Influence of initial system

Consider a system with two lenses, made of BK7 and K5 at 587.56 nm. Both lenses have the thickness 5 mm, between both lenses the air distance is 1 mm. The incoming light bundle is collimated with diameter D = 20 mm, the focal length should be f = 30 mm. The system should be optimized by bending of the lenses only with a simple spot criterion on axis. The optimization result now depends strongly on the initial values of the radii. Try and compare the following possibilities:

a) start with plane surfaces only

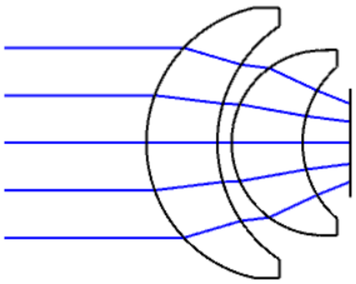
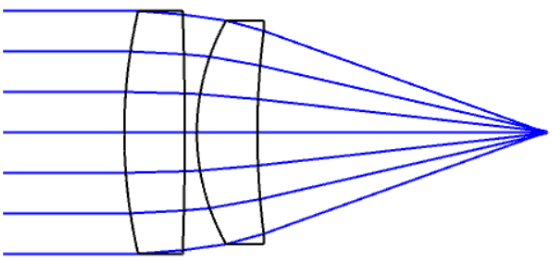
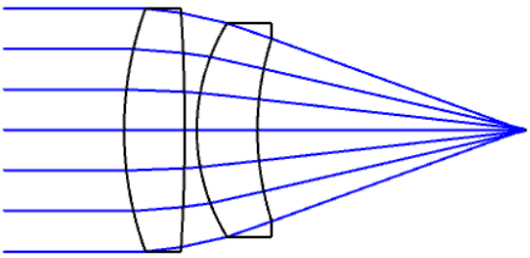
b) start with a final radius of R4 = -20

c) start with a first radius R1 = +20

and compare the different results.

Solution:

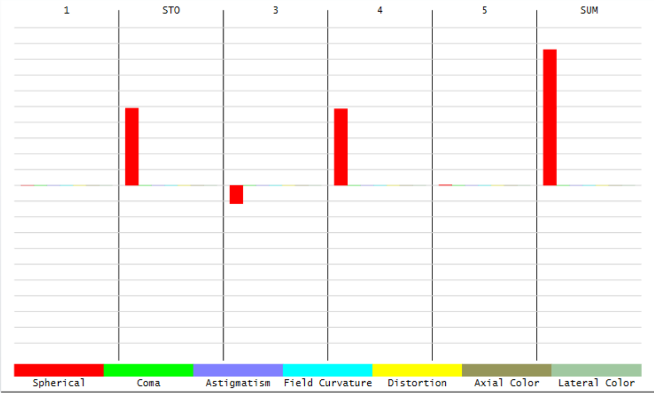
The results as layouts and with the corresponding spot rms radius values are collected in the following table

No	Layout	Start radii	Rms spot size
a		0 - 0 - 0 - 0	2783
b		0 - 0 - 0 - -20	45
c		+20 - 0 - 0 - 0	53

Data and Seidel contribution of the results:

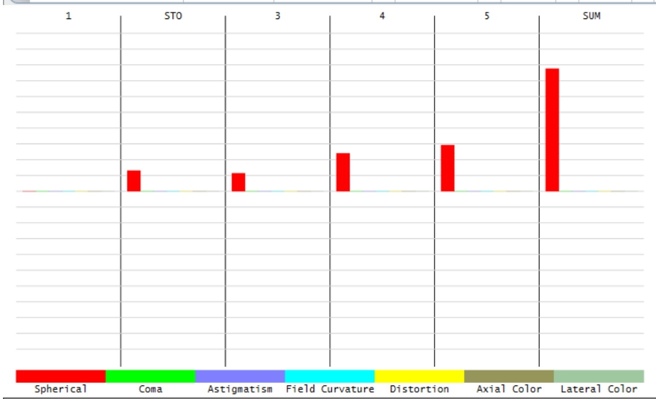
a) No real correction, no compensation in this local minimum.

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity	Infinity			0.000000	0.0000...	0.000000	0.0000...	0.0000...
1	Standard		Infinity	10.0000...			10.000000	0.0000...	10.000000	0.0000...	0.0000...
2	STOP Standard		9.718253 V	5.000000	BK7		9.500000	0.0000...	9.500000	0.0000...	-
3	Standard		9.879375 V	1.000000			8.193723	0.0000...	9.500000	0.0000...	0.0000...
4	Standard		6.511558 V	5.000000	K5		6.511140*	-	-	0.0000...	-
5	Standard		7.063737 V	3.367743 V			5.324871	0.0000...	6.511140	0.0000...	0.0000...
6	IMAGE Standard		Infinity	-			3.818955	0.0000...	3.818955	0.0000...	0.0000...



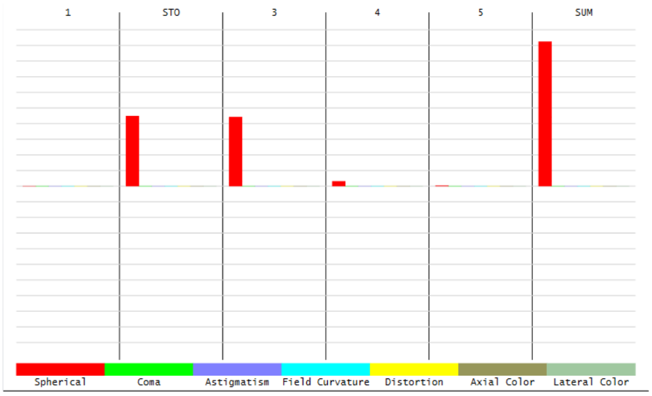
b) Nearly equal contributions at every surface, no compensation, but rather insensitive.

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity	Infinity			0.000000	0.0000...	0.000000	0.0000...	0.0000...
1	Standard		Infinity	10.0000...			10.000000	0.0000...	10.000000	0.0000...	0.0000...
2	STOP Standard		44.156950 V	5.000000	BK7		10.000000	0.0000...	10.000000	0.0000...	-
3	Standard		-284.6707... V	1.000000			9.709660	0.0000...	10.000000	0.0000...	0.0000...
4	Standard		18.813891 V	5.000000	K5		9.215408	0.0000...	9.215408	0.0000...	-
5	Standard		66.287662 V	23.9897... V			8.355421	0.0000...	9.215408	0.0000...	0.0000...
6	IMAGE Standard		Infinity	-			0.070409	0.0000...	0.070409	0.0000...	0.0000...



c) The second lens is quasi-aplanatic. The front lens mostly contributes to the spherical aberration, thus the design is more sensitive.

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT Standard		Infinity	Infinity			0.000000	0.0000...	0.000000	0.0000...	0.0000...
1	Standard		Infinity	10.0000...			10.000000	0.0000...	10.000000	0.0000...	0.0000...
2	STOP Standard		29.262772 V	5.000000	BK7		10.000000	0.0000...	10.000000	0.0000...	-
3	Standard		-156.5931... V	1.000000			9.640838	0.0000...	10.000000	0.0000...	0.0000...
4	Standard		16.771588 V	5.000000	K5		8.800081	0.0000...	8.800081	0.0000...	-
5	Standard		24.575355 V	22.1255... V			7.516674	0.0000...	8.800081	0.0000...	0.0000...
6	IMAGE Standard		Infinity	-			0.082926	0.0000...	0.082926	0.0000...	0.0000...


1
STO
3
4
5
SUM
Spherical
Coma
Astigmatism
Field Curvature
Distortion
Axial Color
Lateral Color

Optimization of Insensitivity

In the usual optimization, only the overall result of the system is minimized with the merit function. Due to the compensation effects, this can cause by quite different orders of magnitude in the size of the various surface contributions. By fixing the surface contributions, this effect of unequal weighting can be reduced and we get a rather uniform aberration loading and as a benefit a tolerance insensitive design, which can be easier to manufacture. To get this result, a poorer performance should be accepted.

a) We are looking for a system with an collimated input ray bundle of diameter D = 10 mm, a wavelength of 546.07 nm and a focal length of 5 mm to obtain a high numerical aperture in the image. This task should be performed by 3 spherical lenses made of BK7 with thicknesses of 2 mm and distances of 1 mm respectively. For the initial setup, we introduce a radius of -10 mm on the last surface. Optimize the system by changing all the radii and the final image distance. Show the result for the spot diameter and the Seidel surface contributions.

b) Now we add the SPHA operator for the individual spherical aberration contributions for every surface. In addition, the sum of squares is formulated by the operand QSUM. Now re-optimize the system by looking for the minimum value of this sum of squares, which then guarantees nearly equal values for the spherical surface contributions. What at the end is the performance in comparison to the previous solution ? What is the spreading of the spherical surface contributions ?

c) Finally as more automatic solution, use the operand EQUA to force the spherical Seidel contributions to have the same values. Start with the result of b). Is the performance now better than in b) ?

Solution:

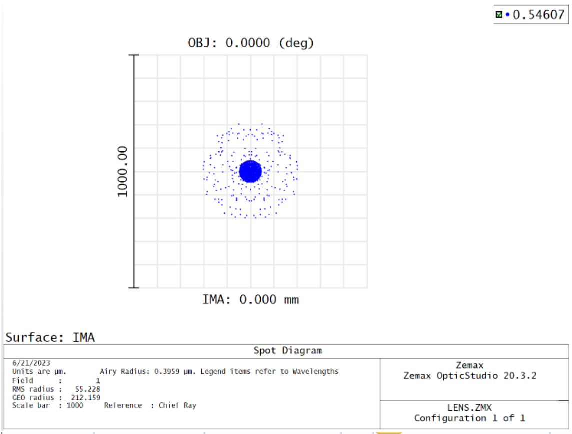
a) The starting system is seen here.

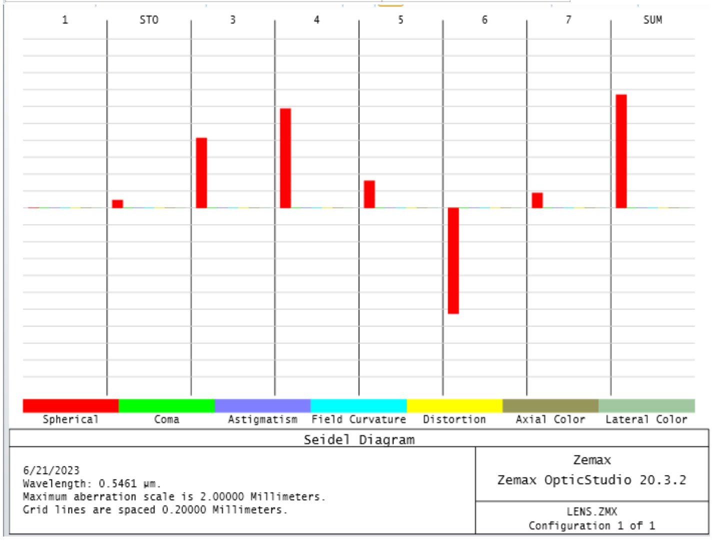
	Surface Type	Comment	Radius		Thickness		Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia
0	OBJECT Standard		Infinity		Infinity				0.000000	0.0000...	0.000000
1	Standard		Infinity		10.0000...				5.000000	0.0000...	5.000000
2	STOP Standard		Infinity	V	2.000000		BK7		5.000000	0.0000...	5.000000
3	Standard		Infinity	V	1.000000				5.000000	0.0000...	5.000000
4	Standard		Infinity	V	2.000000		BK7		5.000000	0.0000...	5.000000
5	Standard		Infinity	V	1.000000				5.000000	0.0000...	5.000000
6	Standard		Infinity	V	2.000000		BK7		5.000000	0.0000...	5.000000
7	Standard		-10.000000	V	0.000000	V			5.000000	0.0000...	5.000000
8	IMAGE Standard		Infinity		-				4.527993	0.0000...	4.527993

The merit function is selected by the default with some more rays and the focal length is forced to be 5 mm. After optimization we get the following system:

	Surface Type	Comment	Radius		Thickness		Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia
0	OBJECT Standard		Infinity		Infinity				0.000000	0.0000...	0.000000
1	Standard		Infinity		10.0000...				5.000000	0.0000...	5.000000
2	STOP Standard		11.522679	V	2.000000		BK7		5.000000	0.0000...	5.017613
3	Standard		-13.482759	V	1.000000				5.017613	0.0000...	5.017613
4	Standard		2.493819	V	2.000000		BK7		2.493806	0.0000...	2.493806
5	Standard		5.002271	V	1.000000				2.350053	0.0000...	2.493806
6	Standard		-13.276533	V	2.000000		BK7		1.310964	0.0000...	1.310964
7	Standard		-4.953844	V	0.075531	V			0.095105	0.0000...	1.310964
8	IMAGE Standard		Infinity		-				0.214096	0.0000...	0.214096

The spot diameter is approximately 55 μm, the Seidel contributions of the surfaces are found in the range between 0.092 ...1.253 and therefore shows factors of approximately 13 between the values.





b) The extended merit function now contains the following additional operands:

Merit Function Editor: 4.174614E+000

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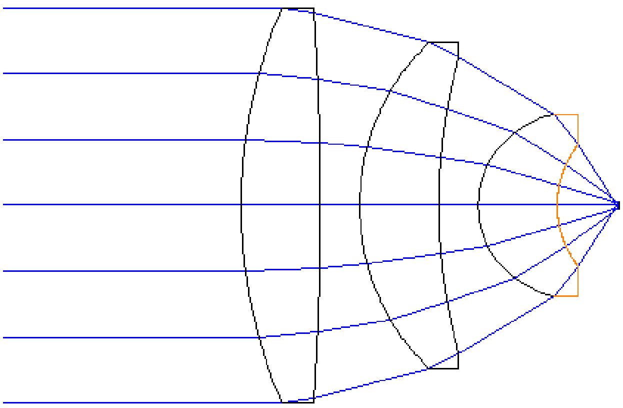
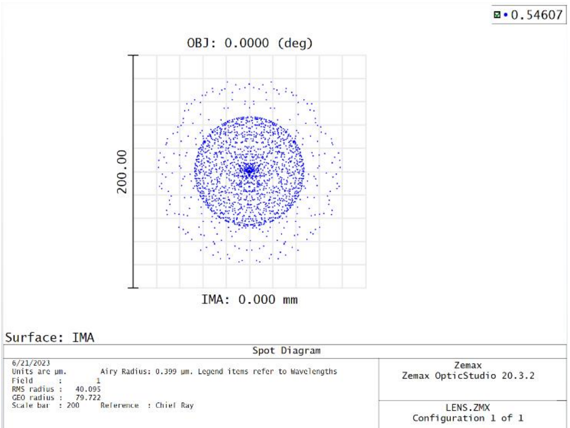
Oper #	Type	Op#1	Op#2					Target	Weight	Value
1: DMFS	DMFS									
2: BLNK	BLNK	Sequential merit function: RMS spot radius centroid GQ 11 rings 6 arms								
3: EFFL	EFFL		1					5.00000	10.00000	5.00342
4: BLNK	BLNK	No default glass thickness boundary constraints.								
5: SPHA	SPHA	2	1					0.00000	0.00000	24.37956
6: SPHA	SPHA	3	1					0.00000	0.00000	29.36266
7: SPHA	SPHA	4	1					0.00000	0.00000	19.77731
8: SPHA	SPHA	5	1					0.00000	0.00000	13.91307
9: SPHA	SPHA	6	1					0.00000	0.00000	5.45003
10: SPHA	SPHA	7	1					0.00000	0.00000	4.17261
11: QSUM	QSUM	5	10					30.00000	1.00000	45.69855
12: BLNK	BLNK									
13: BLNK	BLNK									
14: BLNK	BLNK	Operands for field 1.								
15: TRAC	TRAC		1	0.00000	0.00000	0.10433	0.00000	0.00000	0.08744	0.01529
16: TRAC	TRAC		1	0.00000	0.00000	0.23763	0.00000	0.00000	0.19726	0.03330
17: TRAC	TRAC		1	0.00000	0.00000	0.36732	0.00000	0.00000	0.29262	0.04722

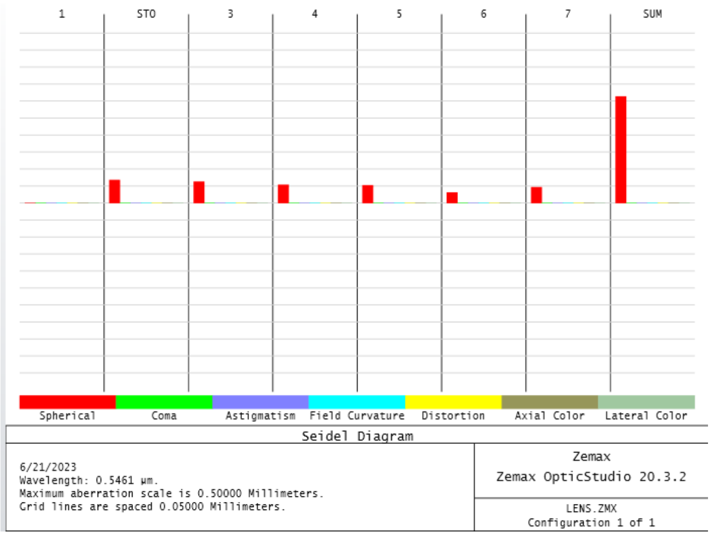
After iterative lowering the target value we find a value of 30, whioch can be reached.
We now obtain the following system data

	Surface Type		Comment	Radius		Thickness		Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia
0	OBJECT	Standard		Infinity		Infinity				0.000000	0.0000...	0.000000
1		Standard		Infinity		10.0000...				5.000000	0.0000...	5.000000
2	STOP	Standard		12.754089	V	2.000000		BK7		5.000000	0.0000...	5.000000
3		Standard		-74.770923	V	1.000000				4.883060	0.0000...	5.000000
4		Standard		5.793088	V	2.000000		BK7		4.136427	0.0000...	4.136427
5		Standard		14.266846	V	1.000000				3.766775	0.0000...	4.136427
6		Standard		2.354535	V	2.000000		BK7		2.312377	0.0000...	2.312377
7		Standard		2.603076	V	1.623953	V			1.576428	0.0000...	2.312377
8	IMAGE	Standard		Infinity		-				0.079978	0.0000...	0.079978





The spot diameter is reduced to 40 µm, the final surface contributions only differ by a factor of 2 at the end.



It is seen by further reducing the target value for the sum of squares of the surface contribution, that the optimizations increases the focal length, which is not desired. This last iterative procedure can also be obtained by the Operand MINN, which looks for the minimum value of the sum of squares.

c)

	Surface Type		Comment	Radius		Thickness		Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia
0	OBJECT	Standard		Infinity		Infinity				0.000000	0.0000...	0.000000
1		Standard		Infinity		10.0000...				5.000000	0.0000...	5.000000
2	STOP	Standard		13.391676	V	2.000000		BK7		5.000000	0.0000...	5.000000
3		Standard		-72.510495	V	1.000000				4.882908	0.0000...	5.000000
4		Standard		5.870316	V	2.000000		BK7		4.167867	0.0000...	4.167867
5		Standard		15.381714	V	1.000000				3.817678	0.0000...	4.167867
6		Standard		2.323456	V	2.000000		BK7		2.302418	0.0000...	2.302418
7		Standard		2.675192	V	1.595781	V			1.627265	0.0000...	2.302418
8	IMAGE	Standard		Infinity		-				0.096902	0.0000...	0.096902

	Type	Comment											
1	DMFS												
2	BLNK	Sequential merit function: RMS spot radius centroid GQ 11 rings 6 arms											
3	EFFL		1							5.0000	10.0000	5.4768	88.4212
4	BLNK	No default glass thickness boundary constraints.											
5	SPHA	2	1							0.0000	0.0000	13.3324	0.0000
6	SPHA	3	1							0.0000	0.0000	13.6013	0.0000
7	SPHA	4	1							0.0000	0.0000	13.8545	0.0000
8	SPHA	5	1							0.0000	0.0000	13.6189	0.0000
9	SPHA	6	1							0.0000	0.0000	13.6018	0.0000
10	SPHA	7	1							0.0000	0.0000	13.6018	0.0000
11	EQUA	5	10							0.0000	1.0000	0.5397	11.3298
12	BLNK												
13	BLNK	Operands for field 1.											
14	TRAC		1	0.0000	0.0000	0.1043	0.0000			0.0000	0.0874	0.0152	7.8624E-04
15	TRAC		1	0.0000	0.0000	0.2376	0.0000			0.0000	0.1973	0.0331	8.4093E-03

The result is now worse by approx. 15%, but the Seidel coefficients are exactly the same.