Solution of Exercises
Lecture Optical design with Zemax – Part 6

6   Illumination / Handling

6.1 Ring illumination with axicon
Establish an illumination system with a ring shaped profile with the help of an axicon.
First load an achromatic lens with focal length \( f = 100 \text{ mm} \) out of a vendor catalog and create a collimated monochromatic beam with diameter \( D = 20 \text{ mm} \) and the wavelength 632.8 nm of HeNe as a laser source. The axicon consists of a plane an a conic surface. The conic surface can be approximated by a classical hyperbolic conic section with an extremme small radius of curvature. The conic constant must have a large negative value.

What happens, if the 'Quick focus' option is used ?
Now insert between the lens and the axicon a 'negative axicon', which diverges the light. What happens, if negative axicon is moved along the optical axis ?

Solution:

<table>
<thead>
<tr>
<th>Surf Type</th>
<th>Comment</th>
<th>Radius</th>
<th>Thickness</th>
<th>Glass</th>
<th>Semi-Diameter</th>
<th>Conic</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJ</td>
<td>Standard</td>
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<td>Infinity</td>
<td></td>
<td>0.00000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>1</td>
<td>Standard</td>
<td>Infinity</td>
<td>10.000000</td>
<td></td>
<td>10.0000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>*</td>
<td>Standard</td>
<td>LAG123</td>
<td>4.5000000</td>
<td>SK11</td>
<td>13.2500000</td>
<td>0.000000</td>
</tr>
<tr>
<td>3*</td>
<td>Standard</td>
<td>-41.75855</td>
<td>2.5000000</td>
<td>SF12</td>
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<tr>
<td>4*</td>
<td>Standard</td>
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<td>10.000000</td>
<td></td>
<td>12.0000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>5*</td>
<td>Standard</td>
<td>1.00E-005</td>
<td>5.0000000</td>
<td>M-K5</td>
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<td>-40.00000</td>
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<tr>
<td>6*</td>
<td>Standard</td>
<td>Infinity</td>
<td>90.000000</td>
<td></td>
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<td>0.000000</td>
</tr>
<tr>
<td>IME</td>
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<td>Infinity</td>
<td>-</td>
<td></td>
<td>8.630076</td>
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</table>
d4 = 10 mm:
It is seen, that in the plane of the smallest ring width, the diameter of the ring is changed, keeping the width constant.

6.2 Fiber coupling and radiation

An initial collimated laser beam of an Ar-Laser at $\lambda = 505$ nm and diameter $D = 4$ mm has to be coupled into a fiber of diameter $4 \, \mu m$, length $L = 20$ mm and numerical aperture of $NA = 0.1$. As a second step, the light should be re-collimated.

a) Extract an appropriate achromate out of a vendors catalog and check, if a good and efficient coupling can be achieved.

b) Estimate the coupling efficiency in the geometrical and the diffraction model.

c) Establish a fiber component with length 20 mm length as a non-sequential component and calculate the radiation profile at the exit surface in the geometrical optical model.

d) Now the emitted light should be collimated again by an achromate with focal length of $f = 50$ mm.

e) Discuss the homogeneity of the light behind this lens in the spatial domain. Are the rays perfectly collimated?

**Solution:**

a) The necessary focal length of the achromate should be $f = D/2/NA = 20$ mm.

In the catalog of Melles-Griot, we find a system with $f = 20$ mm: LAO-20.0-12.5
b) In the geometrical model, we get 100% incoupling efficiency:

In the diffraction model, we get 78% coupling efficiency:
c) To setup a fiber, the surface type non-sequential and circular light pipe with the parameters:
Exit location z: 20 mm
Material: mirror
Length: 20 mm
Front R: 0.002 mm
Back R: 0.002 mm

Due to the small fiber diameter, for larger angles a high number of reflections take place. Therefore a higher allowed allocation must be set in the general menu to avoid the error message.
Spot diagram at the exit surface is not uniform, there is a hot spot in the center.

d) In the Melles Griot catalog, we find the achromate LAO - 50.0 - 25 with focal length $f = 50$. This lens must be reversed and the correct distance must be found by a small optimization run with the angular spot radius as criterion. We then get the following data:

<table>
<thead>
<tr>
<th>Surf:Type</th>
<th>Comment</th>
<th>Radius</th>
<th>Thickness</th>
<th>Glass</th>
<th>Semi-Diameter</th>
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</thead>
<tbody>
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<td>Infinity</td>
<td></td>
<td>0.0000000</td>
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<td></td>
<td>2.0000000</td>
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<td>2a Standard</td>
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<td>N-BAK4</td>
<td>6.2500000 U</td>
</tr>
<tr>
<td>3a Standard</td>
<td></td>
<td>-9.911000</td>
<td>1.5000000</td>
<td>N-SF16</td>
<td>6.2500000 U</td>
</tr>
<tr>
<td>4 Standard</td>
<td></td>
<td>-32.97000</td>
<td>16.191141</td>
<td></td>
<td>6.2500000 U</td>
</tr>
<tr>
<td>5 Non-Sequ.</td>
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<td>-</td>
<td>QUARTZ</td>
<td>1.58E-003</td>
<td></td>
</tr>
<tr>
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<td></td>
<td>Infinity</td>
<td>44.042195</td>
<td>V</td>
<td>1.13E-003 U</td>
</tr>
<tr>
<td>7a Standard</td>
<td></td>
<td>78.956000</td>
<td>2.5000000</td>
<td>N-SF10</td>
<td>12.5000000 U</td>
</tr>
<tr>
<td>8 Standard</td>
<td></td>
<td>24.125000</td>
<td>9.0000000</td>
<td>N-BAK4</td>
<td>12.5000000 U</td>
</tr>
<tr>
<td>9 Standard</td>
<td>LAO-50.0-25.0</td>
<td>-31.94600</td>
<td>10.000000</td>
<td></td>
<td>12.5000000 U</td>
</tr>
<tr>
<td>IMA</td>
<td>Standard</td>
<td>Infinity</td>
<td>-</td>
<td></td>
<td>2.00E-003 U</td>
</tr>
</tbody>
</table>

e) The spot diagram behind the collimating lens in the spatial and the angle domain looks as follows.
The results is:
The angle distribution is not uniform but collimated well, the spatial distribution is uniform. The diameter of the collimated beam is D = 10.06 mm corresponding to a numerical aperture of NA = D/2f = 0.1 as in on the coupling side.

6.3 Multiconfiguration and Universal Plot

Load a classical achromate with a focal length of f = 100 mm, no field and numerical aperture NA = 0.1 from one of the vendor catalogs. Fix the wavelength to \( \lambda = 546.07 \) nm.

a) Add a thin mensicus shaped lens behind the system with an artificial refractive index of n = 2 to enlarge the numerical aperture by a factor of 2 without introducing spherical aberration. To achieve this, the surfaces must be aplanatic and concentric.

b) Now reduce the numerical aperture to a diameter of 2 mm and set a folding mirror in the front focal plane of the system. The incoming beam should be come from below and is deflected to the right side.

c) Generate a multi-configuration system for a scan system by rotating the mirror. The first coordinate break angle can take the values -50°, -47.5°, -45°, -42.5° and -40°. The second coordinate break should be defined by a pick up with a resulting bending angle of the system axis of -90°.

d) The chief ray of the scan system is telecentric in the paraxial approximation. Due to the residual aberrations of the system, there is a deviation from the telecentricity in the real system. Show this by a corresponding universal plot.

e) Show the variation of the spot in the image plane by using the slider.

Solution:

As a first step, the achromate AAP-100.0-25.4 from the Mess Griot catalog is loaded. The field is set to zero, the aperture has a diameter of D = 20 and the wavelength is set to 546 nm.

a) Two surfaces are added, the distances are chosen to be 1 and 2 mm. The first surface radius is taken as a solve to be aplanatic, the second to force the marginal ray angle to be -0.2. This corresponds to an aplanatic-concentric lens. Finally the image distance is optimized with the Quick focus menu.
In the Seidel bar menus it can be verified, that this lens does not introduce any spherical aberration.

b) First the two radii of the meniscus lens are frozen to be constant. Then the first distance is set to 0 and the cardinal points are calculated.
It is seen, that the front focal plane lies 46.8 mm in front of the system. The bending mirror is introduced in a corresponding distance.
c) The multi-configuration is established as follows:

\[
\begin{array}{ccccccc}
& \text{Active} & \text{Config 1} & \text{Config 2} & \text{Config 3} & \text{Config 4} & \text{Config 5} \\
1: & FRM & 2/3 & -50.0000000 & -47.5000000 & -45.0000000 & -42.5000000 & -40.0000000 \\
\end{array}
\]

\[10\]

\[c)\] The multi-configuration is established as follows:

\[\text{d) The universal plot is generated with a REAB-operand in the merit function for the 1st configuration.}\]
e) The spot diagram is used with dithered ray sampling and a fixed scale. The slider is configured as follows:

![Slider Configuration](image)

### 6.4 Multiconfiguration Interferometer 1

A Mach-Zehnder interferometer has the following principal geometry

![Interferometer Diagram](image)

a) Set up a Mach-Zehnder interferometer as a multi configuration. The incoming beam should have a wavelength of $\lambda = 632.8$ nm and is collimated with 10 mm diameter. The long sides of the interferometer are 100 mm long and the short ones 50 mm.

b) Introduce a Zernike surface on one side of the sample and make it visible in the interferogram. As an example, a spherical aberation of 5th order (term No. 16 in Fringe nomenclature) with 1 $\lambda$ coefficient should be used.

c) Show the effect on the interferogram, if one mirror is shifted in a direction by 1 mm, which causes a lateral displacement of the test beam. What happens, if the combining mirror is tilted wrong by 0.1°? What happens, if a tilt is set in the interferogramm settings?

**Solution:**

a) Setup of the interferometer:
b) On the front surface of the sample, a Zernike-Fringe type is introduced. In the reference arm, this surface is an air-to-air surface and therefore has no impact on the beam. The data of the surface can be viewed in the Extra Data Editor. A 16-term setup with normalization radius 5 mm is established, the coefficient is scaled in mm and therefore set to 0.0006328 mm.
To view the Interferogram, the following settings are realized. It has to be noticed, that the reference wave is plane. Therefore in the General menu, the option 'Afocal Image Space' must be activated.

c) A lateral shift between the two arms can be e.g. simulated by changing the vertical distance of the reference arm from 50 mm to 51 mm. Since the reference wave is plane, the interferogram is not changed. The lack of overlapping diameters, which occurs in practice, is not seen in Zemax. The same happens, if the beam combining mirror is tilted. It seems to be an error in the software, that a difference in beam position or orientation is not detected from the data.

If a tilt is set in the wavefront / interferogram menu, the interferogram is changed dramatically due to a tilt overlay.