Tolerance in CODE V

Opti 521 Presentation

Yu-Hsiang Lai

College of Optical Sciences, The University of Arizona,
1630 E. University Blvd. Tucson, AZ 85721, USA

Outlines

- Abstract
- Summary of Tolerance in CODE V
- Typical procedure
- Tolerance Analysis in CODE V
- Demo
- Conclusion

Abstract

- Tolerance analysis is required to ensure system performance
- Each component in the optical system needs to be constrained with certain tolerance value
- CODE V provides complete tolerance analysis in three methods :
  - Wavefront Differential
  - Finite Difference
  - Monte Carlo Simulation

Tolerancing Methods

- **Finite Difference**:

  changes each parameter within its tolerance range and predicts the system performance degradation on a tolerance-by-tolerance basis.

- Disadvantage:
  - Prediction of overall performance is likely too optimistic.
  - does not consider parameter changes simultaneously in multiple components

Tolerancing Methods

- Monte Carlo:

  change all of the parameters that have an associated tolerance by random amounts, but within each tolerance range.
- Advantage:
  – It considered at the same time, the Monte Carlo method accurately accounts for cross-terms
- Disadvantage:
  – The individual tolerance for each components can't be obtained using this method.

Tolerancing Methods

- Wavefront Differential: (most common)
- Advantage:
  - It is very fast
  - provides information about both individual tolerance sensitivities (like the Finite Differences method)
  - an accurate performance prediction, including the effect of corss-terms(like the Monte Carlo method)

Comparison

Table 1. CODE V's tolerancing methods

Algorithm	CODE V Feature	Supported Performance Metric	Supported Tolerances	Comments
Wavefront Differentials	TOR	• RMS Wavefront Error • Diffraction MTF • Fiber Coupling Efficiency into a SMF • Polarization Dependent Loss into a SMF	CODE V pre-programmed tolerances (e.g., DLR, DLT, TIR, BTI, etc.)	• Very fast • Very accurate for tolerances that result in a small degradation in system performance **(includes cross-terms)** • Provides individual tolerance sensitivities AND accurate performance prediction • Both Inverse Sensitivity & Sensitivity analysis supported
Finite Differences	TOLFDIF	Any quantity that CODE V can compute	CODE V pre-programmed tolerances & *User-defined tolerances*	• Can be slow depending on number of tolerances, fields, zooms and type of performance metric analyzed. • Provides accurate individual tolerance sensitivities, particularly for larger tolerances • Performance summary is optimistic since this method does not include cross-terms. • Performance summary is approximate since this method assumes that the performance variation is quadratic with tolerance. This assumption may not be valid for the requested performance metric
Monte Carlo Simulation	TOLMONTE	Any quantity that CODE V can compute	CODE V pre-programmed tolerances & *User-defined tolerances*	• Can be slow depending on the number of trials requested and type of performance metric analyzed. • Provides accurate performance prediction (if many trials are requested), but no information about individual tolerance sensitivities

TOR Function

- Sensitivity Mode
  - includes the effect of adjustable parameters specified by the user to simulate the assembly procedure
- Inverse Sensitivity Mode
  - the program can select an appropriate set of tolerance parameters, ranges for the parameters, and specific values that provides a predetermined individual MTF drop.
- RMS wavefront eroor & MTF

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Procedure

1. Define quantitative figures of merit for requirements
2. Estimate component tolerances
3. Define assembly/alignment procedure and estimate tolerances
4. Calculate sensitivities
5. Estimate Performance
6. Adjust tolerances, balance cost and schedule with performance
7. Iterate with system engineer, fabricators, management

Tolerance Analysis in CODE V

1. Start with the unperturbed system
2. Adjust the parameter whose tolerance is being evaluated at the minimum value
3. Adjust the compensator
4. Record the resulting criteria
5. Repeat the previous steps for maximum tolerance
6. Repeat the entire procedure again

Example Demo

- An optical system that is used to focus a collimated HeNe laser beam onto a Position Sensing Detector (PSD)

- **System Specification**

  Entrance Pupil Diameter = 20 mm

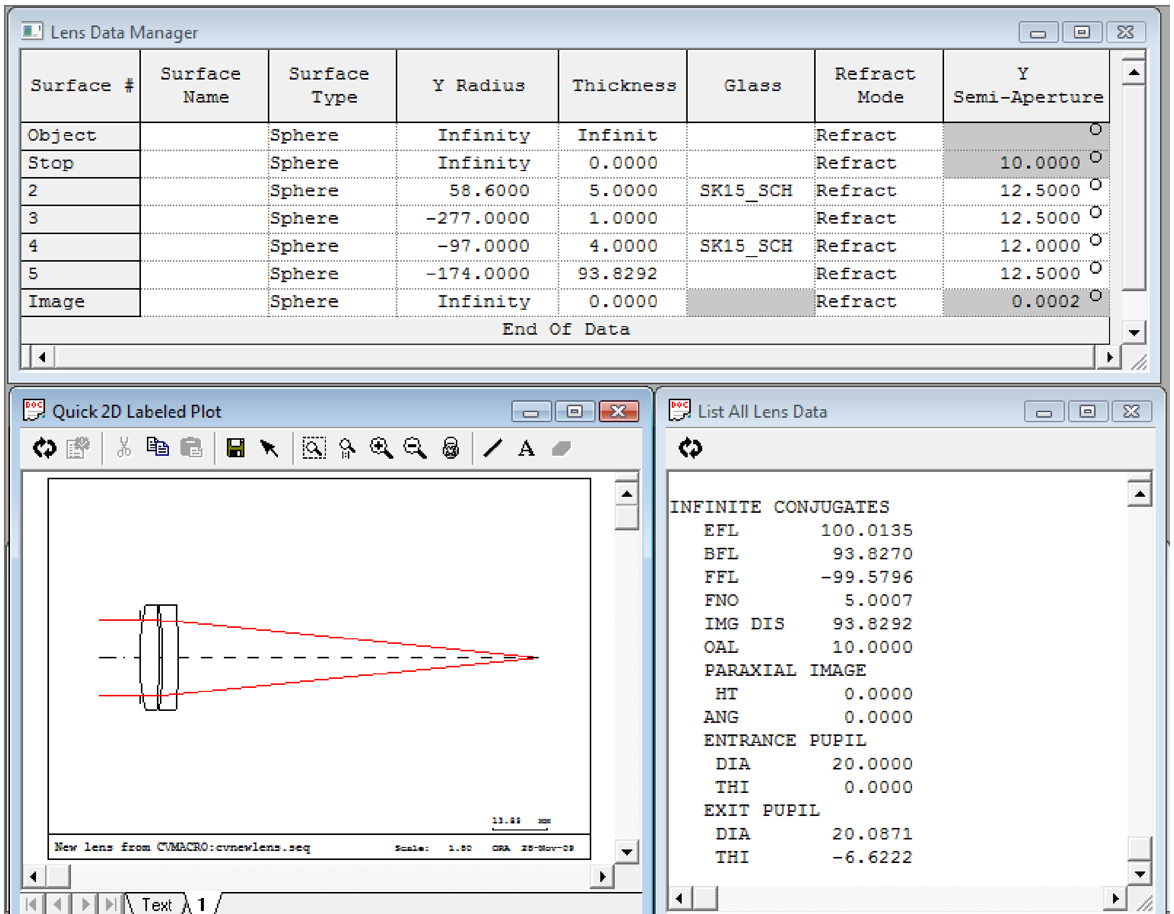
  Nominal EFL = 100 mm

  Wavelength = 632.8 nm(HeNe)

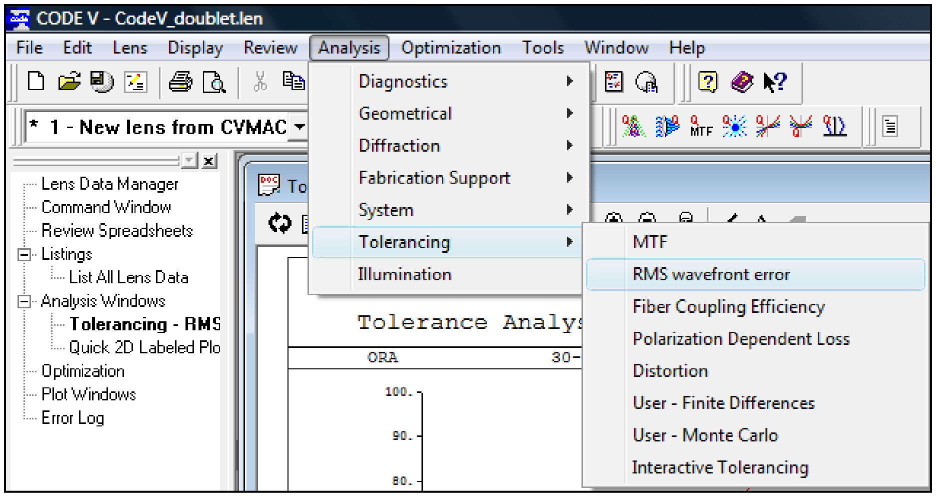
  Diffraction Limited Operation SR > 80%

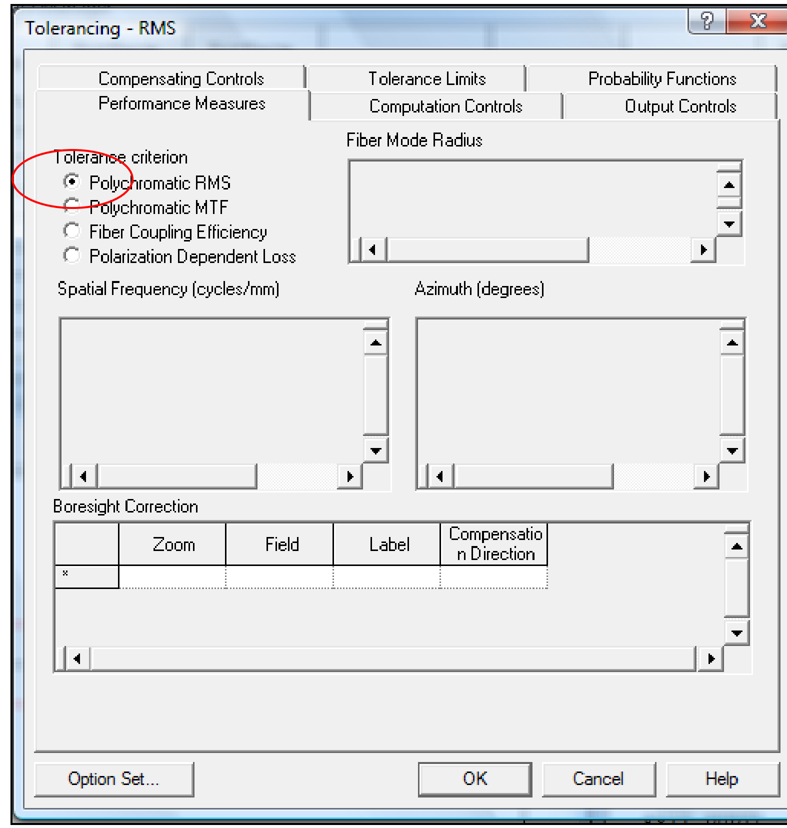
  Adjustment Resolution is about (+/-) 5 μm

Step 1: Opening the File



Step 2: **Analysis →Tolernacing→RMS Wavefront Error** menu





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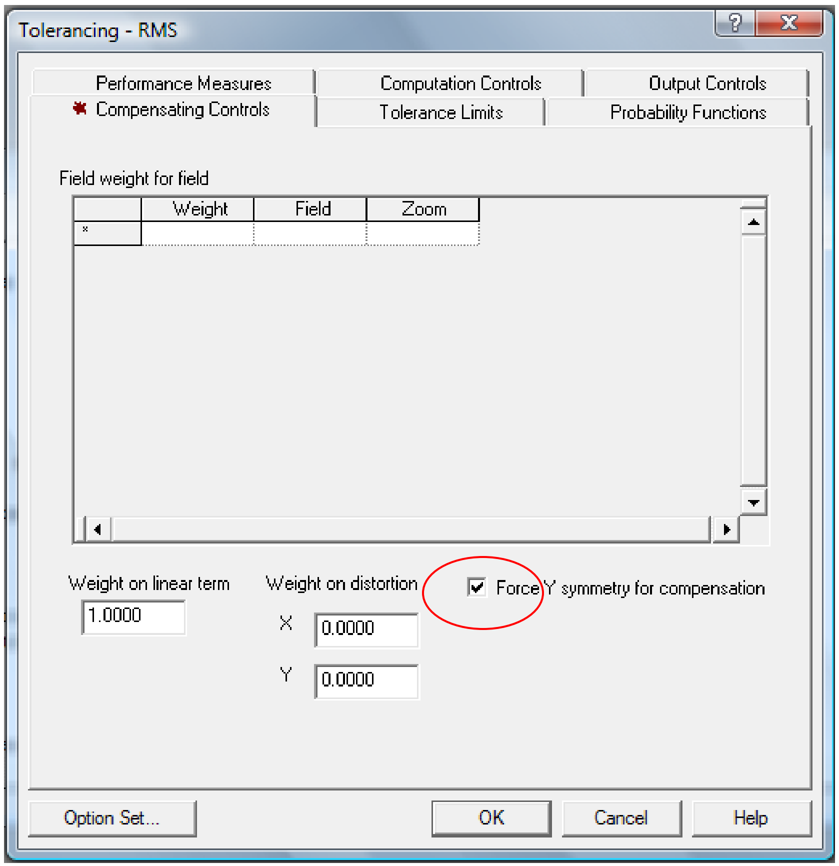
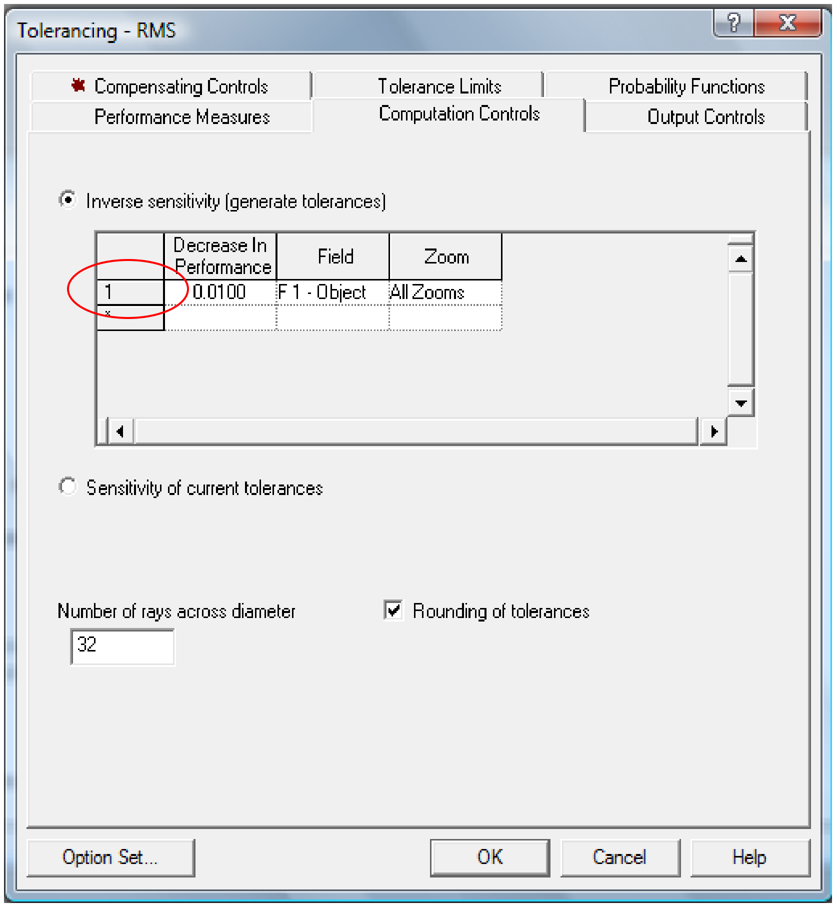
Step 3: *Compensation Control tab*



- Check the box where it says "*Force Y symmetry for compensation*".
- Ensure that the perturbation effect is considered the entire field of view instead of half field.

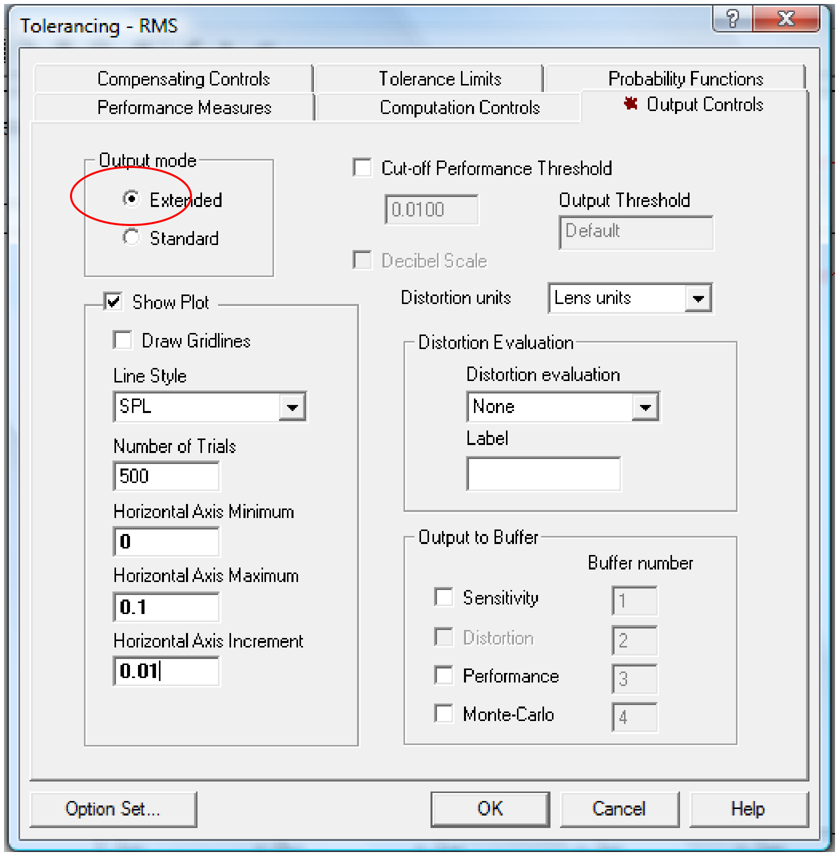
Step 4 : *Computation Control* tab



- single-click on the column where it says one under the "*Inverse Sensitivity*" mode.

- This will set the default decrease in performance to be 0.01 waves. This value can be modified to meet your specification.

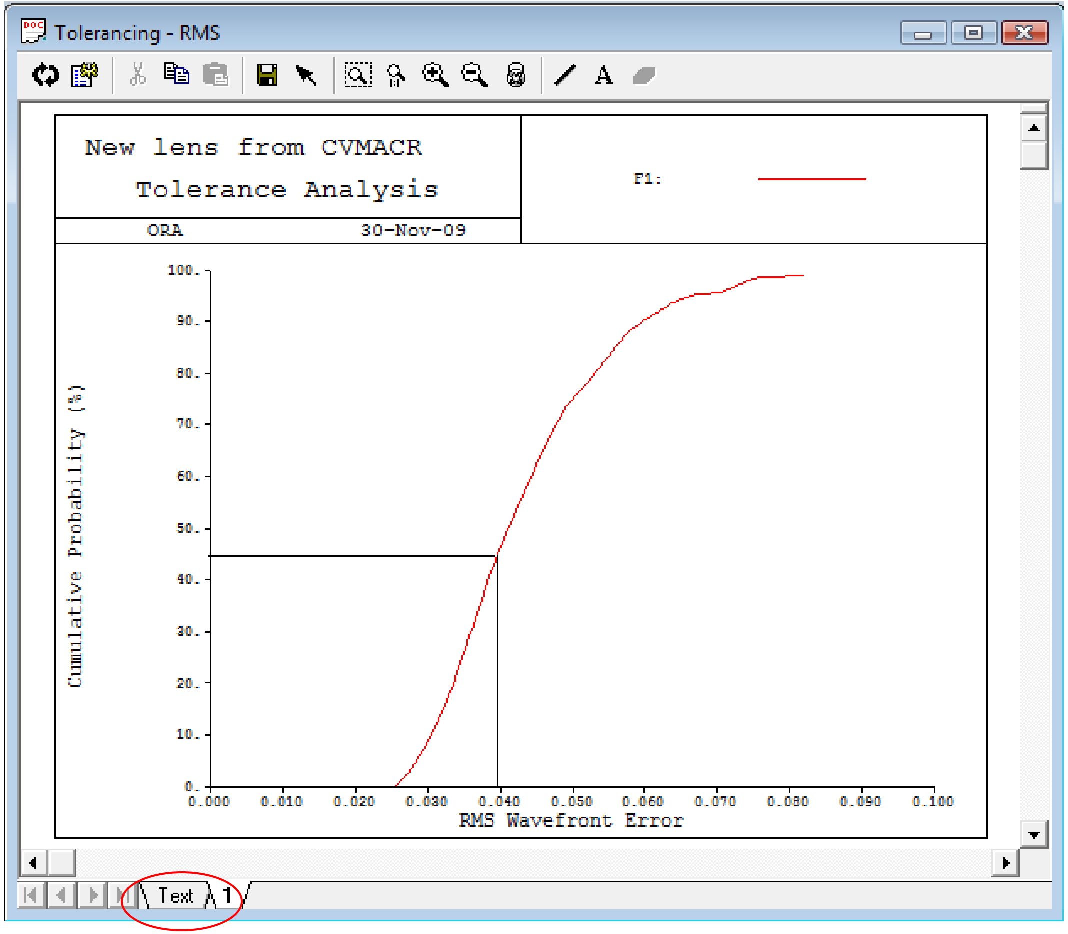
Step 5 : *Output Controls tab*



- choose the "*Extended*" output mode

- modify the "*Horizontal Axis Minimum*", "*Horizontal Axis Maximum*", "*Horizontal Axis Increment*" option to adjust your plot scale

Step 6 : Generate Plot



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Step 7 : Interpret the data

Possible Perturbation in DODE V

BTX	Tilt in X (in radians) of the group of surfaces about the pole of the first surface
BTY	Tilt in Y (in radians) of the group of surfaces about the pole of the first surface
CYD	Cylinder (at 45 degrees) irregularity in fringes at 546.1 nm. over the clear aperture
CYN	Cylinder (at 0 degrees) irregularity in fringes at 546.1 nm. over the clear aperture
DLF	Test plate fit (power) in fringes at 546.1 nm. over the clear aperture
DLN	Change of index of refraction
DLR	Change of radius in mm.
DLT	Change of thickness in mm.
DLZ	Axial displacement of the surface in mm.
DSX	Lateral displacement of the group of surfaces in the X-direction in mm.
DSY	Lateral displacement of the group of surfaces in the Y-direction in mm.
TRX	Total indicator runout in X (resulting in a surface tilt) at the clear aperture in mm.
TRY	Total indicator runout in Y (resulting in a surface tilt) at the clear aperture in mm.

Text File – Extended Mode

```
                                                                RMS = SQRT(A*T**2 + B*T + C)

                                                               (T=SCALE FACTOR FOR CHANGE)

                                                                         C = 0.000556

--------------------------------------------------------------------------------------------------------

                                                     COMPENSATING PARAMETERS
                                                     -----------------------
                                                             DLZ S6
 MANUFACTURING ERROR            CHANGES IN RMS FOR     RMS OF
                                  PLUS AND MINUS      CHANGE IN
TYPE              CHANGE       MANUFACTURING ERRORS  WAVEFRONT                              A            B

DLF S2         2.0000000v       0.0000     0.0000      0.0003             -0.043819     0.000000     0.000000
DLF S3         2.0000000v       0.0000     0.0000      0.0004              0.041228     0.000000     0.000000
DLF S4         2.0000000v       0.0000     0.0000      0.0009             -0.044359     0.000001     0.000000
DLF S5         2.0000000v       0.0000     0.0000      0.0005              0.039019     0.000000     0.000000
```

Centered Tolerance

30-Nov-09 POSITION 1

C E N T E R E D
T O L E R A N C E S

New lens from CVMACRO:cvnewlens.seq

SUR	RADIUS	RADIUS TOL	FRINGES POW/IRR	THICKNESS	THICKNESS TOL	GLASS	INDEX TOL	V-NO (%)	INHOMO-GENEITY
1				0.00000	0.50000				
2	58.60000	2.2000	2.0/ 0.50	5.00000	0.50000	SK15	0.00200		
3	-277.00000	34.0000	2.0/ 0.50	1.00000	0.50000				
4	-97.00000	1.9000	2.0/ 0.50	4.00000	0.50000	SK15	0.00200		
5	-174.00000	9.9000	2.0/ 0.50	93.82924					
6				0.00000					

Radius, radius tolerance, thickness and thickness tolerance are given in mm.

Fringes of power and irregularity are at 546.1 nm. over the clear aperture

Irregularity is defined as fringes of cylinder power in test plate fit

De-centered Tolerance

D E C E N T E R E D
T O L E R A N C E S

New lens from CVMACRO:cvnewlens.seq

ELEMENT NO.	FRONT RADIUS	BACK RADIUS	ELEMENT WEDGE TIR	ELEMENT WEDGE ARC MIN	ELEMENT TILT TIR	ELEMENT TILT ARC MIN	EL. DEC/ROLL(R) TIR	EL. DEC/ROLL(R) mm.
1	58.60000	-277.00000	0.0700	9.6	0.0625	8.6	0.0517	0.1000
2	-97.00000	-174.00000	0.0200	2.9	0.0480	6.9	0.0104	0.1000

Radii are given in units of mm.

For wedge and tilt, TIR is a single indicator measurement taken at the smaller of the two clear apertures. For decenter and roll, TIR is a measurement of the induced wedge and is the maximum difference in readings between two indicators, one for each surface, with both surfaces measured at their respective clear apertures. The direction of measurement is parallel to the original optical axis of the element before the perturbation is applied. TIR is measured in mm.

Decenter or roll is measured perpendicular to the optical axis in mm.

Result

Tolerancing - RMS

CYN S5	0.5000000v	0.0048	0.0048	0.0159
TRY S2	0.0700000v	0.0093	0.0093	0.0229
TRX S2	0.0700000v	0.0093	0.0093	0.0229
BTY S2..3	0.0025000v	0.0048	0.0048	0.0157
BTX S2..3	0.0025000v	0.0048	0.0048	0.0157
DSY S2..3	0.1000000v	0.0069	0.0069	0.0193
DSX S2..3	0.1000000v	0.0069	0.0069	0.0193
TRY S4	0.0200000v	0.0097	0.0097	0.0235
TRX S4	0.0200000v	0.0097	0.0097	0.0235
BTY S4..5	0.0020000v	0.0095	0.0095	0.0232
BTX S4..5	0.0020000v	0.0095	0.0095	0.0232
DSY S4..5	0.1000000v	0.0069	0.0069	0.0193
DSX S4..5	0.1000000v	0.0069	0.0069	0.0193
RSS				0.0996

- Lens 1(DSX S2..3)
  DeCenter 1 = 0.0193 / 0.1 = 0.193 λ/mm
- Lens 2(DSX S4..5)
  DeCenter 2 = 0.0193 / 0.1 = 0.193 λ/mm
- Tilt1 = 0.0157/0.0025 rad = 0.0157 λ/0.143 degrees = 0.1096 λ/degree
- Tilt2 = 0.0232/0.002 rad = 0.0157 λ/0.143 degrees = 0.2025 λ/degree

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Comparison

Parameters	**CodeV TOR**	**Manual**
Decenter1 (λ/mm)	0.193	**0.19096**
Tilt 1 (λ/degree)	0.1096	**0.11325**
Decenter2(λ/mm)	0.193	**0.18794**
Tilt 2 (λ/degree)	0.2025	**0.19799**

Conclusion

- Shows that the sensitivity analysis obtained through the automatic “tolerance” button is actually really close to the values we got through manual perturbations.
- To minimize production cost, the ideal optical system design will maintain the required performance with achievable component and assembly tolerances, using well-chosen post-assembly adjustment.
- The unique suite of tolerancing capabilities in CodeV will do just the trick when building the ideal system.