Optical Design with Zemax for PhD - Basics

Lecture 8: Advanced handling

2018-12-12

Herbert Gross

Speaker: Uwe Lippmann
<table>
<thead>
<tr>
<th>No</th>
<th>Date</th>
<th>Subject</th>
<th>Detailed content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.10.</td>
<td>Introduction</td>
<td>Zemax interface, menus, file handling, system description, editors, preferences, updates, system reports, coordinate systems, aperture, field, wavelength, layouts, diameters, stop and pupil, solves</td>
</tr>
<tr>
<td>2</td>
<td>24.10.</td>
<td>Basic Zemax handling</td>
<td>Raytrace, ray fans, paraxial optics, surface types, quick focus, catalogs, vignetting, footprints, system insertion, scaling, component reversal</td>
</tr>
<tr>
<td>3</td>
<td>07.11.</td>
<td>Properties of optical systems</td>
<td>aspheres, gradient media, gratings and diffractive surfaces, special types of surfaces, telecentricity, ray aiming, afocal systems</td>
</tr>
<tr>
<td>4</td>
<td>14.11.</td>
<td>Aberrations I</td>
<td>representations, spot, Seidel, transverse aberration curves, Zernike wave aberrations</td>
</tr>
<tr>
<td>5</td>
<td>21.11.</td>
<td>Aberrations II</td>
<td>Point spread function and transfer function</td>
</tr>
<tr>
<td>6</td>
<td>28.11.</td>
<td>Optimization I</td>
<td>algorithms, merit function, variables, pick up’s</td>
</tr>
<tr>
<td>7</td>
<td>05.12.</td>
<td>Optimization II</td>
<td>methodology, correction process, special requirements, examples</td>
</tr>
<tr>
<td>8</td>
<td>12.12.</td>
<td>Advanced handling</td>
<td>slider, universal plot, I/O of data, material index fit, multi configuration, macro language</td>
</tr>
<tr>
<td>9</td>
<td>09.01.</td>
<td>Imaging</td>
<td>Fourier imaging, geometrical images</td>
</tr>
<tr>
<td>10</td>
<td>16.01.</td>
<td>Correction I</td>
<td>Symmetry, field flattening, color correction</td>
</tr>
<tr>
<td>11</td>
<td>23.01.</td>
<td>Correction II</td>
<td>Higher orders, aspheres, freeforms, miscellaneous</td>
</tr>
<tr>
<td>12</td>
<td>30.01.</td>
<td>Tolerancing I</td>
<td>Practical tolerancing, sensitivity</td>
</tr>
<tr>
<td>13</td>
<td>06.02.</td>
<td>Tolerancing II</td>
<td>Adjustment, thermal loading, ghosts</td>
</tr>
<tr>
<td>14</td>
<td>13.02.</td>
<td>Illumination I</td>
<td>Photometry, light sources, non-sequential raytrace, homogenization, simple examples</td>
</tr>
<tr>
<td>15</td>
<td>20.02.</td>
<td>Illumination II</td>
<td>Examples, special components</td>
</tr>
<tr>
<td>16</td>
<td>27.02.</td>
<td>Physical modeling I</td>
<td>Gaussian beams, Gauss-Schell beams, general propagation, POP</td>
</tr>
<tr>
<td>17</td>
<td>06.03.</td>
<td>Physical modeling II</td>
<td>Polarization, Jones matrix, Stokes, propagation, birefringence, components</td>
</tr>
<tr>
<td>18</td>
<td>13.03.</td>
<td>Physical modeling III</td>
<td>Coatings, Fresnel formulas, matrix algorithm, types of coatings</td>
</tr>
<tr>
<td>19</td>
<td>20.03.</td>
<td>Physical modeling IV</td>
<td>Scattering and straylight, PSD, calculation schemes, volume scattering, biomedical applications</td>
</tr>
<tr>
<td>20</td>
<td>27.03.</td>
<td>Additional topics</td>
<td>Adaptive optics, stock lens matching, index fit, Macro language, coupling Zemax-Matlab / Python</td>
</tr>
</tbody>
</table>
1. Miscellaneous
2. Vignetting, diameter types, ray aiming
3. Material index fit
4. Lens catalogs
5. Graphical options
6. Slider and visual optimization
7. Multi configuration
8. Data IO
9. Macro language
Special Infinity Cases

- **Object in infinity**
  - incoming marginal ray parallel to axis
  - first distance infinity
  - off-axis field only as angle
  - no initial NA possible

- **Image in infinity**
  - outgoing marginal ray ideally parallel to axis
  - explicit declaration: ’afocal image space‘
  - geometrical aberrations as angles
  - wave aberration reference is plane wave
  - definition of Airy diameter in mrad

- **Entrance pupil in infinity**
  - incoming chief ray parallel to axis
  - explicit declaration: ’telecentric object space‘

- **Exit pupil in infinity**
  - outgoing chief ray ideally parallel to axis
The Special Infinity Cases

- **Simple case:**
  - object, image and pupils are lying in a finite distance
  - non-telecentric relay systems

- **Special case 1:**
  - object at infinity
  - object sided afocal
  - example: camera lens for distant objects

- **Special case 2:**
  - image at infinity
  - image sided afocal
  - example: eyepiece

- **Special case 3:**
  - exit pupil at infinity
  - image side telecentric
  - example: camera lens for metrology

- **Special case 4:**
  - exit pupil at infinity
  - image sided telecentric
  - example: old fashion lithographic lens
The Special Infinity Cases

- Very special: combination of above cases
  Examples:
  - both sided telecentric: 4f-system, lithographic lens
  - both sided afocal: afocal zoom
  - object sided telecentric, image sided afocal: microscopic lens

- Notice: telecentricity and afocality can not be combined on the same side of a system
Cardinal Elements in Zemax

- Cardinal elements of a selected surface range (lens or group)
In the menu Optimize → 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 Optimize → 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 radius or angular radius are available

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

Spots before and after the adjustment
System changes

- Useful commands for system changes:
  - Scaling (e.g. patents)
    Setup → Scale Lens
  - Insert system:
    load surface data from other file
    File → Insert Lens
  - Reverse system
    Lens Data Editor → Reverse Elements
System changes:

- Tilt/Decenter Elements
- Reverse Elements
- Scale Lens
- Make Focal
- Add Fold Mirror
- Delete Double Pass
- Local to Global
- Global to Local
- Convert Semi-Diameters to Circular Apertures
- Convert Semi-Diameters to Floating Apertures
- Convert Semi-Diameters to Maximum Apertures
- Remove All Apertures
- Replace Vignetting With Apertures
Local tilt and decenter of a surface

- no direct visibility in lens editor, only “(tilt/dec)” near surface index
- input in surface properties
- with or without effect on following system surfaces
Coordinate Break Surface

- dedicated surface for changing the coordinate system for subsequent surfaces
- Decenter in local X/Y and tilts about local X/Y/Z axes specified as surface parameters
- Order flag determines order of operations:
  0: dec X, dec Y, tilt X, tilt Y, tilt Z
  1: tilt Z, tilt Y, tilt X, dec Y, dec X

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Conic</th>
<th>TCE x 1E-6</th>
<th>Decenter X</th>
<th>Decenter Y</th>
<th>Tilt About X</th>
<th>Tilt About Y</th>
<th>Tilt About Z</th>
<th>Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJECT</td>
<td>Standard</td>
<td>.000</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Standard</td>
<td>.000</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Standard</td>
<td>.000</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Coordinate Break</td>
<td>-</td>
<td><strong>0.000</strong></td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Standard</td>
<td>.000</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Standard</td>
<td>.000</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Standard</td>
<td>.000</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Coordinate Break</td>
<td>-</td>
<td>0.000F</td>
<td>0.000F</td>
<td>0.000F</td>
<td>0.000F</td>
<td>0.000F</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Standard</td>
<td>.000</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Different possible options for specification of the aperture in Zemax:

1. Entrance pupil diameter
2. Image space F#
3. Object space NA
4. Paraxial working F#
5. Object cone angle
6. Floating by stop size

Stop location:

1. Fixes the chief ray intersection point
2. input not necessary for telecentric object space
3. is used for aperture determination in case of aiming

Special cases:

1. Object in infinity (NA, cone angle input impossible)
2. Image in infinity (afocal)
3. Object space telecentric
There are several different types of diameters in Zemax:

1. Surface stop
   - defines the axis intersection of the chief ray
   - usually no influence on aperture size
   - only one stop in the system
   - is indicated in the Lens Data Editor by STOP
   - if the initial aperture is defined, the size of the stop semi-diameter is determined by marginal raytrace
2. User-defined diameter at a surface in the Lens Data Editor (U)
   - serves also as drawing size in the layout (for nice layouts)
   - if the diameter in the stop plane is fixed, the initial aperture can be computed automatically by
     General / Aperture Type / Float by Stop Size
     This corresponds to a ray aiming

3. Individual apertures of perhaps complicated shape at every surface
   - is indicated in the Lens Data Editor by “aper“
   - Apertures and obscurations
   - Circles, Ellipses, Rectangles, “Spider” Structures for telescopes
   - Complicated user-defined composite aperture defined by *.UDA aperture files
4. Individual aperture sizes for every field point can be set by the vignetting factors of the Field Data Editor
- real diameters at surfaces must be set
- reduces light cones are drawn in the layout
VDX, VDY: relative decenter of light cone in x, y
VCX, VCY: compression factors in x, y
VAN: azimuthal rotation angle of light cone
- If limiting diameters are set in the system, the corresponding factors can be calculated by the Set All Vignetting command
In the Lend Data Editor toolbar, the diameters and apertures can be converted automatically.
Ray Aiming

- If the stop surface is within the system:
  - by default rays are aimed at the center of the entrance pupil
  - first lens group introduces aberrations that prevent the chief ray from hitting the exact center of the physical stop

- Ray Aiming iterates the chief ray direction to hit the center of the physical stop
  - proper chief ray trace
  - adds computational effort
  - can fail for systems with large pupil aberrations (wide-angle systems)
Material Index Fit

- Establishing a special own material
- Select: Libraries → Materials Catalog
- 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

- Libraries → Materials Tools → Glass Fitting for fitting with larger datasets

- Two option for data input:
  1. manual entering of 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

→ check results for suitable accuracy, especially at wavelengths and temperatures with sparse input data and at intervall edges
- 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
- Top results are listed
- Combination of best single lens substitution is possible.

Ref.: D. Lokanathan
Stock Lens Matching

- Optimize → Stock Lens Matching
- Selection from all or just selected vendors from the list (click to select)

Ref.: D. Lokanathan
Stock Lens Matching

### Output

<table>
<thead>
<tr>
<th>Surfaces</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vendors</td>
<td>All</td>
</tr>
<tr>
<td>Show Matches</td>
<td>5</td>
</tr>
<tr>
<td>EFL Tolerance (%)</td>
<td>25</td>
</tr>
<tr>
<td>EPD Tolerance (%)</td>
<td>25</td>
</tr>
<tr>
<td>Air Thickness Comp.</td>
<td>On</td>
</tr>
<tr>
<td>Nominal Criterion</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>Component 1 Component</th>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>014-3470</td>
<td>0.003102</td>
<td>0.000008</td>
</tr>
<tr>
<td>013-2460</td>
<td>0.003109</td>
<td>0.000015</td>
</tr>
<tr>
<td>LDX-30.0-155.0-C</td>
<td>0.003109</td>
<td>0.000015</td>
</tr>
<tr>
<td>L-BCX148</td>
<td>0.003109</td>
<td>0.000015</td>
</tr>
<tr>
<td>GCL010223</td>
<td>0.003118</td>
<td>0.000024</td>
</tr>
</tbody>
</table>

Component 2 (Surfaces 13-14)

1) 313380000 (LINOS PHOTONICS)  
2) LDK-30.0-104.1-C (CVI MELLES GRIOT)  
3) IL4-0214 (EKSMA OPTICS)  
4) GCL010407 (DaHeng Optics)  
5) SLB-30B-100N (Sigma Koki)

<table>
<thead>
<tr>
<th>Component 2 Component</th>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>313380000</td>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>LDK-30.0-104.1-C</td>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>IL4-0214</td>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>GCL010407</td>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>SLB-30B-100N</td>
<td>0.003102</td>
<td>0.000008</td>
</tr>
</tbody>
</table>

Best Combinations

1) 1: 014-3470 (OPTOSIGMA)  
   2: 313380000 (LINOS PHOTONICS)

<table>
<thead>
<tr>
<th>Best Combinations</th>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>014-3470</td>
<td>0.003107</td>
<td>0.000012</td>
</tr>
<tr>
<td>313380000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Best Combinations</th>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>014-3470</td>
<td>0.003107</td>
<td>0.000012</td>
</tr>
<tr>
<td>LDK-30.0-104.1-C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Best Combinations</th>
<th>MF Value</th>
<th>MF Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>014-3470</td>
<td>0.003107</td>
<td>0.000013</td>
</tr>
<tr>
<td>SLB-30B-100N</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ref.: D. Lokanathan
Compact window with 4, 6 or 9 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

### Lens Data Editor

<table>
<thead>
<tr>
<th>Surf:Type</th>
<th>Thickness</th>
<th>Glass</th>
<th>Semi-Diameter</th>
<th>2nd Order Term</th>
<th>4th Order Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJ</td>
<td>Standard</td>
<td>Infinity</td>
<td>Infinity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STO</td>
<td>Standard</td>
<td>5.0000000</td>
<td>2.0000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2* Even Asph.</td>
<td>10.000000</td>
<td>BK7</td>
<td>15.0000000 U</td>
<td>0.0000000</td>
<td>-1.507E-005</td>
</tr>
<tr>
<td>3* Even Asph.</td>
<td>52.4612830</td>
<td></td>
<td>15.0000000 U</td>
<td>0.0000000</td>
<td>-1.269E-005</td>
</tr>
<tr>
<td>IMA</td>
<td>Standard</td>
<td>-</td>
<td>4.9563392</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
- One-dimensional: change of 4th order coefficient at first surface
- Two-dimensional case: dependence on the coefficients on both sides
Universal Plot

- Universal plot configurations can be saved and called later
- Useful example: spot diameter as a function of a variable: operator RSCH
- Many frequently used features are accessible with keyboard shortcuts
- Current assignments can be viewed and customized in Setup → Project Preferences → Shortcut Keys
- Most important are:
  - Help: F1
  - Edit a cell’s content: F2
  - Undo: F3
  - Glass Catalog: F4
  - Lens Catalog: F5
  - Merit Function: F6
  - Multi-Config Editor: F7
  - Insert surface before/after current surface: Insert/Ctrl+Insert
  - Toggle Variable: Ctrl+Z (works on all selected cells)
  - Optimize: Ctrl+Shift+O
  - Fold Mirror: Ctrl+Shift+F
  - Quick Focus: Ctrl+Shift+Q
- Slider option in menu: Optimize → 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 1](image)

- Example 2: Optical compensated zoom system

![Slider 2](image)
Visual optimization

- Optimize → Visual Optimizer
- Change of variable quantities by slider and instantaneous change of all or selected windows
- 'Optimization' under visual control of the consequences
Multi Configuration

- Multi configuration editor
- Establishment of different system paths or configurations
- Forward/backward switch between configurations with Ctrl+A/Ctrl+Shift+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 configurations in the 3D layout drawing simultaneously
  1. shifted, for comparison
  2. with same reference, overlayed
Multi Configuration

- Demonstrational example: Twyman-Green interferometer
Output of numerical data of results:
Text option with save: generation of ASCII file
Export of IGES / STEP files, for CAD data transfer
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: Programming → ZPL Macros Group
- 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

- \( a = \text{AVAL()} \)  
  system aperture value
- \( \rho = \text{CURV}(j) \)  
  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 \( j \)

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

! 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

```fortran
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
  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 " ",
  PRINT ",",","," centroid yc = ",yc," My2 = ",My2
  print " 
!
end of field loop
next
```