1.1 Fourier filtering and Imaging (ODZ 12)

Set up a telecentric 4f-system with a magnification of m = 4. The system should be arranged by two appropriate achromates from conventional vendor catalogs with the focal lengths f₁ = 25 mm and f₂ = 100 mm. The wavelength of the application is the e-line, the object size is 3 mm and the numerical aperture should be NA = 0.1.

a) Set up the system with telecentric behavior in the object and the image space. In particular adjust the system and a rectangular stop with appropriate size in the intermediate focal plane. The adjustment should be performed on axis only.

b) Check the magnification of the realized lens. Calculate the performance of the system in the center and the edge of the field size. Is the system diffraction limited? What are the dominant aberrations in the field?

c) Show that the resolution of the system in the field is anisotropic due to the elongated shape of the spot by inspecting the MTF of the system.

d) Calculate a diffraction-based imaging of the complete object field. Take a rectangular grid as an object. Can the anisotropic resolution be seen?

Now calculate a geometrical imaging model of the same grid. What is the difference between the results of both models?

e) To demonstrate the Fourier filtering in the pupil plane, replace the rectangular pupil stop by a slit with dimensions Dₓ = 5 mm, Dᵧ = 0.15 mm. What changes with the diffraction limited image? What is the consequence for the geometrical image?

f) Calculate the Airy diameter of the system and constitute an object with size 10 times the Airy diameter. Put this small object in the center and at the edge of the field. Discuss the results and compare them. Is the grid resolved?

Solution:

a) Corresponding achromates are found for example in the catalog of Melles&Griot as:
First lens with f = 25 mm: LAO – 25.0 – 12.5
Second lens with f = 100 mm: LAO – 25.0 – 12.5

The first achromate must be reversed. The distances must be adjusted in a way to guarantee a collimated ray bundle between the lenses and to let the chief ray cross the optical axis in the back focal plane of the first lens. The system stop has to be fixed at the intermediate focal point. Correspondingly the distance between the stop and the second lens must be arranged to get telecentricity in the image space, the final image distance must be adjusted to get a sharp image.

1st step: find t1, merit function angular radius
2nd step: find t2, not telecentric, initial distance infinity, entrance pupil at lens with diameter D = 3 mm
3rd step: after adding the second lens:
4th step: adjusting the distance behind the stop: chief ray parallel to axis, merit function with REAB = 0
5th step: focusing image plane on axis; merit function with spot criterion

The result is (for this choice of lenses):

<table>
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<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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</table>

In the intermediate focal plane, a rectangular diaphragm with half widths 2.5 is placed.

b) The performance of the system can be estimated by a spot diagram as follows.

From this diagram or the Prescription data –menu we get a magnification of m = -4.004.
In the center, the system is nearly diffraction limited, for the field of y = 1.5 mm, it is worse.
If the spot diagram is considered, mainly coma, and defocus seems to be the reasons for the decrease of the performance. The defocus can be astigmatism or field curvature. To decide about this question, the Seidel diagram is considered. It is seen, that both aberration types are there but the astigmatism dominates by a factor of 2.

c) The MTF shows a large separation of the tangential and sagittal contrast curves. This describes the anisotropic resolution of the coma/elliptical spot shape.
d) The result look like this picture, the settings are documented on the right. The difference in the resolution can not be recognized in this coarse representation.

The following figure shows the result of the geometrical calculation for $10^6$ rays.

Both models shows a comparable sharp imaging of the grid. In the diffraction model, the special effects of diffraction are seen at the crossing points, where a higher intensity is calculated. Furthermore, in the diffraction calculation we have a stronger profile across a bar cross section. This can be seen in a zoom representation of a single crossing point at higher resolution.
e) If a rectangular slit stop is established in the system, we get the following results:

In diffraction calculation, a filtering and blocking of the higher diffraction orders has nearly completely removed the horizontal grid lines. Therefore the image is no longer similar to the object. In the geometrical picture, a first sight seem to have an unchanged image. A close look shows, that the width of the horizontal and vertical bars is now different. This comes from the fact, that the slit diaphragm truncates those parts of the pupil, where large aberration are present.

The large number of blocked rays can also be recognized at thereduces computational time.

f) The Airy diameter is $D = 13.4 \, \mu m$. Therefore the field size in the image calculation is chosen to be 0.134 mm. The results of the imaging calculations in the center and at the edge are as follow:

It is seen, that the gridbars are resolved on axis, but the degradation is seen clearly. In the field, the resolution of the grid bars is only given in the sagittal direction. Therefore, the cossed grid degenerates to a line grid.