

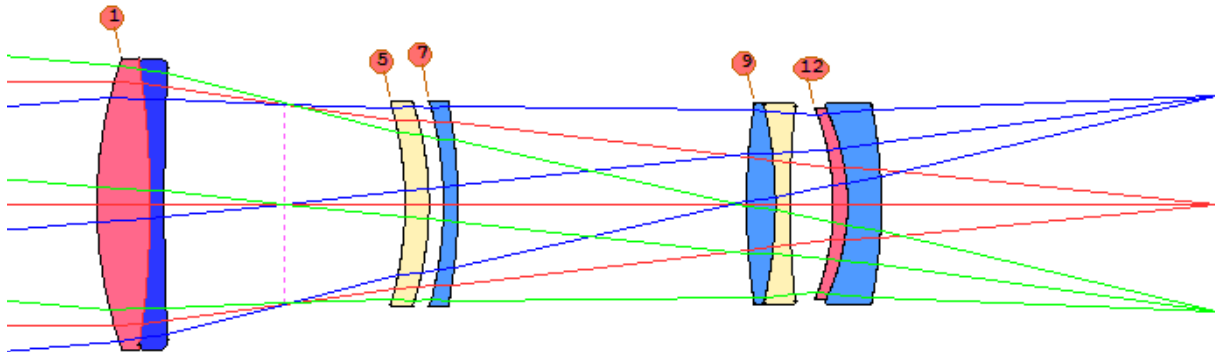
Lesson 24: Tolerance Example with Clocking of Element Wedge Errors and AI Analysis of an Image Error

This lesson applies some of the features discussed earlier and adds some interesting and powerful new options. Here, we will use BTOL to calculate a tolerance budget for an eight-element lens, and then look at the image quality statistics for the case where the wedge errors are compensated by clocking the elements in the cell. Finally, we will examine the statistics of the lateral color of a set of 100 lenses subject to the budget, after refocusing the lens and clocking the elements.

Here is a MACro that will create the tolerance budget:

```

FETCH X33                ! Get out the starting lens.
BTOL 90                  ! Ask for 90% confidence level.
TPR ALL                  ! All surfaces are matched to testplates.
EXACT ALL INDEX          ! Assume melt data are received,
EXACT ALL VNO            ! so the index and dispersion tolerances are zero.
TOL WAF .18 .32 .18     ! Ask for this wavefront variance at three field points.
FOCUS REAL               ! Focus the on-axis image point
ADJUST 14 TH 100        ! with thickness 14 (the last airspace).
PREP MC                  ! Prepare the input for Monte-Carlo evaluation.
GO                       ! Start BTOL.
    
```



The lens is distributed with SYNOPSIS™ as file X33.RLE, and we get it out with the FETCH command. When this MACro is run, the BTOL budget is prepared and listed on the monitor. Now we need to use MC. An adjustment MACro was prepared by BTOL, called MCFILE.MAC. Let's see what it contains. We type LM MCFILE to load that MACro:

```

PANT
VY 14 TH
END
AANT
M 0.000000E+00 0.3333 A 2 XC 0.000 0 .1 0.000
M 0.297953E-05 0.3333 SR A 2 YC 0.000 0 .1 0.000
M 0.000000E+00 0.3333 A 2 XC 0.000 0 -.1 0.000
M -0.297953E-05 0.3333 SR A 2 YC 0.000 0 -.1 0.000
M 0.297953E-05 0.3333 A 2 XC 0.000 .1 0 0.000
M 0.000000E+00 0.3333 SR A 2 YC 0.000 .1 0 0.000
    
```

```

M -0.297953E-05 0.3333 A 2 XC 0.000 -.1 0 0.000
M 0.000000E+00 0.3333 SR A 2 YC 0.000 -.1 0 0.000
M -0.177180E-02 0.3333 A 2 XC 0.000 -.64 .64 0.000
M 0.177180E-02 0.3333 SR A 2 YC 0.000 -.64 .64 0.000
M 0.177180E-02 0.3333 A 2 XC 0.000 .64 .64 0.000
M 0.177180E-02 0.3333 SR A 2 YC 0.000 .64 .64 0.000
M 0.177180E-02 0.3333 A 2 XC 0.000 .64 -.64 0.000
M -0.177180E-02 0.3333 SR A 2 YC 0.000 .64 -.64 0.000
M -0.177180E-02 0.3333 A 2 XC 0.000 -.64 -.64 0.000
M -0.177180E-02 0.3333 SR A 2 YC 0.000 -.64 -.64 0.000
M 0.000000E+00 0.6667 A 3 XC 0.000 0 0. 0.000
M 0.000000E+00 0.6667 A 3 YC 0.000 0 0. 0.000
M 0.000000E+00 0.6667 A 3 XC 0.000 0 .1 0.000
M 0.149918E-03 0.6667 A 3 YC 0.000 0 .1 0.000
M 0.000000E+00 0.6667 A 3 XC 0.000 0 -.1 0.000
M -0.149918E-03 0.6667 A 3 YC 0.000 0 -.1 0.000
M 0.149918E-03 0.6667 A 3 XC 0.000 .1 0. 0.000
M 0.000000E+00 0.6667 A 3 YC 0.000 .1 0. 0.000
M -0.149918E-03 0.6667 A 3 XC 0.000 -.1 0 0.000
M 0.000000E+00 0.6667 A 3 YC 0.000 -.1 0 0.000
END
SYNOPSIS 10
MC

```

As requested, the last airspace is varied in the PANT file, and the AANT file defines a merit function that will converge exactly to zero if the adjustment is able to restore exactly the same ray pattern as the nominal design. Now we need to prepare our MC MACro. (This is the file where we specify what kind of Monte-Carlo analysis we want, whereas the file MCFILE.MAC, shown above, specifies the *adjustments* we want to run on each case. They are separate files.)

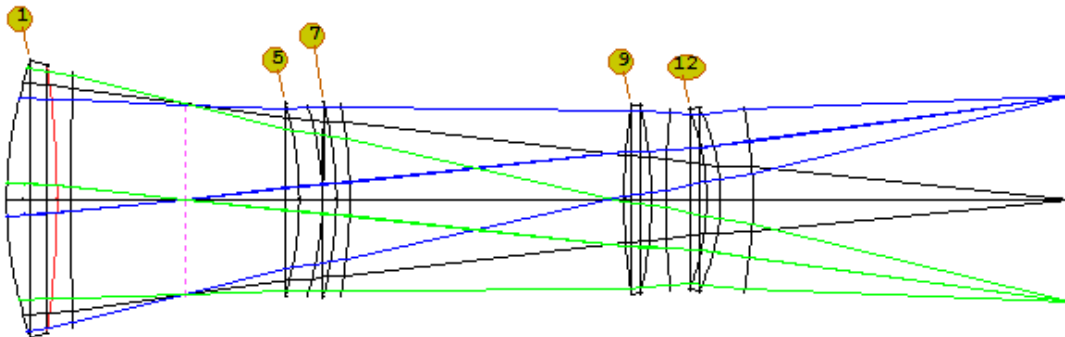
To start with, we will run MC with random wedge orientation. Here is the MACro:

```

MC ITEMIZE
SAMPLES 1 ! One case, please.
LIBRARY 5 ! We saved the initial lens in library location 5.
WORST ALL 1 ! Later we may want to see a worst case.
THSTAT UNIFORM ! Uniform thickness statistics.
WEDGES RANDOM ! Wedges have random orientation.
TEST ! Let's just look at a perturbed example.
GO ! Run MC.

```

Here, we do not optimize anything, just prepare a single perturbed example so we can examine it. (The elements all have a wedge error now, so the PAD display cannot color the elements as before.)



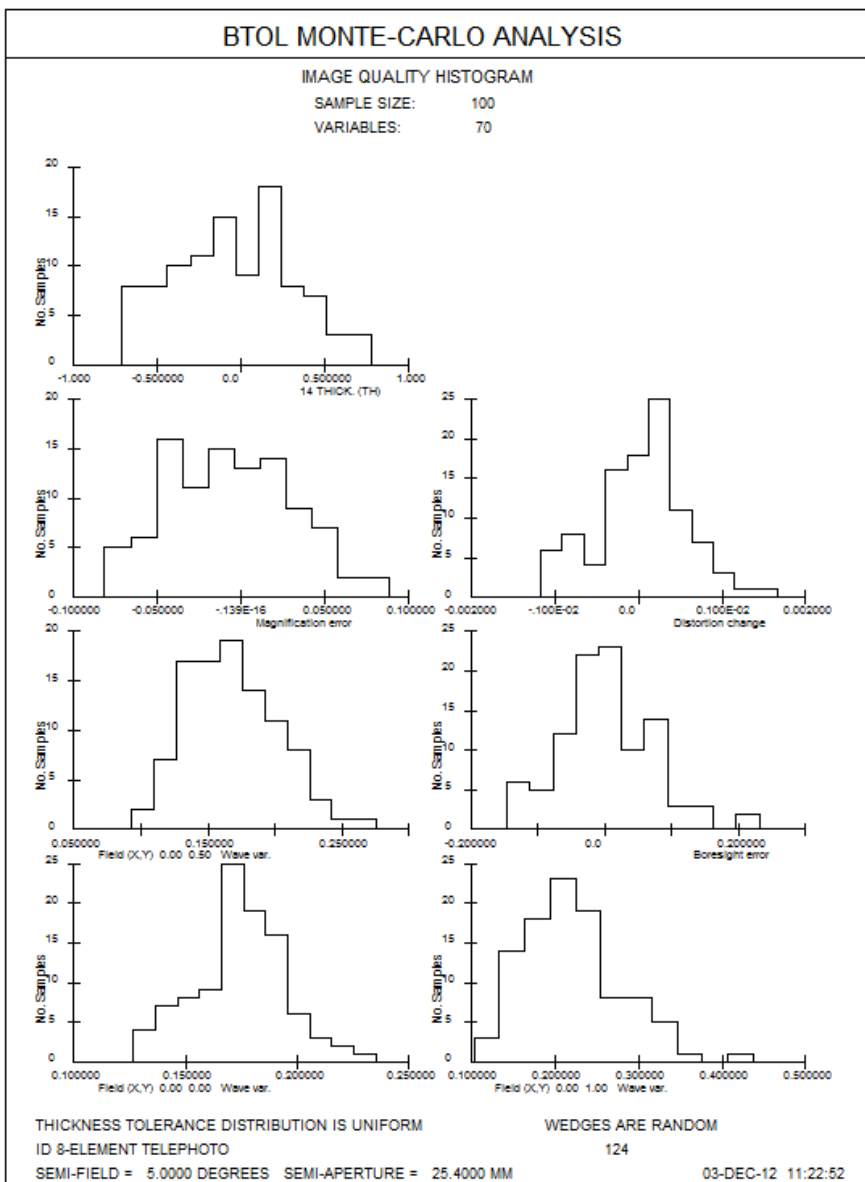
Okay, let's run a set of 100 lenses and look at the statistics. First we GET 5 (to restore the nominal lens), and then comment out the TEST directive and change the samples number.

```

MC ITEMIZE
SAMPLES 100 ! Ask for a set of 100 lenses.
LIBRARY 5
QUIET
WORST ALL 1
THSTAT UNIFORM
WEDGES RANDOM
!TEST
GO

```

When MC finishes, we get a plot of the statistics with MC PLOT.



All of this is pretty simple, so now we make things more interesting. We change our MACro as follows:

```

MC ITEMIZE
SAMPLES 100
LIBRARY 5
QUIET
WORST ALL 1
THSTAT UNIFORM
WEDGES CLOCK      ! Clock the wedge errors for each case.
TEST              ! Again make a single TEST case.
GO

```

Now the program will model the element tilts with a different protocol, using GROUP instead of RELATIVE tilts. This frees up the gamma tilt on each element to be used for cocking the wedge errors. We ask for a test case so we can examine how the errors have been defined. When this has executed, we look at the ASY listing for the perturbed lens:

```

TILT AND DECENTER DATA
LEFT-HANDED COORDINATES

```

SURF TYPE	X	Y	Z	ALPHA	BETA	GAMMA
TILT OR DECENTER GROUP SIZE: 3						
1 GROUP	0.00358	-0.00501	0.00000	0.0142	0.0000	0.0000
2 REL	0.00000	0.00000	0.00000	-0.0088	0.0000	0.0000
3 REL	0.00000	0.00000	0.00000	0.0112	0.0000	0.0000
TILT OR DECENTER GROUP SIZE: 2						
5 GROUP	-0.00977	-0.00652	0.00000	0.0749	0.0000	0.0000
6 REL	0.00000	0.00000	0.00000	0.0000	0.0235	0.0000
TILT OR DECENTER GROUP SIZE: 2						
7 GROUP	-0.01686	0.02519	0.00000	0.0701	0.0000	0.0000
8 REL	0.00000	0.00000	0.00000	0.0000	-0.0103	0.0000
TILT OR DECENTER GROUP SIZE: 3						
9 GROUP	-0.01049	-0.02937	0.00000	0.0000	0.0462	0.0000
10 REL	0.00000	0.00000	0.00000	0.0000	0.0183	0.0000
11 REL	0.00000	0.00000	0.00000	-0.0140	0.0000	0.0000
TILT OR DECENTER GROUP SIZE: 3						
12 GROUP	0.00107	-0.02203	0.00000	0.0000	0.0215	0.0000
13 REL	0.00000	0.00000	0.00000	-0.0291	0.0000	0.0000
14 REL	0.00000	0.00000	0.00000	0.0198	0.0000	0.0000
15 REL	0.00000	0.00000	0.00000	0.0000	0.0060	0.0000

From this listing we see that surfaces 1, 5, 7, 9, and 12 have been assigned a group tilt. We will vary all of them except the gamma tilt on surface 1, which furnishes a reference direction.

Okay, we need to modify our file MCFILE.MAC, adding the gamma tilt variables. We also elect to do a more sophisticated optimization while we are at it. Then we save the new MACro so MC will be able to open it and see the changes. It looks like this:

```

PANT
VY 14 TH
VY 5 GPG ! Vary group gamma tilt on surfaces 5, 7, 9, and 12 (but not surface 1).
VY 7 GPG
VY 9 GPG
VY 12 GPG
END

AANT

```

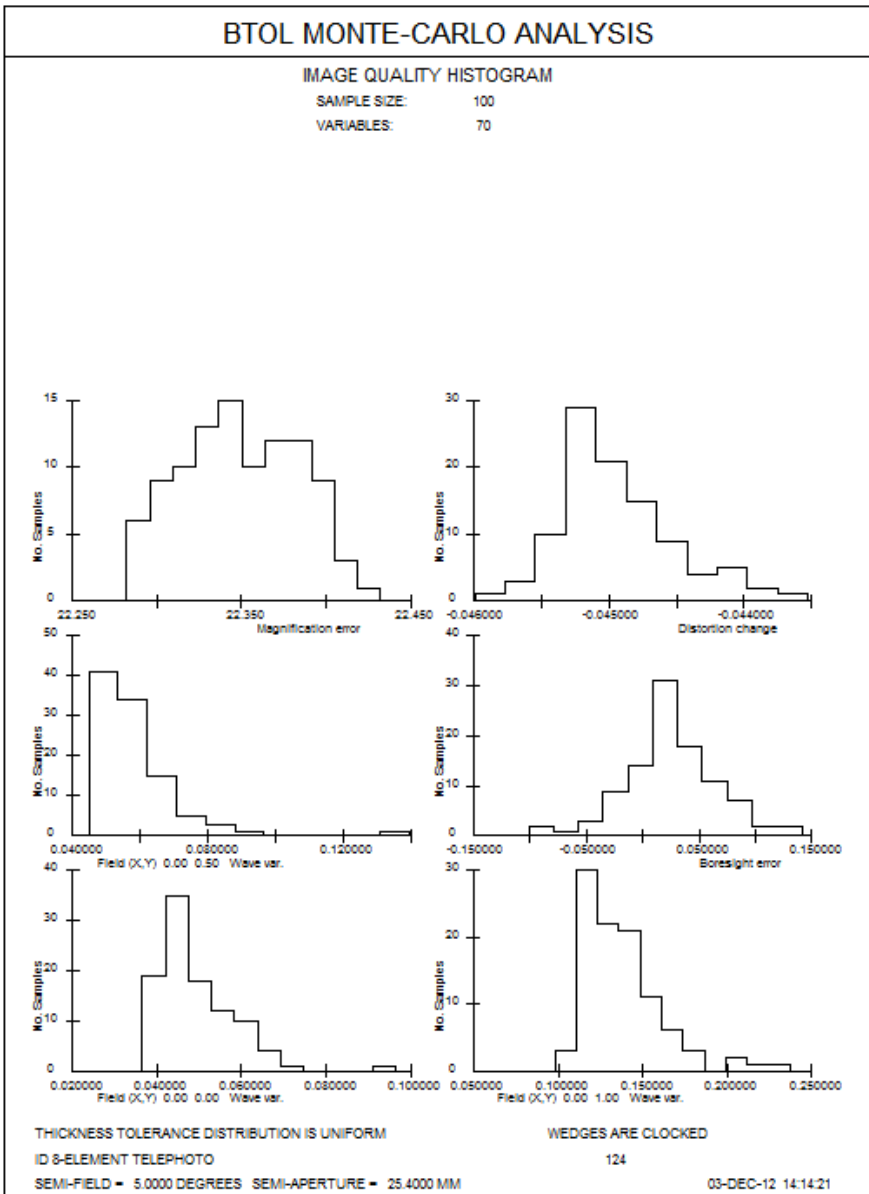
```

M 0 1 A P YA      ! Control the boresight error this way.
M 0 1 A P XA
GSR .5 10 5 M 0 0 0 F      ! Correct over the full pupil since the lens no longer has
GNR .5 2 3 M .7 0 0 F      ! bilateral symmetry.
GNR .5 1 3 M 1 0 0 F

GNR .5 2 3 M -.7 0 0 F      ! For the same reason we also control the negative field.
GNR .5 1 3 M -1 0 0 F
END
SYNOPSIS 10
MC

```

When we run it, we get improved statistics:



The lesson is almost finished – but suppose this lens is used in a device where the lateral color must be well controlled. We would like to know the statistics of the resulting aberration as each case is optimized. We add to the file MCFILE.MAC some AI input, and it now reads as follows:

```

PANT
VY 14 TH
VY 5 GPG
VY 7 GPG
VY 9 GPG
VY 12 GPG

END
AANT
M 0 1 A P YA
M 0 1 A P XA
GSR .5 10 5 M 0 0 0 F
GNR .5 2 3 M .7 0 0 F
GNR .5 1 3 M 1 0 0 F

GNR .5 2 3 M -.7 0 0 F
GNR .5 1 3 M -1 0 0 F
END
SYNOPSIS 10

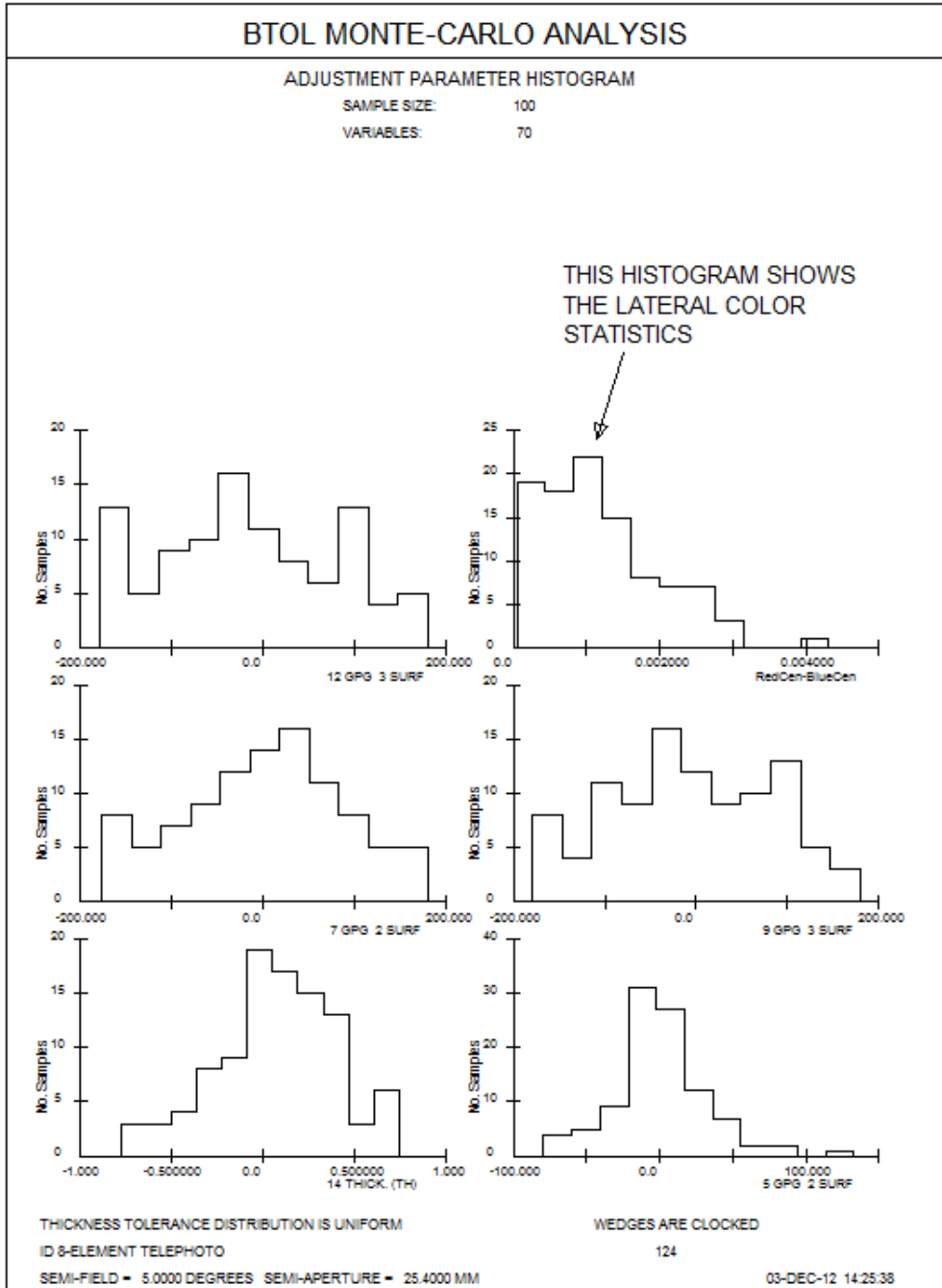
Z1 = XA IN COLOR 1 ! Get the actual X coordinate of the chief ray in color 1.
RMS 1 0 555 ! Run the RMS command, which also finds the centroid.
Z2 = FILE 4 ! This is the X-centroid location, relative to the chief ray,
Z3 = FILE 5 ! and this is the Y.
Z4 = YA IN COLOR 1 ! Also get the actual Y coordinate.

Z5 = XA IN COLOR 3 ! Do the same thing in color 3.
RMS 3 0 555
Z6 = FILE 4
Z7 = FILE 5
Z8 = YA IN COLOR 3

= SQRT((Z1 + Z2 - Z5 - Z6)**2 + (Z3 + Z4 - Z7 - Z8)**2) ! The separation.
Z9 = FILE 1 ! Load it into variable Z9, and tell MC
MC IZ9 "RedCen-BlueCen" ! to gather the statistics and plot Z9 with this label.
MC ! Next case, please.

```

Now, when we run our MACro, MC adds the statistics of the lateral color to the second plot page, which also shows the adjustment statistics.



This has been a somewhat advanced lesson, one that shows some of the unusual power available in SYNOPSIS™. We think you will find many other unique and friendly features when you become familiar with the code.