
\text{if (ierr == 0)} \\
\quad \text{Mx2} = \text{Mx2} + (xp-xc)(xp-xc)\times 1.e6 \\
\quad \text{My2} = \text{My2} + (yp-yc)(yp-yc)\times 1.e6 \\
\quad \text{endif} \\
\]

! end of pupil loops

\[
\quad \text{next} \\
\quad \text{next} \\
\]

! final calculation of moments for present field location and print of results

\[
\text{Mx2} = \text{Mx2} / \text{Nray} / 3.14159 \\
\text{My2} = \text{My2} / \text{Nray} / 3.14159 \\
\]

! \quad \text{determine field size}

\[
\text{Hy} = \text{fldy}(jy) \\
\text{FORMAT 8.4} \\
\text{PRINT " ",""," centroid yc = ",yc," My2 = ",My2 \\
\text{print " "} \\
\]

! \quad \text{end of field loop}

\text{next}
Matlab Coupling with MZDDE

- Calling Zemax as Raytrace-engine from Matlab
- Freeware MZDDE (Mathworks File Exchange) allows coupling of Matlab with Zemax
  Zemax DDE server toolbox
- Zemax must be opened
- Debugging is complicated
- Problems with timeout, refreshing and updating of data, especially under 64 bit windows

```matlab
% Direct called subroutines:

ierr = 0;  vig = ones(npv, npx, 1);  cz = zeros(nzern, 1);
focL = 0;  NA = 0;  distP = zeros(21, 1);
auto = 0;

% Initializing Zemax system data
chan = zDDEInit;
Status = zLoadFile(fname);
Timeout = 5;  UpdateFlag = 1;
Status = zPushLens(Timeout, UpdateFlag);

% set desired wavelength for wavenumber 1
WaveNumber = 1;  % check old wavelength
WaveData = zGetWave(WaveNumber);  wvlold = WaveData;
WaveData = zSetWave(WaveNumber, wvl*1000, 1);
Status = zPushLens(Timeout, UpdateFlag);

% set of desired chief ray coordinates
FieldInfo = zGetField(0);
FieldData = zSetField(1, xi, yi, 1, 0, 0, 0, 0, 0);
Status = zPushLens(Timeout, UpdateFlag);
pause(0.2);
zGetRefresh;

% number of surfaces
SystemData = zGetSystem;
nsurf = SystemData(1);
```
- Close DDE communications channel to ZENAX.
- Open communications channel to ZENAX DDE server.
- Attempt `addInit`. If no ZENAX running, attempt to s'.
- Delete a lens surface.
- Export lens CAD data (IGES, STEP, SAT) to a file.
- Check if lens CAD export has completed.
- Find integer label attached to a lens surface using
- Set lens surface data to 'fixed' mode.
- Set all lens surface data to 'fixed' mode.
- Get address line in Preferences/Address.
- Get the aspect ratio of ZENAX graphics or print win.
- Get DDE client specific data from a ZENAX window.
- Get a list of available coatings from the ZENAX COAT.
- Get current lens configuration, number of configurations.
- Get current date from ZENAX DDE server.
- Get single extra data value from ZENAX DDE server.
- Get data on lens field points.
- Get the filename of the currently loaded lens.
- Get first order data about the lens.
- Get data on a glass at a particular lens surface.
- Get a list of available text glass catalogues from.
- Get transformation matrix from local surface coord.
- Get index of refraction data at a lens surface.
- Retrieve integer label associated with a surface.
- Create Windows Metafile of a ZENAX graphic analysis
- As for `getMetaFile`, but with Save As dialog box.
- Get data from the ZENAX multi-configuration editor.
- Get .MTP computation from ZENAX for current lens. Re
- Get the name of the lens in ZENAX.
- Get number of NSC objects.
- Get data describing NSC objects in ZENAX.
- Get position data for an NSC object in ZENAX.
- Get numeric parameters associated with an NSC object.
- Get ZENAX settings affecting raytracing in non-seq