Optical Design with Zemax for PhD - Basics

Lecture 2: Basic Zemax handling

2019-10-30

Herbert Gross

Speaker: Yi Zhong

Winter term 2019
<table>
<thead>
<tr>
<th>No</th>
<th>Date</th>
<th>Subject</th>
<th>Detailed content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23.10.</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>30.10.</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>06.11.</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>13.11.</td>
<td>Aberrations I</td>
<td>representations, spot, Seidel, transverse aberration curves, Zernike wave aberrations</td>
</tr>
<tr>
<td>5</td>
<td>20.11.</td>
<td>Aberrations II</td>
<td>Point spread function and transfer function</td>
</tr>
<tr>
<td>6</td>
<td>27.11.</td>
<td>Optimization I</td>
<td>algorithms, merit function, variables, pick up’s</td>
</tr>
<tr>
<td>7</td>
<td>04.12.</td>
<td>Optimization II</td>
<td>methodology, correction process, special requirements, examples</td>
</tr>
<tr>
<td>8</td>
<td>11.12.</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>08.01.</td>
<td>Imaging</td>
<td>Fourier imaging, geometrical images</td>
</tr>
<tr>
<td>10</td>
<td>15.01.</td>
<td>Correction I</td>
<td>Symmetry, field flattening, color correction</td>
</tr>
<tr>
<td>11</td>
<td>22.01.</td>
<td>Correction II</td>
<td>Higher orders, aspheres, freeforms, miscellaneous</td>
</tr>
<tr>
<td>12</td>
<td>29.01.</td>
<td>Tolerancing I</td>
<td>Practical tolerancing, sensitivity</td>
</tr>
<tr>
<td>13</td>
<td>05.02.</td>
<td>Tolerancing II</td>
<td>Adjustment, thermal loading, ghosts</td>
</tr>
<tr>
<td>14</td>
<td>12.02.</td>
<td>Illumination I</td>
<td>Photometry, light sources, non-sequential raytrace, homogenization, simple examples</td>
</tr>
<tr>
<td>15</td>
<td>19.02.</td>
<td>Illumination II</td>
<td>Examples, special components</td>
</tr>
<tr>
<td>16</td>
<td>26.02.</td>
<td>Physical modeling I</td>
<td>Gaussian beams, Gauss-Schell beams, general propagation, POP</td>
</tr>
<tr>
<td>17</td>
<td>04.03.</td>
<td>Physical modeling II</td>
<td>Polarization, Jones matrix, Stokes, propagation, birefringence, components</td>
</tr>
<tr>
<td>18</td>
<td>11.03.</td>
<td>Physical modeling III</td>
<td>Coatings, Fresnel formulas, matrix algorithm, types of coatings</td>
</tr>
<tr>
<td>19</td>
<td>18.03.</td>
<td>Physical modeling IV</td>
<td>Scattering and straylight, PSD, calculation schemes, volume scattering, biomedical applications</td>
</tr>
<tr>
<td>20</td>
<td>25.03.</td>
<td>Additional topics</td>
<td>Adaptive optics, stock lens matching, index fit, Macro language, coupling Zemax-Matlab / Python</td>
</tr>
</tbody>
</table>
1. Raytrace
2. Paraxial optics
3. Surface types
4. Glass catalogs
5. Lens catalogs
6. Quick focus and adjustment
7. Vignetting
8. Footprints
9. System changes
**Scheme of raytrace**

- **Ray:** straight line between two intersection points
- **System:** sequence of spherical surfaces
- **Data:**
  - radii, curvature $c=1/r$
  - vertex distances
  - refractive indices
  - transverse diameter
- **Surfaces of 2nd order:**
  Calculation of intersection points analytically possible: fast computation

![Diagram showing ray trace](image)
Definition of a single ray by two points

First point in object plane:
relative normalized coordinates: Hx, Hy

Second point in entrance pupil plane:
relative normalized coordinates Px, Py
- Selection of 2 points on the ray on object and entrance pupil plane
- Real and paraxial rays are tabulated
- Coordinate reference can be selected to be local or global

### Raytrace in Zemax

#### Single Ray Trace

<table>
<thead>
<tr>
<th>Settings</th>
<th>OK</th>
<th>Cancel</th>
<th>Save</th>
<th>Load</th>
<th>Reset</th>
</tr>
</thead>
</table>

| Norm. X Field Coord (Xx) | 0.0000000000 |
| Norm. Y Field Coord (Yy) | 0.0000000000 |
| Norm. X Pupil Coord (Fx) | 0.0000000000 |
| Norm. Y Pupil Coord (Fy) | 1.0000000000 |

### Ray Trace Data

<table>
<thead>
<tr>
<th>Surf</th>
<th>X-coordinate</th>
<th>Y-coordinate</th>
<th>Z-coordinate</th>
<th>X-cosine</th>
<th>Y-cosine</th>
<th>Z-cosine</th>
<th>X-normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJ</td>
<td>Infinity</td>
<td>Infinity</td>
<td>Infinity</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.0000000000E+00</td>
<td>5.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>5.0000000000E+00</td>
<td>6.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>6.0000000000E+00</td>
<td>7.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>7.0000000000E+00</td>
<td>8.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>8.0000000000E+00</td>
<td>9.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>9.0000000000E+00</td>
<td>1.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1.0000000000E+00</td>
<td>1.1000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>1.1000000000E+00</td>
<td>1.2000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>1.2000000000E+00</td>
<td>1.3000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>1.3000000000E+00</td>
<td>1.4000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>1.4000000000E+00</td>
<td>1.5000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1.5000000000E+00</td>
<td>1.6000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>1.6000000000E+00</td>
<td>1.7000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>1.7000000000E+00</td>
<td>1.8000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>1.8000000000E+00</td>
<td>1.9000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>1.9000000000E+00</td>
<td>2.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>2.0000000000E+00</td>
<td>2.1000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
</tbody>
</table>

### Paraxial Ray Trace Data

<table>
<thead>
<tr>
<th>Surf</th>
<th>X-coordinate</th>
<th>Y-coordinate</th>
<th>Z-coordinate</th>
<th>X-cosine</th>
<th>Y-cosine</th>
<th>Z-cosine</th>
<th>X-normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJ</td>
<td>Infinity</td>
<td>Infinity</td>
<td>Infinity</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.0000000000E+00</td>
<td>5.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>5.0000000000E+00</td>
<td>6.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>6.0000000000E+00</td>
<td>7.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>7.0000000000E+00</td>
<td>8.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>8.0000000000E+00</td>
<td>9.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>9.0000000000E+00</td>
<td>1.0000000000E+00</td>
<td>0.0000000000E+00</td>
<td>0.0000000000</td>
<td>0.0000000000</td>
<td>1.0000000000</td>
<td></td>
</tr>
</tbody>
</table>
Ray fans and ray cones

- Ray fan: 2-dimensional plane set of rays
- Ray cone: 3-dimensional filled ray cone
- Optical Image formation:
  All ray emerging from one object point meet in the perfect image point

- Region near axis:
  Gaussian imaging
  Ideal, paraxial

- Image field size:
  Chief ray

- Aperture/size of light cone:
  Marginal ray defined by pupil stop
Formulas for surface and lens imaging

- Single surface imaging equation
  \[ \frac{n'}{s'} - \frac{n}{s} = \frac{n'-n}{r} = \frac{1}{f'} \]

- Thin lens in air focal length
  \[ \frac{1}{f'} = (n-1) \cdot \left( \frac{1}{r_1} - \frac{1}{r_2} \right) \]

- Thin lens in air with one plane surface, focal length
  \[ f' = \frac{r}{n-1} \]

- Thin symmetrical bi-lens
  \[ f' = \frac{r}{2 \cdot (n-1)} \]

- Thick lens in air focal length
  \[ \frac{1}{f'} = (n-1) \cdot \left( \frac{1}{r_1} - \frac{1}{r_2} \right) + \frac{(n-1)^2 d}{n \cdot r_1 r_2} \]
- Imaging by a lens in air: lens makers formula

\[
\frac{1}{s'} - \frac{1}{s} = \frac{1}{f}
\]

- Magnification

\[
m = \frac{s'}{s}
\]

- Real imaging: 

\[s < 0, s' > 0\]

- Intersection lengths \(s, s'\) measured with respective to the principal planes \(P, P'\)
Magnification

- Lateral magnification for finite imaging
- Scaling of image size

$$m = \frac{y'}{y} = -\frac{f \cdot \tan u}{f' \cdot \tan u'}$$
- Afocal systems with object/image in infinity
- Definition with field angle \( w \)
  - Angular magnification

\[
\Gamma = \frac{\tan w'}{\tan w} = \frac{nh}{n'h'}
\]

- Relation with finite-distance magnification

\[
m \cdot \Gamma = -\frac{f}{f'}
\]
Surface properties and settings

- Setting of surface properties

- Surface type
- Additional drawing switches
- Diameter
- Scattering options

- Local tilt and decenter
- Operator and sampling for POP
- Coating
- Import data file
Surface properties and settings

- Setting of surface properties
- Special surface types
- Data in Lens Data Editor
- Gradient media are described as 'special surfaces'
- Diffractive / micro structured surfaces described by simple ray tracing model in one order
Important Surface Types

- Special surface types
- Data in Lens Data Editor or in Extra Data Editor
- Gradient media are described as 'special surfaces'
- Diffractive / micro structured surfaces described by simple ray tracing model in one order

- Standard spherical and conic sections
- Even asphere classical asphere
- Paraxial ideal lens
- Paraxial XY ideal toric lens
- Coordinate break change of coordinate system
- Diffraction grating line grating
- Gradient 1 gradient medium
- Toroidal cylindrical lens
- Zernike Fringe sag surface as superposition of Zernike functions
- Extended polynomial generalized asphere
- Black Box Lens hidden system, from vendors
- ABCD paraxial segment
Surface Analysis in Zemax

- Analysis of surfaces
Surface Analysis in Zemax

- Analysis of surface sag
Surface Analysis in Zemax

- Analysis of surface curvature

![Diagram of Surface Analysis in Zemax](image)

- Surface Curvature
  - Sampling: 65 x 65
  - Data: Tangential Curvature
  - Show As: Contour

- Tangential Curvature
  - Width = 14, Decenter x = 0, y = 0 Millimeters
  - Curvature units are inverse Millimeters
  - Cross section is oriented at an angle of 0 degrees.
Surface Analysis in Zemax

- Analysis of freeform surfaces
Diffractive Surfaces in Zemax

- **Diffraction grating**
  
  Classical grating with straight lines
  
  Parameters: LP/mm, diffraction order

  Substrate can be curved, lines are straight in the local coordinate system on the surface

- **Elliptical grating 1:**
  
  Similar, but grooves can be curved for projection onto x-y-plane,

  Substrate can be aspheric

- **Elliptical grating 2:**
  
  Similar to 1, but curved lines defined by intersection of planes with asphere

- **Binary1**
  
  Substrate rotational symmetric asphere

  \[
  z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)c^2r^2}} + \alpha_1 r^2 + \alpha_2 r^4 + \alpha_3 r^6 + \alpha_4 r^8 + \alpha_5 r^{10} + \alpha_6 r^{12} + \alpha_7 r^{14} + \alpha_8 r^{16},
  \]

  Phase of binary element: extended polynomial, scaled on normalization radius in radiant

  \[
  \Phi = M \sum_{i=1}^{N} A_i E_i(x, y)
  \]
Diffractive Surfaces in Zemax

- **Binary2**
  Similar to 1, but phase only circular symmetric
  \[ \Phi = M \sum_{i=1}^{N} A_i \rho_i^{2i} \]

- **Binary3**
  Substrate and phase circular symmetric
  Two different data sets on two ring zones
  \[ z_1 = \frac{c_1 r^2}{1 + \sqrt{1 - (1 + k_1)c_1^2 r^2}} + \sum_{i=1}^{N} \alpha_{1i} r^{2i}, \text{ for } r \leq A_1, \]
  \[ z_2 = z_0 + \frac{c_2 r^2}{1 + \sqrt{1 - (1 + k_2)c_2^2 r^2}} + \sum_{i=1}^{N} \alpha_{2i} r^{2i}, \text{ for } r > A_1, \]
  \[ \Phi_1 = M_1 \sum_{i=1}^{N} \beta_{1i} \rho_1^{2i}, \text{ and } \rho_1 = \frac{r}{A_1}, \]
  \[ \Phi_2 = \delta_0 + M_2 \sum_{i=1}^{N} \beta_{2i} \rho_2^{2i}, \text{ where } \rho_2 = \frac{r}{A_2}. \]

- **Binary4**
  Similar to 3, but several zones possible
  \[ z_j(r) = \frac{c_j r^2}{1 + \sqrt{1 - (1 + k_j)c_j^2 r^2}} + \sum_{i=1}^{N \alpha} \alpha_{ji} \rho_i^{2i} + z_0. \]
  \[ \Phi_j = \delta_0 + M_j \sum_{i=1}^{N_p} \beta_{ji} \rho_j^{2i}, \]
Diffractive Surfaces in Zemax

- **Radial grating**
  Grating with circular symmetry and a line spacing, which changes over the radius

- **Variable line space grating**
  Straight lines but unevenly separated

- **Hologram 1**

- **Hologram 2**

- **Toroidal hologram**

- **Optically fabricated hologram**
  Defined by corresponding lens systems to generate the interference with residual aberrations

- **Toroidal grating**
  Cylindrical surface with usual line grating structure

- **Extended toroidal grating**

\[ d(p) = A_0 + A_1 p^1 + A_2 p^{-1} + A_3 p^2 + A_4 p^{-2} + \ldots , \]
Description of Grin Media in Zemax

- **Gradient 1**
  \[ n = n_0 + n_{r_2}r^2 + n_{r_1}r, \]

- **Gradient 2**
  \[ n^2 = n_0 + n_{r_2}r^2 + n_{r_4}r^4 + n_{r_6}r^6 + n_{r_8}r^8 + n_{r_{10}}r^{10} + n_{r_{12}}r^{12} \]

- **Gradient 3**
  \[ n = n_0 + n_{r_2}r^2 + n_{r_4}r^4 + n_{r_6}r^6 + n_{z_1}z + n_{z_2}z^2 + n_{z_3}z^3 \]

- **Gradient 4**
  \[ n = n_0 + n_{x_1}x + n_{x_2}x^2 + n_{y_1}y + n_{y_2}y^2 + n_{z_1}z + n_{z_2}z^2 \]

- **Gradient 5**
  \[ z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)c^2r^2}} + x\tan(\alpha) + y\tan(\beta) \]

- **Gradient 6**
  with dispersion
  \[ n = n_0 + n_1r^2 + n_2r^4 + n_3r^6 + n_4r^8 \]
  \[ n_x = A_x + B_x\lambda^2 + \frac{C_x}{\lambda^2} + \frac{D_x}{\lambda^4} \]

- **Gradient 7**
  spherical shells
  \[ n = n_0 + \alpha(r - R) + \beta(r - R)^2, \text{ where} \]
  \[ r = \frac{R}{|R|}\sqrt{x^2 + y^2 + (R - z)^2}. \]
Description of Grin Media in Zemax

- **GRADIUM**
  
  \[ n = \sum_{i=0}^{11} n_i \left( \frac{z + \Delta z}{z_{\text{max}}} \right)^i \]

- **Gradient 9**
  iso-index lines as z-surfaces

  \[ z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)c^2 r^2}} + x\tan(\alpha) + y\tan(\beta) \]

  \[ n = n_0 \left[ 1.0 - \frac{A}{2} r^2 \right] \quad A(\lambda) = \left[ K_0 + \frac{K_1}{\lambda^2} + \frac{K_2}{\lambda^4} \right]^2 \]

- **Gradient 10**

  \[ n = n_0 + n_1 y_1 a + n_2 y_2 a^2 + n_3 y_3 a^3 + n_4 y_4 a^4 + n_5 y_5 a^5 + n_6 y_6 a^6 \]

- **Grid gradient**
Description of Grin Media in Zemax

- **Gradient 1**
  \[ n = n_0 + n_{r2} r^2 + n_{r1} r, \]

- **Gradient 2**
  \[ n^2 = n_0 + n_{r2} r^2 + n_{r4} r^4 + n_{r6} r^6 + n_{r8} r^8 + n_{r10} r^{10} + n_{r12} r^{12} \]

- **Gradient 3**
  \[ n = n_0 + n_{r2} r^2 + n_{r4} r^4 + n_{r6} r^6 + n_{z1} z + n_{z2} z^2 + n_{z3} z^3 \]

- **Gradient 4**
  \[ n = n_0 + n_{x1} x + n_{x2} x^2 + n_{y1} y + n_{y2} y^2 + n_{z1} z + n_{z2} z^2 \]

- **Gradient 5**
  \[ z = \frac{c r^2}{1 + \sqrt{1 - (1 + k) c^2 r^2}} + x \tan(\alpha) + y \tan(\beta) \]

- **Gradient 6**
  with dispersion
  \[ n = n_0 + n_{1} r^2 + n_{2} r^4 + n_{3} r^6 + n_{4} r^8 \]
  \[ n_x = A_x + B_x \frac{\lambda^2}{\lambda^2} + C_x \frac{\lambda}{\lambda} + D_x \frac{1}{\lambda^4} \]

- **Gradient 7**
  spherical shells
  \[ n = n_0 + \alpha (r - R) + \beta (r - R)^2, \text{ where } \]
  \[ r = \frac{R}{|R|} \sqrt{x^2 + y^2 + (R - z)^2}. \]
Description of Grin Media in Zemax

- **GRADIUM**

\[ n = \sum_{i=0}^{11} n_i \left( \frac{z + \Delta z}{z_{max}} \right)^i \]

- **Gradient 9**
  iso-index lines as z-surfaces

- **Gradient 10**

- **Grid gradient**

\[ z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)c^2r^2}} + x\tan(\alpha) + y\tan(\beta) \]

\[ n = n_0 \left[ \frac{1.0 - \frac{A}{2}r^2}{A} \right] \]

\[ A(\lambda) = \left[ K_0 + \frac{K_1}{\lambda^2} + \frac{K_2}{\lambda^4} \right]^2 \]

\[ n = n_0 + n_{y1}y_a + n_{y2}y_a^2 + n_{y3}y_a^3 + n_{y4}y_a^4 + n_{y5}y_a^5 + n_{y6}y_a^6 \]
Relative Partial Dispersion

- Relative partial dispersion:
  Change of dispersion slope with \( \lambda \)
  Different curvature of dispersion curve

- Definition of local slope for selected wavelengths relative to secondary colors

\[
P_{\lambda_1 \lambda_2} = \frac{n(\lambda_1) - n(\lambda_2)}{n_F - n_C}
\]

- Special \( \lambda \)-selections for characteristic ranges of the visible spectrum

\( \lambda = 656 / 1014 \) nm far IR
\( \lambda = 656 / 852 \) nm near IR
\( \lambda = 486 / 546 \) nm blue edge of VIS
\( \lambda = 435 / 486 \) nm near UV
\( \lambda = 365 / 435 \) nm far UV

![Graph showing n(\( \lambda \)) vs. \( \lambda \) with marked wavelengths and colors.](image)
Anormal partial dispersion and normal line
Glasses in Zemax

- Selection of glass catalogs in
  - system Explorer / Material catalogs
  - use your own catalog
- Viewing of glass properties in
  Material analyses
Glasses in Zemax

- For optimization
  - Definition of a glass as a variable point in the glass map
    → model glass

- Establish own glass catalogs with
  - additional glasses
  - preferred choices as an individual library

Ref.: B. Böhme
Material Index Fit

- choice of 4 dispersion formula
- after fit:
  - PV and RMS of approximation visible
  - no individual errors seen

→ check results for suitable accuracy, especially at wavelengths and temperatures with sparse input data and at interval edges

- add to catalog
- enter additional data
- Save catalog
■ 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?)
- **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
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
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</th>
<th>Variables</th>
<th>Vendors</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show Matches</td>
<td>5</td>
<td>EFL Tolerance (%)</td>
<td>25</td>
</tr>
<tr>
<td>EPD Tolerance (%)</td>
<td>25</td>
<td>Air Thickness Comp.</td>
<td>On</td>
</tr>
<tr>
<td>Nominal Criterion</td>
<td>0.003094</td>
<td>Component 1 (Surfaces 10-11)</td>
<td></td>
</tr>
<tr>
<td>1)</td>
<td>014-3470 (OPTOSIGMA)</td>
<td>0.003102</td>
<td>0.000008</td>
</tr>
<tr>
<td>2)</td>
<td>013-2450 (OPTOSIGMA)</td>
<td>0.003109</td>
<td>0.000015</td>
</tr>
<tr>
<td>3)</td>
<td>LDX-30.0-155.0-C (CVI MELLES GRIOT)</td>
<td>0.003109</td>
<td>0.000015</td>
</tr>
<tr>
<td>4)</td>
<td>L-BCX148 (ROSS OPTICAL)</td>
<td>0.003109</td>
<td>0.000015</td>
</tr>
<tr>
<td>5)</td>
<td>GCL010223 (DaHeng Optics)</td>
<td>0.003118</td>
<td>0.000024</td>
</tr>
<tr>
<td>Component 2 (Surfaces 13-14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1)</td>
<td>31338000 (LINOS PHOTONICS)</td>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>2)</td>
<td>LDK-30.0-104.1-C (CVI MELLES GRIOT)</td>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>3)</td>
<td>114-0214 (EKSM OPTICS)</td>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>4)</td>
<td>GCL010407 (DaHeng Optics)</td>
<td>0.003094</td>
<td>-0.000000</td>
</tr>
<tr>
<td>5)</td>
<td>SLB-30B-100N (Sigma Koki)</td>
<td>0.003102</td>
<td>0.000008</td>
</tr>
</tbody>
</table>

Best Combinations

1) 1: 014-3470 (OPTOSIGMA)
   2: 31338000 (LINOS PHOTONICS)
   MF Value | MF Change
   0.003107 | 0.000012

2) 1: 014-3470 (OPTOSIGMA)
   2: LDK-30.0-104.1-C (CVI MELLES GRIOT)
   MF Value | MF Change
   0.003107 | 0.000012

3) 1: 014-3470 (OPTOSIGMA)
   2: SLB-30B-100N (Sigma Koki)
   MF Value | MF Change
   0.003107 | 0.000013

Ref.: D. Lokanathan
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.
   But: the effect is iterative, in case of nonlinearities, some calls are necessary.

- Special application: adjust the air distance before a collimation lens to get the best collimation.
- As criteria, wavefront, spot diameter of angular radius.
- Example: Move a lens in between a system to focus the image.
  Spots before and after the adjustment.
Cardinal elements of a lens

- **Focal points:**
  1. incoming parallel ray intersects the axis in F'
  2. ray through F is leaves the lens parallel to the axis

- **Principal plane P:** location of apparent ray bending

- **Nodal points:**
  Ray through N goes through N' and preserves the direction
Cardinal Elements in Zemax

- Cardinal elements of a selected index range (lens or group)

File: C:\Users\zhong\Documents\Zemax\Samples\Sequential\Objectives\Double Gauss
Title: DOUBLE GAUSS
Date: 9/19/2018

Starting surface: 1
Ending surface: 12
Wavelength: 0.587600
Orientation: Y-Z
Lens units: Millimeters

Object space positions are measured with respect to surface 1.
Image space positions are measured with respect to surface 12.
The index in both the object space and image space is considered.

<table>
<thead>
<tr>
<th></th>
<th>Object Space</th>
<th>Image Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal Length</td>
<td>-99.500679</td>
<td>99.500679</td>
</tr>
<tr>
<td>Focal Planes</td>
<td>-32.524673</td>
<td>0.183431</td>
</tr>
<tr>
<td>Principal Planes</td>
<td>66.976066</td>
<td>-99.317248</td>
</tr>
<tr>
<td>Anti-Principal Planes</td>
<td>-132.025352</td>
<td>99.684110</td>
</tr>
<tr>
<td>Nodal Planes</td>
<td>66.976066</td>
<td>-99.317248</td>
</tr>
<tr>
<td>Anti-Nodal Planes</td>
<td>-132.025352</td>
<td>99.684110</td>
</tr>
</tbody>
</table>
Vignetting

- Artificial vignetting:
  Truncation of the free area of the aperture light cone

- Natural Vignetting:
  Decrease of brightness according to \( \cos w \) due to oblique projection of areas and changed photometric distances
- 3D-effects due to vignetting
- Truncation of the at different surfaces for the upper and the lower part of the cone
- Truncation of the light cone with asymmetric ray path for off-axis field points
- Intensity decrease towards the edge of the image
- Definition of the chief ray: ray through energetic centroid
- Vignetting can be used to avoid uncorrectable coma aberrations in the outer field
- Effective free area with extrem aspect ratio: anamorphic resolution

Diagram:
- Vignetting
- Projection of the rim of the 1st lens
- Projection of the rim of the 2nd lens
- Free area of the aperture
- Chief ray
- Meridional coma rays
- Sagittal coma rays
Vignetting

- Illumination fall off in the image due to vignetting at the field boundary
Footprints

- Looking for the ray bundle cross sections
- Equivalent to spot diagram
Modifications and System Setups

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