Design and Correction of optical Systems

Part 14: Optical system classification

Summer term 2012
Herbert Gross
<table>
<thead>
<tr>
<th></th>
<th>Topic</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basics</td>
<td>2012-04-18</td>
</tr>
<tr>
<td>2</td>
<td>Materials</td>
<td>2012-04-25</td>
</tr>
<tr>
<td>3</td>
<td>Components</td>
<td>2012-05-02</td>
</tr>
<tr>
<td>4</td>
<td>Paraxial optics</td>
<td>2012-05-09</td>
</tr>
<tr>
<td>5</td>
<td>Properties of optical systems</td>
<td>2012-05-16</td>
</tr>
<tr>
<td>6</td>
<td>Photometry</td>
<td>2012-05-23</td>
</tr>
<tr>
<td>7</td>
<td>Geometrical aberrations</td>
<td>2012-05-30</td>
</tr>
<tr>
<td>8</td>
<td>Wave optical aberrations</td>
<td>2012-06-06</td>
</tr>
<tr>
<td>9</td>
<td>Fourier optical image formation</td>
<td>2012-06-13</td>
</tr>
<tr>
<td>10</td>
<td>Performance criteria 1</td>
<td>2012-06-20</td>
</tr>
<tr>
<td>11</td>
<td>Performance criteria 2</td>
<td>2012-06-27</td>
</tr>
<tr>
<td>12</td>
<td>Measurement of system quality</td>
<td>2012-07-04</td>
</tr>
<tr>
<td>13</td>
<td>Correction of aberrations 1</td>
<td>2012-07-11</td>
</tr>
<tr>
<td>14</td>
<td>Optical system classification</td>
<td>2012-07-18</td>
</tr>
</tbody>
</table>
14.1 Overview and classification
14.2 Achromate
14.3 Collimator
14.4 Microscope optics
14.5 Photographic optics
14.6 Zoom lenses
14.7 Telescopes
14.8 Miscellaneous
14.9 Lithographic projection systems
- Classification of systems with field and aperture size

- Scheme is related to size, correction goals and etendue of the systems

- Aperture dominated:
  Disk lenses, microscopy, Collimator

- Field dominated:
  Projection lenses, camera lenses, Photographic lenses

- Spectral width as a correction requirement is missed in this chart
1. Photo objective lens

2. Microscope objective lens

3. Binocular

4. Infrared afocal system
5. Relay optics

6. Scan-objective lens

7. Collimator objective lens

possible surfaces under test
8. Projector lens

9. Telescope

10. Lithography projection lens
11. Illumination collector system

12. Illumination condenser system

13. Head mounted display
14. Stereo microscope

15. Zoom system
Achromate:
- Axial colour correction by cementing two different glasses
- Bending: correction of spherical aberration at the full aperture
- Aplanatic coma correction possible be clever choice of materials

Four possible solutions:
- Crown in front, two different bendings
- Flint in front, two different bendings

Typical:
- Correction for object in infinity
- Spherical correction at center wavelength with zone
- Diffraction limited for NA < 0.1
- Only very small field corrected
Advantage of cementing:
- solid state setup is stable at sensitive middle surface with large curvature

Disadvantage:
- loss of one degree of freedom

Different possible realization forms in practice
Achromate : Basic Formulas

- Idea:
  1. Two thin lenses close together with different materials
  2. Total power
     \[ F = F_1 + F_2 \]
  3. Achromatic correction condition
     \[ \frac{F_1}{\nu_1} + \frac{F_2}{\nu_2} = 0 \]

- Individual power values
  \[ F_1 = \frac{1}{1 - \frac{\nu_2}{\nu_1}} \cdot F \]
  \[ F_2 = \frac{1}{1 - \frac{\nu_1}{\nu_2}} \cdot F \]

- Properties:
  1. One positive and one negative lens necessary
  2. Two different sequences of plus (crown) / minus (flint)
  3. Large \( \nu \)-difference relaxes the bendings
  4. Achromatic correction independent from bending
  5. Bending corrects spherical aberration at the margin
  6. Aplanatic coma correction for special glass choices
  7. Further optimization of materials reduces the spherical zonal aberration
- Cemented achromate:
  6 degrees of freedom:
  3 radii, 2 indices, ratio $v_1/v_2$

- Correction of spherical aberration:
  diverging cemented surface with positive
  spherical contribution for $n_{\text{neg}} > n_{\text{pos}}$

- Choice of glass: possible goals
  1. aplanatic coma correction
  2. minimization of spherochromatism
  3. minimization of secondary spectrum

- Bending has no impact on chromatical correction:
  is used to correct spherical aberration at the edge

- Three solution regions for bending
  1. no spherical correction
  2. two equivalent solutions
  3. one aplanatic solution, very stable
Achromatic solutions in the Glass Diagram

- flint negative lens
- crown positive lens
- Achromat
- Achromate
- Longitudinal aberration
- Transverse aberration
- Spot diagram
- Residual aberrations of an achromate
- Clearly seen:
  1. Distortion
  2. Chromatical magnification
  3. Astigmatism
Collimation source radiation:
  Finite divergence angle is reality
- Geometrical part due to finite size:
  \[ \theta_G = \frac{D}{f} \]
- Diffraction part:
  \[ \theta_D = \frac{\lambda}{D} \]
- Defocussing contribution to divergence
  \[ \Delta \theta = -\frac{2\Delta z}{f} \cdot \sin u \]
- Monochromatic doublet
- Correction only spherical and coma:
  Seidel surface contributions
  Limiting: astigmatism and curvature

- Enlarged aperture: meniscus added
- Enlarging numerical aperture by aplanatic-concentric meniscus lenses
- Extreme good correction of spherical aberration
- Upper row: image planes
- Lower row: pupil planes
- Köhler setup
Sub-systems:

1. Detection / Imaging path
   1.1 objective lens
   1.2 tube with tube lens and binocular beam splitter
   1.3 eyepieces
   1.4 optional equipment for photo-detection

2. Illumination
   2.1 lamps with collector and filters
   2.2 field aperture
   2.3 condenser with aperture stop
- Seidel surface contributions for 100x/0.90
- No field flattening group
- Lateral color in tube lens corrected
- Three different classes:
  1. No effort
  2. Semi-flat
  3. Completely flat
- Possible setups for flattening the field
- Goal:
  - reduction of Petzval sum
  - keeping astigmatism corrected
mechanical setup

1. thread
2. interface plane
3. spring for damage protection
4. -7. middle lens groups
8. correction ring
9. front lens group
10. socket of front lens
Families of photographic lenses
- Long history
- Not unique
Photographic Lenses

- Tessar
- Double Gauss
- Super Angulon
- Distagon
- Tele system
- Wide angle Fish-eye
- Example lens 2

- Distagon
- Nikon 210°

- Pleon
  (air reconnaissance)
- Distance $t$ increased
- First lens fixed
- Distance $t$ increased
- Image plane fixed
- System layout

\[
\begin{align*}
  f &= 50 \text{ mm} \\
  f &= 67 \text{ mm} \\
  f &= 100 \text{ mm} \\
  f &= 133 \text{ mm} \\
  f &= 200 \text{ mm}
\end{align*}
\]
Seidel surface contrib.
• Zoom lens

• Three moving groups
- **Kepler typ:**
  - internal focus
  - longer total track
  - \( \Gamma > 0 \)

- **Galilei typ:**
  - no internal focus
  - shorter total track
  - \( \Gamma < 0 \)
- Maksutov compact

- Klevtsov
Primary and secondary mirror
- Typical:
  - system layout with two groups
- Telecentricity error due to vignetting
- Telecentricity forces large diameters
- Transport over large distances
- Combination of several relay subsystems
- Large field-angle objective lens
- Applications: Technical or medical

Different subsystems:

- Objective
- 1. relay
- 2. relay
- 3. relay

![Diagram of relay systems](image)
Examples

- **US 7643225**
  - \(L = 4.2 \text{ mm}, F' = 2.8, f = 3.67 \text{ mm}, 2w = 2\times 34^\circ\)

- **US 6844989**
  - \(L = 6.0 \text{ mm}, F' = 2.8, f = 4.0 \text{ mm}, 2w = 2\times 31^\circ\)

- **EP 1357414**
  - \(L = 5.37 \text{ mm}, F' = 2.88, f = 3.32 \text{ mm}, 2w = 2\times 33.9^\circ\)

- **Olympus 2**
  - \(L = 7.5 \text{ mm}, F' = 2.8, f = 4.57 \text{ mm}, 2w = 2\times 33^\circ\)

Ref: T. Steinich
- Transport of laser light over large distances
- Adaptation of beam diameter
- Solutions:
  Telescopes of Kepler or Galilei type
- Comparison:
  Kepler:
  - internal focus
  - large overall length

  Galilei:
  - shorter length
  - better correction
- Wide angle model for larger fields
- Parameters for all accommodations
- Description of chromatical aberrations
The rings seem to move
- Distortion corrected
- General problems with eyepieces:
  - remote eye pupil
  - typical eye relief 22 mm
- Non-telecentric
- Scan angle 2x30°
- Monochromatic
- F-θ-corrected
System with
1. Illumination (horizontal)
2. Mask projection (vertical)
Lithographic Lens Example Layouts

1. relay group
2. relay group

reticle
stop
mask
wafer
intermediate image
mirror with relay group
- EUV $\alpha$-Tool 2008
A possible classification of optical systems is a sorting into field size and aperture size.

Aperture, field size and width of wavelength range are responsible for complexity.

Achromate: chromatical and spherical correction.

Achromate: additional degree of freedom allows for coma correction or reduction of spherochromatism.

Achromate: different realization options possible.

There exist quite different types of optical systems with individual specific problems.
Next lecture: Special lectures and applications in the context of optical design
Date: Winter term / October 2012