Reading Aberrations

Lens Design OPTI 517
Reading aberrations

- We cannot intelligently improve a lens system if we cannot recognize its aberrations
- Wave aberration fans
- It is critical that we learn to ‘read’ the aberrations of an optical system
Field of view

- Very small FOV: arc seconds, minutes
- Small FOV: sub-degree to a few degrees
- Small FOV: 5 to 30 degrees
- Medium FOV: 30 to 60 degrees
- Wide angle: > 60 degrees
- Hyper FOV: >180 degrees
Field of view

- Eye resolution and field of view
- The Moon
- The Sun
- 35 mm camera (f=50 mm)
Speed

- F/# > 10 slow
- F/# < 2.8 fast
- Eye speed?
Display of aberrations

- Historical nature
- Transverse ray aberration fans
- Wave aberration fans
- Field curves
- Aberration coefficients
- Spot diagrams
- Zernike decomposition
- Total aberration vs fourth-order
### Fourth-order wave aberrations fans

**Left plot: meridional. Right plot sagittal.**

<table>
<thead>
<tr>
<th>$W_{040}(\tilde{\rho} \cdot \tilde{\rho})^2$</th>
<th>$W_{131}(\tilde{H} \cdot \tilde{\rho})(\tilde{\rho} \cdot \tilde{\rho})$</th>
<th>$W_{222}(\tilde{H} \cdot \tilde{\rho})^2$</th>
</tr>
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### Fourth-order wavefront aberration shapes

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Transverse ray aberration fans
Left plot meridional, right plot sagittal.

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<tr>
<td></td>
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<tr>
<td>( W_{000} = 0 )</td>
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<table>
<thead>
<tr>
<th>First-order</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_{000} = 0 ) \hspace{1cm} ( W_{111} \bar{H} ) \hspace{1cm} ( 2W_{020} \bar{\rho} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th>Third-order</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 4W_{040} (\bar{\rho} \cdot \bar{\rho}) \bar{\rho} ) \hspace{1cm} ( W_{131} (\bar{\rho} \cdot \bar{\rho}) \bar{H} + 2(\bar{H} \cdot \bar{\rho}) \bar{\rho} ) \hspace{1cm} ( 2W_{222} (\bar{H} \cdot \bar{\rho}) \bar{H} )</td>
</tr>
<tr>
<td>( 2W_{220} (\bar{H} \cdot \bar{H}) \bar{\rho} ) \hspace{1cm} ( W_{311} (\bar{H} \cdot \bar{H}) \bar{H} ) \hspace{1cm} ( W_{400} = 0 )</td>
</tr>
</tbody>
</table>

\[ \vec{e} = \bar{y}_I \Delta \bar{H} \]

\[ \Delta \bar{H} = -\frac{1}{\mathcal{K}} \vec{\nabla}_\rho W \]
Guide to identifying aberrations from wave-fans

Monochromatic
1) Be aware of the speed and field of view
2) First, pay attention to the on axis aberrations
   • is it properly in focus?
   • is there spherical aberration W040?
   • is there higher order spherical?
   • what are the magnitudes?
3) Second, take a look at the full field aberrations
   • spherical
   • astigmatism
   • coma
   • Field curvature
   • higher order
Guide to identifying aberrations from wave-fans

4) Take a look at the 7/10 field
5) Verify with field curves, spot diagrams, and fourth-order coefficients

• Note: Real ray wavefront fans have fourth-order aberrations as components.
• Slow systems with small fields may be well described by fourth-order theory.
What is going on here?
Meridional and Sagittal planes

- A meridional plane contains the optical axis
- Sagittal from the Latin meaning arrow
Coddington Equations

\[
\frac{n' - n}{s'} - \frac{n' \cos I' - n \cos I}{s} = \frac{n' \cos^2 I' - n \cos^2 I}{R_s}
\]

\[
\frac{n' \cos^2 I' - n \cos^2 I}{t'} - \frac{n' \cos I' - n \cos I}{t} = \frac{n' \cos I' - n \cos I}{R_t}
\]

- s is the distance along the ray from the object point to the surface vertex
- s’ is the distance along the ray from the surface vertex to the image point
- t is the distance along the ray from the object point to the surface vertex
- t’ is the distance along the ray from the surface vertex to the image point
- Rs is the sagittal radius of curvature at the intersection point
- Rt is the tangential radius of curvature at the intersection point

- Actually Thomas Young equations
- Note change of aberration metric: longitudinal
Astigmatism
Field curves

Distortion = (H-h) * 100 / h
Field curves

Program may trace two close real rays

Distortion = (H-h) \times 100/h
Summary

• Being aware of the system speed and FOV

• Knowing how to read/identify aberrations

• Coddington/Thomas Young equations

• Article by R. Kingslake

WHO DISCOVERED CODDINGTON'S Equations?