Optical Design with Zemax

Lecture 1: Introduction
2014-04-11
Herbert Gross
Overview

- Time: Friday, 8.15 – 9.45
- Location: Computerpool, Helmholtzweg 4
- Web page on IAP homepage under 'learning/materials' provides slides and exercises Zemax files
- Contents (type of the lecture):
  - Not: pure Zemax handling
  - But: - optical design with Zemax as tool
    - understanding of simulation opportunities and limits
    - learning by doing
    - mix of theory/principles, presented examples and own exercises
    - questions and dialog welcome
- The content is adapted and is changed depending on progress
- Seminar: Exercises and solution of given problems
  - time: Tuesday, 10.15 -11.45
  - Computerpool, Helmholtzweg 4
- starting date: 2014-04-15
- Shift of some dates could be possible
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<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Topic</th>
<th>Details</th>
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<td>Properties of optical systems I</td>
<td>Diameters, stop and pupil, vignetting, Layouts, Materials, Glass catalogs, Raytrace, Ray fans and sampling, Footprints</td>
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<td>Properties of optical systems II</td>
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<td>Aberrations I</td>
<td>Representation of geometrical aberrations, Spot diagram, Transverse aberration diagrams, Aberration expansions, Primary aberrations,</td>
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<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>
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<td>Symmetry principle, Lens bending, Correcting spherical aberration, Coma, stop position, Astigmatism, Field flattening, Chromatical correction, Retrofocus and telephoto setup, Design method</td>
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<td>Gaussian beams, POP propagation, polarization raytrace, illumination</td>
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## Literature on optical design

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<th>Title</th>
<th>Publisher</th>
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<tr>
<td>1.</td>
<td>Kingslake</td>
<td>Lens design fundamentals, SPIE Press</td>
<td>2010</td>
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<td>2.</td>
<td>Mouroulis / McDonald</td>
<td>Geometrical Optics and Optical Design</td>
<td>Oxford</td>
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<td>Laikin</td>
<td>Lens Design</td>
<td>Dekker</td>
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<td>8.</td>
<td>Geary</td>
<td>Lens Design with practical Examples</td>
<td>Willmann-Bell</td>
<td>2002</td>
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<td>9.</td>
<td>Gross (Ed.)</td>
<td>Handbook of optical systems</td>
<td>Wiley</td>
<td>2005</td>
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<td>10.</td>
<td>Shannon</td>
<td>The art and science of optical design</td>
<td>Cambridge Univ. Press</td>
<td>1997</td>
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<td>11.</td>
<td>G. Smith</td>
<td>Practical computer-aided lens design</td>
<td>Willman Bell</td>
<td>1998</td>
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</table>
Contents 1st Lecture

1. Introduction
2. Zemax interface, menus, file handling, preferences
3. Editors, updates, windows
4. Coordinate systems and notations
5. System description
6. Component reversal, system insertion, scaling
7. Solves and pickups, variables
8. 3D geometry
9. Aperture, field, wavelength
Modelling of Optical Systems

- Principal purpose of calculations:
  - System, data of the structure (radii, distances, indices, ...)
  - Function, data of properties, quality performance (spot diameter, MTF, Strehl ratio, ...)
  - Analysis imaging aberration theorie
  - Synthesis lens design

- Imaging model with levels of refinement
  - Paraxial model (focal length, magnification, aperture, ...)
    - Analytical approximation and classification (aberrations, ...)
    - Geometrical optics (transverse aberrations, wave aberration, distortion, ...)
      - with diffraction
      - approximation $\lambda \rightarrow 0$
    - Wave optics (point spread function, OTF, ...)
  - linear approximation
  - Taylor expansion

Ref: W. Richter
Five levels of modelling:

1. Geometrical raytrace with analysis
2. Equivalent geometrical quantities, classification
3. Physical model: complex pupil function
4. Primary physical quantities
5. Secondary physical quantities

Blue arrows: conversion of quantities
There are 4 types of windows in Zemax:
1. Editors for data input:
   - lens data, extra data, multiconfiguration, tolerances
2. Output windows for graphical representation of results
   - Here mostly setting-windowss are supported to optimize the layout
3. Text windows for output in ASCII numerical numbers (can be exported)
4. Dialog boxes for data input, error reports and more

There are several files associates with Zemax
1. Data files (.ZMX)
2. Session files (.SES) for system settings (can be de-activated)
3. Glass catalogs, lens catalogs, coating catalogs, BRDF catalogs, macros, images, POP data, refractive index files,...

There are in general two working modes of Zemax
1. Sequential raytrace (or partial non-sequencial)
2. Non-sequential
Settings and Environment

- The settings can be customized in the preferences
- All the settings can be saved
- Important:
  - data file folders
  - graphics parameters
  - editor cell size and Text font
  - preferred fast button functions
  - colors
  - language (don't use German !)
Coordinate Systems and Sign of Quantities

- Coordinate systems
  2D sections: y-z shown

- Sign of lengths, radii, angles:
  - Negative: to the left
  - Positive: to the right
  - Reference angle positive: counterclockwise

\[ -s \] negative: to the left
\[ +s \] positive: + R to the right

\[ -R_2 \] positive: C to the right
\[ +R_1 \] negative: C to the left

\[ +\varphi \] angle positive: counterclockwise
Description of Optical Systems

- Interface surfaces
  - mathematical modelled surfaces
  - planes, spheres, aspheres, conics, free shaped surfaces,…

- Size of components
  - thickness and distances along the axis
  - transversal size, circular diameter, complicated contours

- Geometry of the setup
  - special case: rotational symmetry
  - general case: 3D, tilt angles, offsets and decentrations, needs vectorial approach

- Materials
  - refractive indices for all used wavelengths
  - other properties: absorption, birefringence, nonlinear coefficients, index gradients,…

- Special surfaces
  - gratings, diffractive elements
  - arrays, scattering surfaces
**System Model**

- **Single step:**
  - surface and transition
  - parameters: radius, diameter, thickness, refractive index, aspherical constants, conic parameter, decenter, tilt,...

- **Complete system:**
  - sequence of surfaces
  - object has index 0
  - image has index N
  - $t_N$ does not exist

- **Ray path has fixed sequence**
  0-1-2-...-(N-1)-N
### System Data Tables

**Menu: reports / prescription data**

#### Prescription Data Settings

- **General Data**
- **Surface Data**
- **Surface Detail**
- **Edge Thickness**
- **Multi-Config Data**
- **Solves/Variables**
- **Index/TEC Data**

#### Fields

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### System Data Tables

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#### GLOBAL VERTEX COORDINATES, ORI 3D GEOMETRY DATA / OFFSET MATRICES:

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#### INDEX DATA

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</table>
Necessary data for system calculation:
1. system surfaces with parameters (radius)
2. distances with parameters (length, material)
3. stop surface
4. wavelength(s)
5. aperture
6. field point(s)

Optional inputs:
1. finite diameters
2. vignetting factors
3. decenter and tilt
4. coordinate reference
5. weighting factors
6. multi configurations
7. ...
System Changes

- Useful commands for system changes:
  1. Scaling (e.g. patents)
  2. Insert system with other system file
     File - Insert Lens

  2. Reverse system
Important Surface Types

- **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 Properties and Settings

- Setting of surface properties

- Surface type
- Additional drawing switches
- Diameter
- Local tilt and decenter
- Operator and sampling for POP scattering options
- Coating
- Value of the parameter depends on other requirement
- Pickup of radius/thickness: linear dependence on other system parameter
- Determined to have fixed:
  - marginal ray height
  - chief ray angle
  - marginal ray normal
  - chief ray normal
  - aplanatic surface
  - element power
  - concentric surface
  - concentric radius
  - F number
  - marginal ray height
  - chief ray height
  - edge thickness
  - optical path difference
  - position
  - compensator
  - center of curvature
  - pupil position
Examples for solves:
1. last radius forces given image aperture
2. get symmetry of system parts
3. multiple used system parts
4. moving lenses with constant system length
5. bending of a lens with constant focal length
6. non-negative edge thickness of a lens
7. bending angle of a mirror (i' = i)
8. decenter/tilt of a component with return
- Open different menus with a right-mouse-click in the corresponding editor cell
- Solves can be chosen individually
- Individual data for every surface in this menu
3D Geometry

- General input of tilt and decenter:
  - Coordinate break surface
- Change of coordinate system with lateral translation and 3 rotations angles
- Direct listing in lens editor
- Not shown in layout drawing
3D Geometry

- **Auxiliary menus:**
  1. Tilt/Decenter element
  2. Folding mirror
3D Geometry

- Local tilt and decenter of a surface
  1. no direct visibility in lens editor
     only + near surface index
  2. input in surface properties
  3. with effect on following system surfaces
Definition of Aperture and Field

- Imaging on axis: circular / rotational symmetry
  Only spherical aberration and chromatical aberrations

- Finite field size, object point off-axis:
  - chief ray as reference
  - skew ray bundles: coma and distortion
  - Vignetting, cone of ray bundle not circular symmetric
  - to distinguish: tangential and sagittal plane
Quantitative measures of relative opening / size of accepted light cone

- Numerical aperture

\[ NA = n \cdot \sin u' \]

- F-number

\[ F\# = \frac{f'}{D_{EX}} \]

- Approximation for small apertures:

\[ F\# = \frac{1}{2 \cdot NA} \]
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Selection of Wavelengths

- Setting of wavelengths:
  - maximum of 24 values
  - weighting factors allow for spectral modelling
  - unit is always \( \mu m \)
  - selection of primary wavelength: paraxial data are based on it