Lesson 13. Laser Beam Expander with Kinoform Lenses

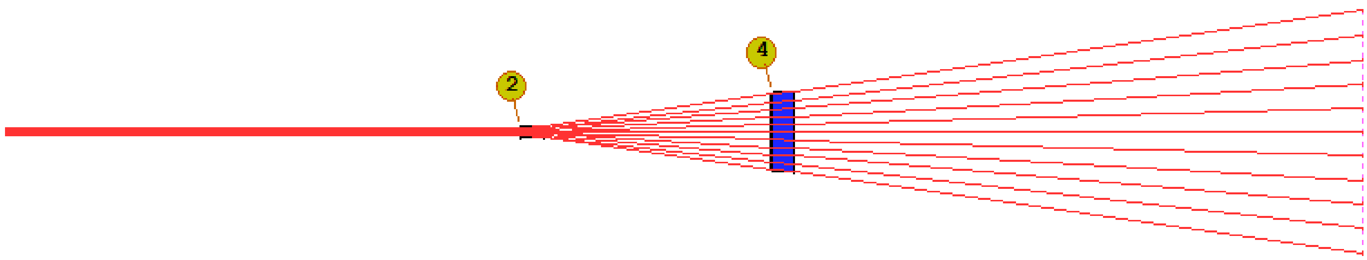
In Lesson 11 you saw how a laser beam expander could be designed with ordinary spherical lenses and learned that one would need many lens elements to achieve good performance that way. Lesson 12 did the same design with only two aspheric elements, with excellent results. This lesson will show that you can do as well with DOEs, also known as kinoform lenses.

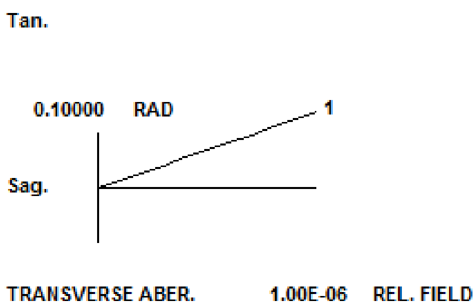
The problem is to convert a HeNe laser with a waist radius of 0.35 mm to a beam that is 10 mm in diameter and uniform to within 10%.

Here is the input file for our starting point:

```
RLE                          ! Beginning of lens input file.
ID KINOFORM BEAM SHAPER
WA1 .6328                    ! Single wavelength
UNI MM               ! Lens is in millimeters
OBG .35 1            ! Gaussian object; waist radius -.35 mm; define full aperture = 1/e**2 point.
1 TH 22              ! Surface 2 is 22 mm from the waist .
2 RD -2 TH 2 GTB S   ! Guess some reasonable lens parameters; use glass type SF6 from Schott catalog
SF6

3 TH 20              ! Surface 3 is a kinoform on side 2 of the first element
3 USS 16             ! Defined as Unusual Surface Shape 16 (simple DOE)
CWAV .6328           ! Zones are defined as one wave phase change at this wavelength
HIN 1.7988 55        ! Assume the zones are machined into the lens.  You can also apply
! a film of a different index.
RNORM 1

4 TH 2 GTB S         ! The first side of the second element is also a DOE
SF6
4 USS 16
CWAV .6328
HIN 1.7988 55
RNORM 1

5 CV 0 TH 50         ! Start with a flat surface
7                    ! Surfaces 6 and 7 exist
AFOCAL               ! because they are required for AFOCAL output.
END                  ! End of lens input file.
```

We guessed a value for RD number 2, and we came close enough to start with. Here is the system at this stage, with no aspheric DOE terms yet:





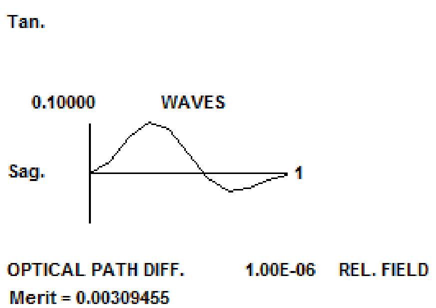
The beam is expanded but is not collimated, and the intensity profile is still that of the Gaussian input beam. The task is to find the DOE OPD terms that will accomplish both of our goals. To start with, let us keep both sides of the second element flat. Here is an optimization MACro that we think might do the job):

```
PANT          ! Start of variable parameter definitions.
RDR .001      ! This is a very small beam, so use smaller derivative increments to start with
VY 2 RAD
VLIST TH 3    ! Vary the airspace
VY 3 G 26     ! Vary term Y**2,
VY 3 G 27     ! Y**4,
VY 3 G 28     ! and Y**6

VY 4 G 26     ! Do the same at surface 4
VY 4 G 27
VY 4 G 28

END

AANT                  ! Start of merit function definition
AEC
ACC
LUL 150 1 1 A TOTL          ! Prevent the system from growing too large
M 5 1 A P YA 0 0 1 0 5      ! Ask for a beam radius of 5 mm on surface 5

M 0 1 A P FLUX 0 0 1 0 6    ! Ask for a flux falloff of zero at several zones
M 0 1 A P FLUX 0 0 .98 0 6
M 0 1 A P FLUX 0 0 .97 0 6
M 0 1 A P FLUX 0 0 .96 0 6
M 0 1 A P FLUX 0 0 .95 0 6
M 0 1 A P FLUX 0 0 .94 0 6
M 0 1 A P FLUX 0 0 .93 0 6
M 0 1 A P FLUX 0 0 .92 0 6
M 0 1 A P FLUX 0 0 .91 0 6
M 0 1 A P FLUX 0 0 .85 0 6
M 0 1 A P FLUX 0 0 .8 0 6
M 0 1 A P FLUX 0 0 .7 0 6
M 0 1 A P FLUX 0 0 .5 0 6
M 0 1 A P FLUX 0 0 .3 0 6
```

```
GSO 0 .1 10 P               ! Control the output ray OPD over an SFAN of 10 rays,
GSR 0 100 10 P              ! and some transverse aberrations too.
END                         ! End of merit function definition.

SNAP
SYNO 40
```

This PANT file varies some of the general-purpose G variables, which we used in the previous lesson to vary some aspheric terms on the lens elements. But in this case, the surfaces are already defined as USS type 16, which is a simple DOE surface, and those terms therefore alter selected coefficients defining that shape. (Type HELP USS to read about the shapes you have available and how the G terms are applied to them.)

We run this, and the lens looks promising. So we run it again and then anneal for a few cycles.



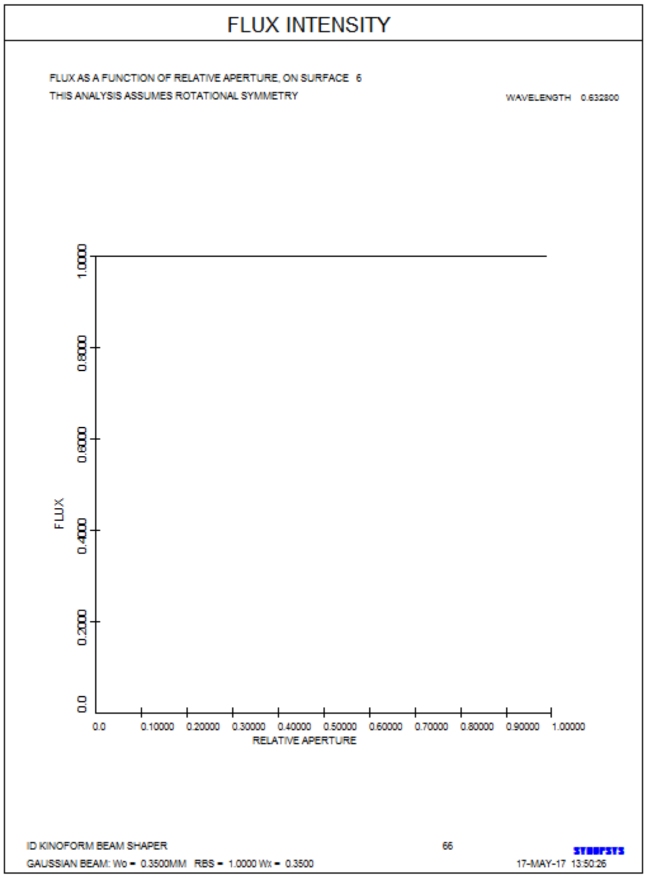
Not bad at all. Let's try varying some of the higher-order coefficients. We add new terms on both DOEs, up to G 31, which is the Y**12 term. After reoptimizing, the lens looks much the same, but the merit function drops to 3.13E-7. Looks like the run converged!

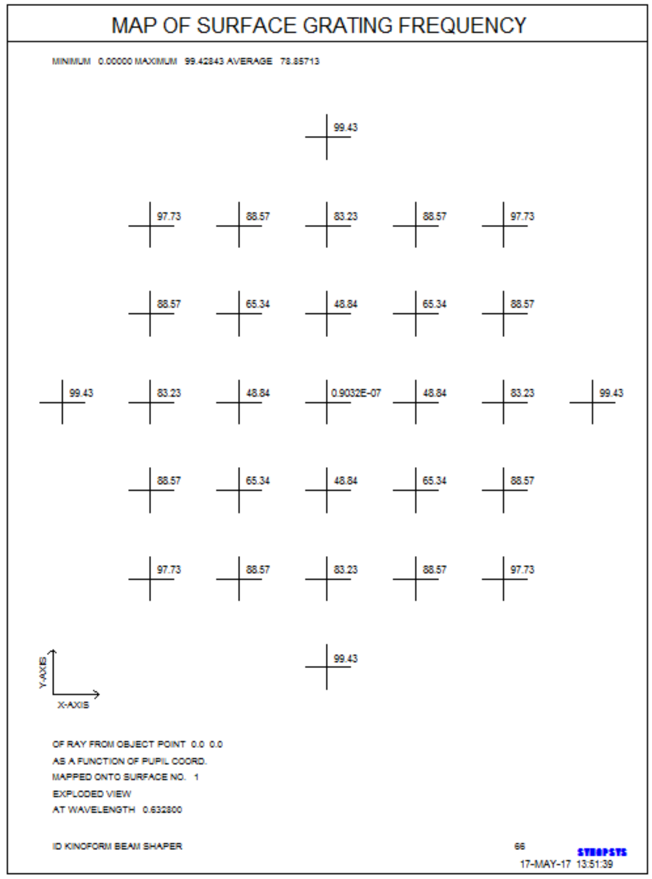
How does the flux vary over the aperture now? We type the command

```
FLUX 100 P 6
```

and get a beautiful curve, almost straight, shown on the left below.

This is indeed an excellent design. The question now is, Can anyone make it? What is the spatial frequency on surface 4? If it is too high, fabrication technology may have trouble with it. We open the MMA dialog to select the input for a MAP command. We select a map of HSFREQ over PUPIL with object POINT 0 and raygrid CREC with a grid of 7, DIGITAL output and PLOT. The result shows a frequency of 99.43 c/mm at the edge of the lens, on the right, below.





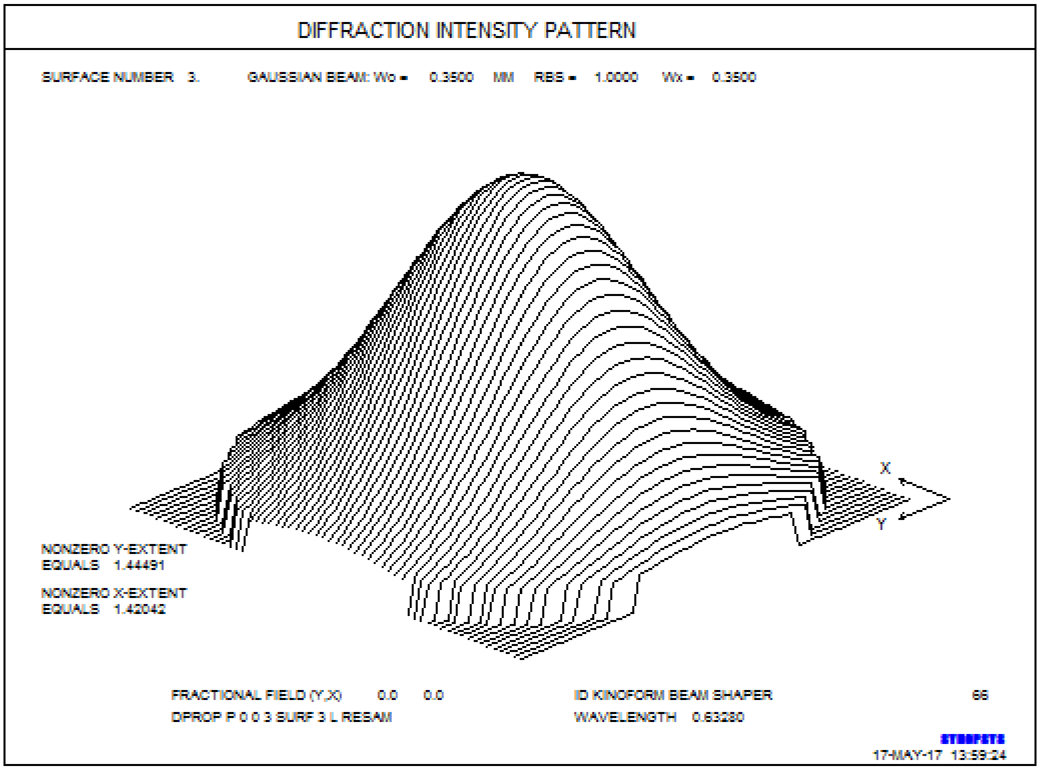
That works out to just under 10 um/cycle, which is possible but not easy. Can we reduce that to, say, 50 c/mm? We add the variable 5 RAD to the variable list and add a new aberration to the AANT file:

```
M 50 .01 A P HSFREQ 0 0 1 0 4
```

The program now controls the frequency on surface 4. We reoptimize, and now surface 5 is slightly convex and the spatial frequency on 4 is right at 50 c/mm. The flux uniformity is as good as before. Mission accomplished!

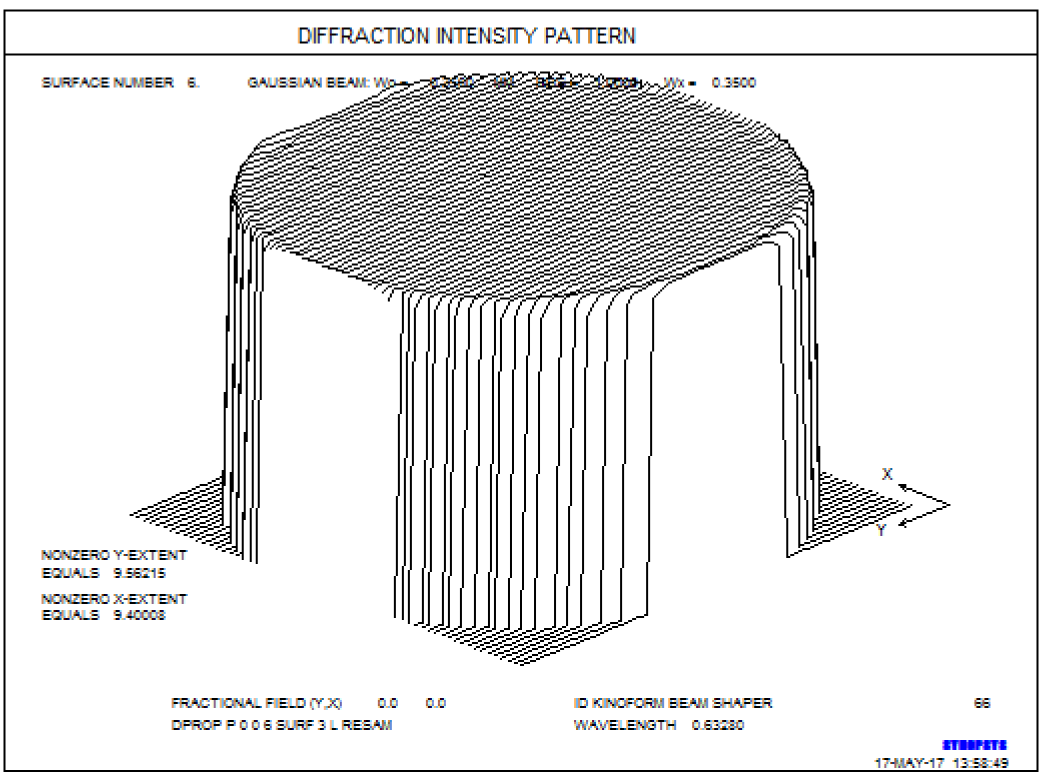
How well did we do? Run the DPROP command, asking for the profile at surface 3, before the beam has been restructured. This shows the Gaussian profile of the beam at that point.

```
DPROP P 0 0 3 SURF 3 L RESAMPLE
```



And now we do the same on surface 6. Essentially perfect!

```
DPROP P 0 0 6 SURF 3 L RESAMPLE
```



Below is the RLE file of the resulting system, which you can copy and paste into an editor if you want to evaluate it yourself:

```
RLE
ID KINOFORM BEAM SHAPER
 FNAME 'L13L1.RLE                                       '
 MERIT   0.270980E-05
 WA1 .6328000
 WT1 1.00000
 APS               1
 AFOCAL
 UNITS MM
 OBG   0.35000000       1.0000000
   0 AIR
   1 CV      0.0000000000000   TH     22.00000000 AIR
   2 RAD     -0.8227781050995   TH      2.00000000
   2 N1 1.79881710
   2 CTE   0.810000E-05
   2 GTB S    'SF6             '
   3 CV      0.0000000000000   TH     74.00214849 AIR
   3 USS  16
 CWAV        0.632800
 HIN        1.798800       55.000000
   RNORM    1.00000
   3 XDD  1   0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
   3 XDD  2   0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
   3 XDD  3   2.6875641E+02  5.7065730E+01 -4.1566734E+01  2.8677115E+01 -1.6241740E+01
   3 XDD  4   4.7211923E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
   4 CV      0.0000000000000   TH      2.00000000
   4 N1 1.79881710
   4 CTE   0.810000E-05
   4 GTB S    'SF6             '
   4 USS  16
 CWAV        0.632800
 HIN        1.798800       55.000000
   RNORM    1.00000
   4 XDD  1   0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
   4 XDD  2   0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
   4 XDD  3   5.6803879E+00 -9.1936550E-03  6.0997390E-04 -5.7203063E-05  2.2090382E-06
   4 XDD  4  -3.5824860E-08  0.0000000E+00  0.0000000E+00  0.0000000E+00
   5 RAD   -159.6274584523634   TH     50.00000000 AIR
   6 CV      0.0000000000000   TH      0.00000000 AIR
   7 CV      0.0000000000000   TH      0.00000000 AIR
 END
```