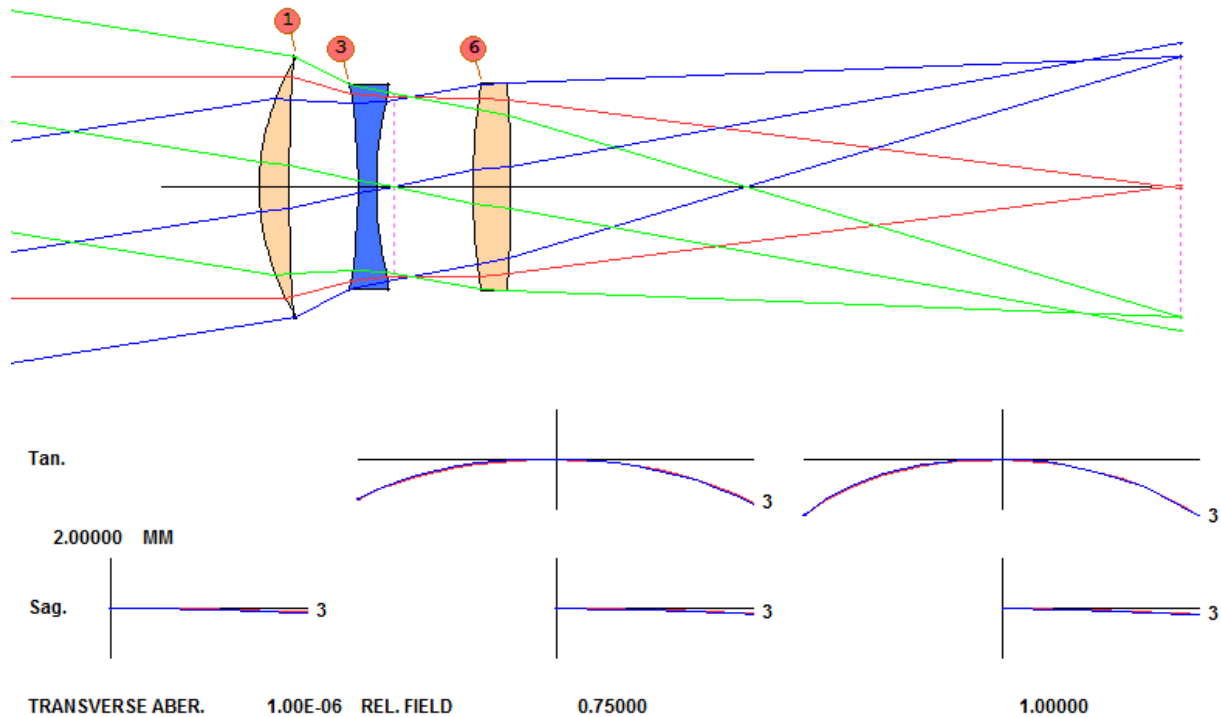# Lesson 20: Designing Aspheres for Manufacturing.

In this lesson we show how to add aspheric terms to a spherical surface, thereby improving the image. Then we reoptimize it, controlling the RMS departure of the aspheric surface from the closest fitting sphere (CFS) in order to make it easier to manufacture.

This is the starting lens, a poorly corrected triplet:

(If you want to run this example yourself, the starting lens comes installed as 6.RLE.)

Let's do a simple optimization run, to see how things improve. First, we use only spherical surfaces. Here is the MACro:

```
FETCH 6
PANT
VLIST RAD 1 2 3 4 6
VY 1 TH 20 3
VY 2 TH
VY 3 TH 20 3
VY 5 TH
VLIST GLM 1 3
END

AANT
AEC          ; AUTOMATIC EDGE CORRECTION
ACC          ; AUTOMATIC CENTER THICKNESS CONTROL

GNR .5 1 3 2 0
GNR .5 1 3 2 .5
```

```
GNR .5 1 3 2 .7
GNR .5 1 3 2 1.
GNR .5 1 2 1 0
GNR .5 1 2 3 0
GNR .5 1 2 1 1
GNR .5 1 2 3 1
END

SNAP                ; REQUEST SNAPSHOTS AS OPTIMIZATION RUNS
SYNO 50             ; REQUEST OPTIMIZATION FOR 50 PASSES
```
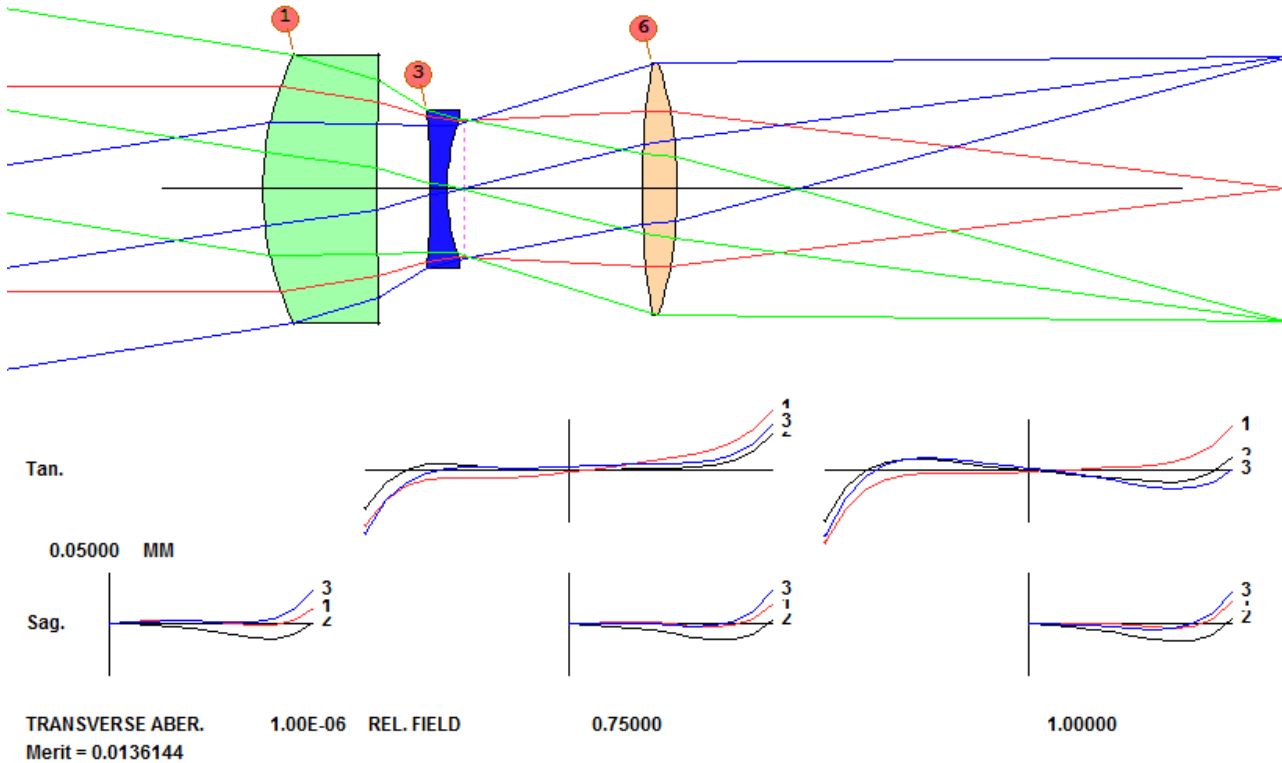
The lens is improved, but the 5th-order spherical aberration is balanced by under-corrected 3rd-order spherical:

It's time to see what an aspheric surface will do. Add the lines below to the PANT file and reoptimize.

```
VY 1 G 3
VY 1 G 6
VY 1 G 10
```

Now the lens is much better, as one would expect -- but what does that aspheric surface look like? The ASY listing gives the coefficients:

```
SPECIAL SURFACE DATA
_____
  SURFACE NO.   1 -- RD + POWER-SERIES ASPHERE
G 3   -3.740105E-08 (R**4)  G 6    1.619749E-11 (R**6)  G 10   2.852988E-14 (R**8)
```
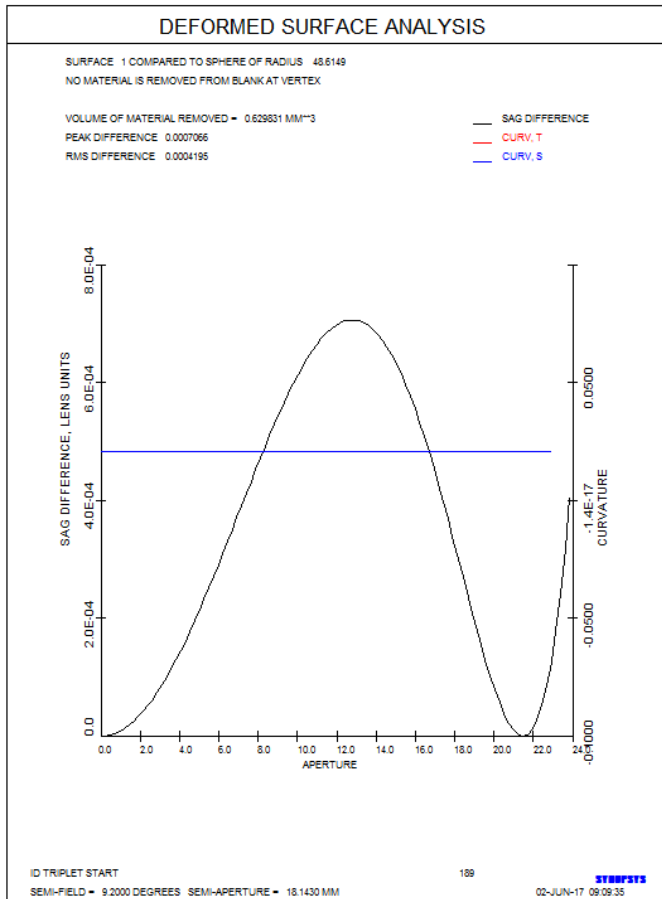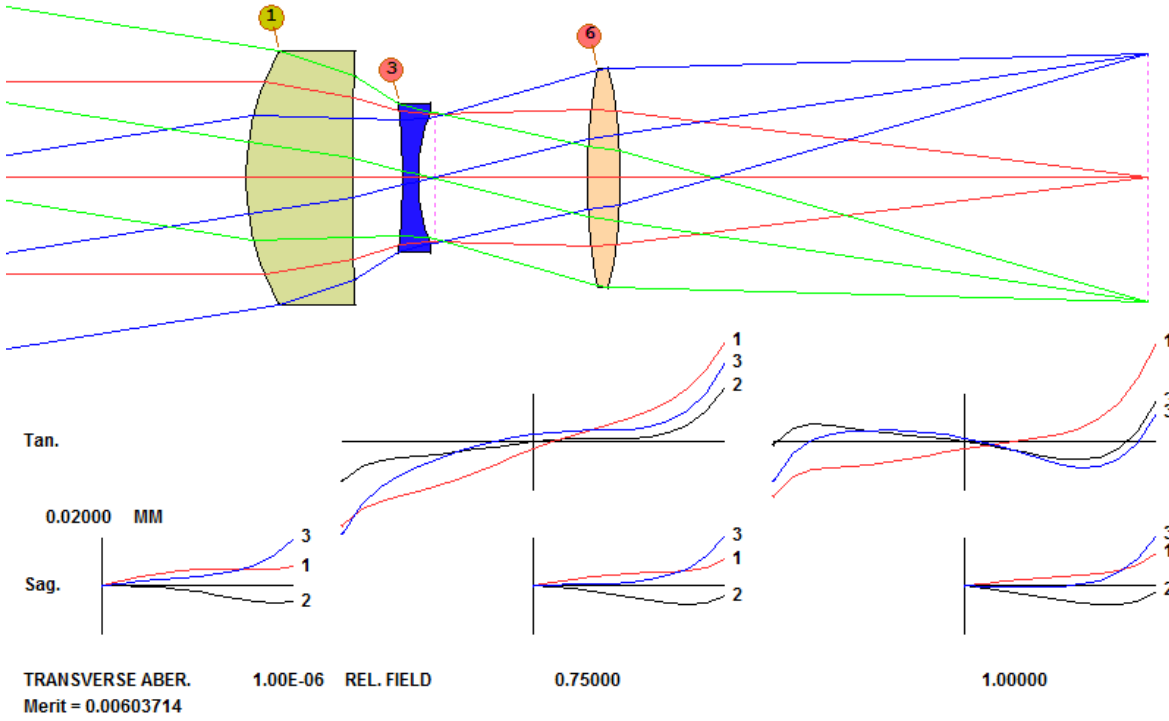
We have used three of the 22 possible G-series aspheric terms. How close is this surface to the closest-fitting sphere (CFS)? Type the command

2

ADEF 1 PLOT.

Tan.

0.02000   MM

Sag.

TRANSVERSE ABER.   1.00E-06   REL. FIELD   0.75000   1.00000
Merit = 0.00603714

DEFORMED SURFACE ANALYSIS

SURFACE   1 COMPARED TO SPHERE OF RADIUS   48.6149
NO MATERIAL IS REMOVED FROM BLANK AT VERTEX

VOLUME OF MATERIAL REMOVED = 0.629831 MM**3   ——— SAG DIFFERENCE
PEAK DIFFERENCE 0.0007066   ——— CURV, T
RMS DIFFERENCE   0.0004195   ——— CURV, S

SAG DIFFERENCE, LENS UNITS

CURVATURE

APERTURE

ID TRIPLET START   189
SEMI-FIELD = 9.2000 DEGREES SEMI-APERTURE = 18.1430 MM   02-JUN-17 09:09:35   SYNOPSYS

3

The plot shows a large departure from the CFS. This may be hard to control accurately. Let's see if we can get similar performance with an asphere that is easier to make. We add to the AANT file the lines

```
M 0 100 CLINK
ADEF 1
CD1 FILE 6
= CD1
```

Here we use the CLINK option, which causes the optimization program to run the next command (ADEF in this case) and then pick up the desired quantity from the FILE BUFFER. (To learn about this powerful feature, type **HELP CLINK** in the CW.)

> **SYNOPSYS already has a command for this kind of analysis, described in Section 10.3.3 of the User's Manual, but what would you do if it did not? This lesson shows how other features can be used to do the same thing, and it is a good idea to know how to use those other features in case you want to do something for which there is no command.**

Where did the weighting factor of 100 come from? The RMS difference between the asphere and the CFS is 0.00042, and the largest of the other aberrations is 0.045. (To see those values, you can use the handy FINAL nb command. We entered FINAL 5, to see the five largest aberrations, and got the following table (it's in the FINAL ERROR column)):

```
FINAL 5
ABERRATION LIST
        NAME                 TARGET          WEIGHT              RAW VAL.   FINAL ERROR   R. EFFECT

  81                       0.0000000      0.9362033 SR       0.0140    0.130792E-01   0.028286
      A    2   YC    0.70000    0.50000    0.83333    0.00000

 103                       0.0000000      1.7262735 SR      -0.0070   -0.120986E-01   0.024204
      A    2   YC    1.00000    0.16667    0.50000    0.00000

 157                       0.0000000      1.1508490 SR       0.0141    0.162809E-01   0.043829
      A    1   YC    1.00000    0.25000    0.75000    0.00000

 161                       0.0000000      2.5733766 SR      -0.0064   -0.165815E-01   0.045462
      A    1   YC    1.00000    0.25000   -0.25000    0.00000

 163                       0.0000000      1.1508490 SR      -0.0111   -0.127588E-01   0.026917
      A    1   YC    1.00000    0.25000   -0.75000    0.00000
```

So this weighting will give the RMS departure comparable to the error of the largest ray aberration. We of course can adjust it later, when we see how things work out.

And how did we figure out the other lines to be added to the AANT file? Simple. When the ADEF command runs, it puts a copy of some of its output into the AI buffer. After running that command, ask the AI question

```
     BUFFER?
```

to see what got put where.

```
BUFF?

 The current FILE BUFFER contains
   1        0.02051954   BEST FIT CV
   2       48.73404382   BEST FIT RD
   3   -5.38236122E-13   VERTEX SHIFT
   4        0.50763222   VOL. REMOVED
```

```
    5         0.00097815   PEAK DIFF.
    6         0.00031781   RMS DIFF.
```

Location number 6 has the desired RMS difference – the quantity we want to control. So we run this new optimization, and the ray fans are almost unchanged. What does the aspheric look like now?
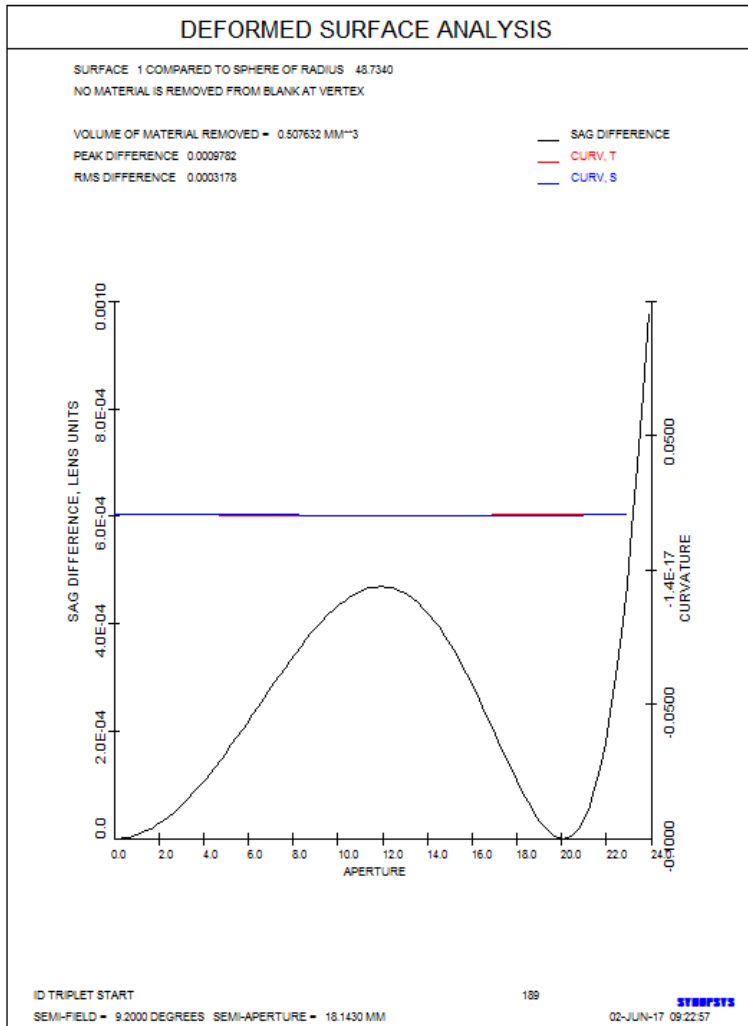
```
 SYNOPSYS AI>ASY

 SPECIAL SURFACE DATA

_____
  SURFACE NO.    1 -- RD + POWER-SERIES ASPHERE
 G 3   -3.290403E-08 (R**4)  G 6    1.879146E-11 (R**6)  G 10   3.012221E-14 (R**8)


 ADEF 1 PLOT
```
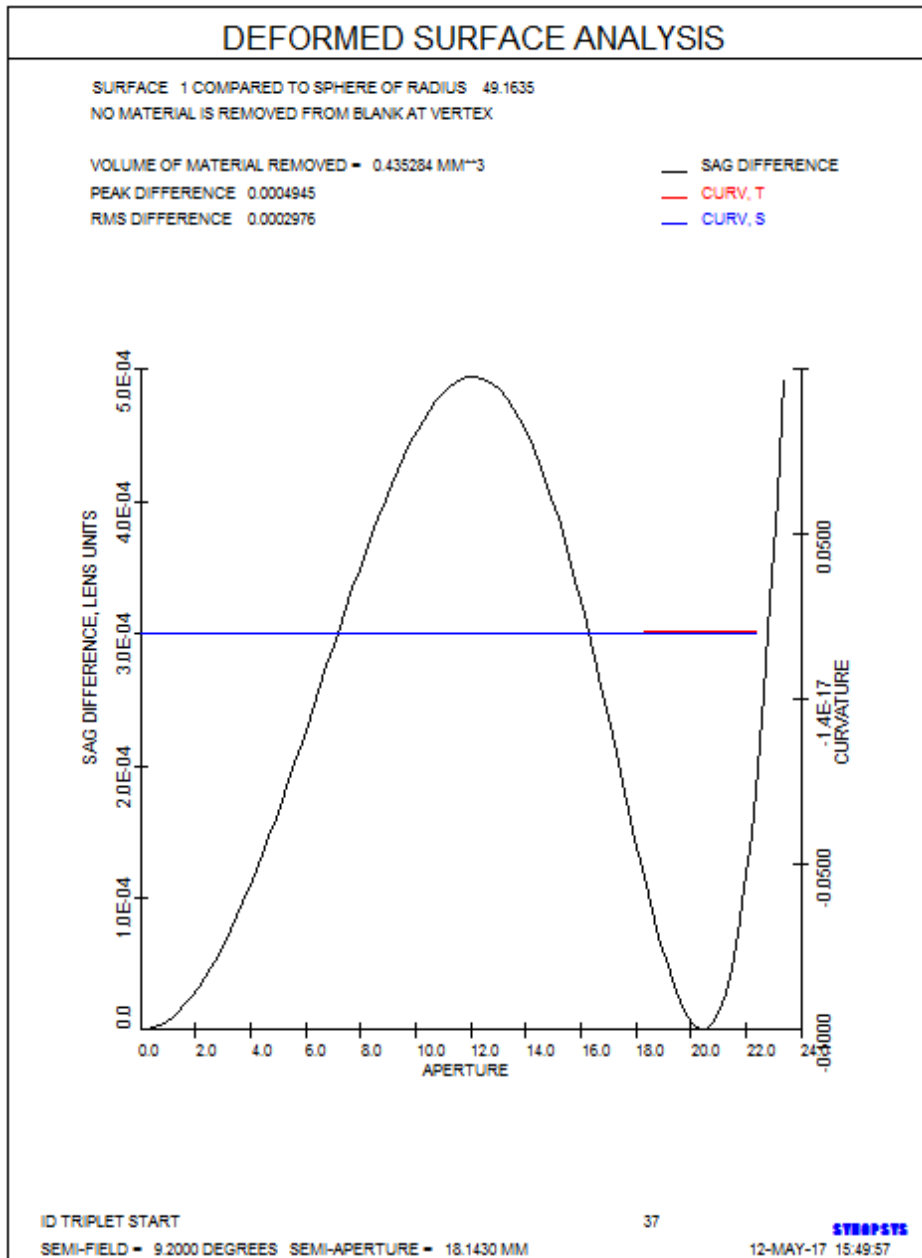

Now the RMS difference is only 0.00018. Here we have a lens with only 43% as much aspheric departure as before, and essentially identical performance.

Now it might make sense to adjust that weighting factor, increasing it in stages until the performance starts to degrade. That might yield a lens that is even easier to make than the one above.

One can also control the peak *difference* instead of the RMS, by simply picking up FILE 5 instead of 6. Let's try that idea. Change the extra AANT entries to
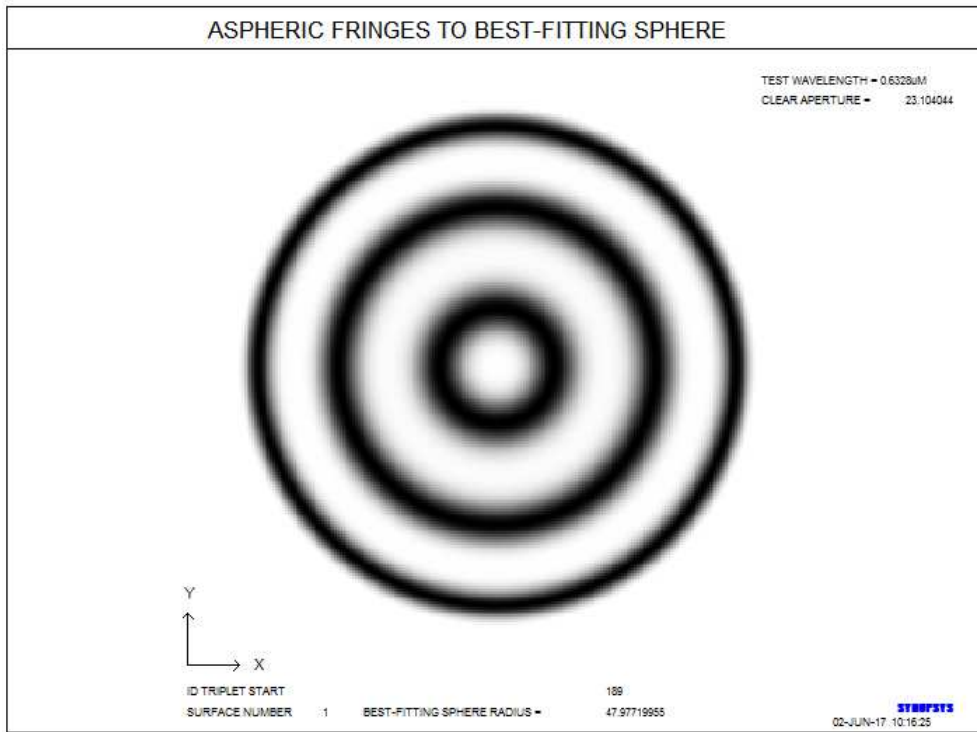
```
M 0 50 CLINK
ADEF 1
CD1 FILE 5
= CD1
```

and reoptimize. Now the peak departure is smaller yet, only 0.00031 mm.

DEFORMED SURFACE ANALYSIS

SURFACE 1 COMPARED TO SPHERE OF RADIUS 49.1635
NO MATERIAL IS REMOVED FROM BLANK AT VERTEX

VOLUME OF MATERIAL REMOVED = 0.435284 MM^^3   —— SAG DIFFERENCE
PEAK DIFFERENCE 0.0004945   —— CURV, T
RMS DIFFERENCE 0.0002976   —— CURV, S

ID TRIPLET START   37
SEMI-FIELD = 9.2000 DEGREES SEMI-APERTURE = 18.1430 MM   12-MAY-17 15:49:57

SYNOPSYS

How hard would it be to make this aspheric?   Let's see:

```
ADEF 1 FRINGES
```

ASPHERIC FRINGES TO BEST-FITTING SPHERE

TEST WAVELENGTH = 0.6328uM
CLEAR APERTURE =   23.104044

Y

X

ID TRIPLET START   189
SURFACE NUMBER   1   BEST-FITTING SPHERE RADIUS =   47.97719955

SYNOPSYS
02-JUN-17 10:16:25

This is a very nice gentle asphere, with only a few fringes to the best-fitting spherical surface. The fringes are seen in double-pass; the actual difference is only half that shown.

With these tools one can utilize aspheric elements while taking care that they are easily manufactured.