Tolerancing in Zemax

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OPTI 521
12/18/2015

Introduction

- Tolerancing is an important skill to have as an optical engineer.
- Having designed a lens, it is important to know how it will perform once it is built.

Basic tolerancing procedure

- Define quantitative figures of merit for the requirements
- Estimate system tolerances
  - Component manufacturing tolerances
  - Mechanical alignment tolerances
  - Optical tolerances
- Execute Zemax tolerance analysis
- Review tolerance results
- Adjust tolerances appropriately. Keep cost and schedule in mind

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System Figure of Merit

- Must propagate all performance specs through to assembly
- Typical requirements
  - RMSWE (Root Mean Square Wavefront Error)
  - MTF at particular spatial frequencies
  - Distortion
  - Fractional encircled energy
  - Beam divergence
  - Geometric RMS image size
  - Dimensional limits

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Rules of thumb for Optical Tolerances

Parameter	Base	Precision	High precision
Lens diameter	100 μm	25 μm	6 μm
Lens thickness	200 μm	50 μm	10 μm
Radius of curvature Surface sag Value of R	20 μm 1%	1.3 μm 0.1%	0.5 μm 0.02%
Wedge (light deviation)	6 arc min	1 arc min	15 arc sec
Surface irregularity	1 wave	λ/4	λ/20
Surface finish	50 Å rms	20 Å rms	5 Å rms
Scratch/dig	80/50	60/40	20/10
Dimension tolerances for complex elements	200 μm	50 μm	10 μm
Angular tolerances for complex elements	6 arc min	1 arc min	15 arc sec
Bevels (0.2 to 0.5 mm typical)	0.2 mm	0.1 mm	0.02 mm

Rules of thumb for machined parts

- ± 1 mm for coarse dimensions that are not important
- ± 0.25 mm for typical machining without difficulty
- ± 0.025 mm precision machining, readily accessible
- < ± 0.002 mm high-precision, requires special tooling

Rules of Thumb for Optical Assemblies

Parameter	Base	Precision	High precision
Spacing (manual machined bores or spacers)	200 µm	25 µm	6 µm
Spacing (NC machined bores or spacers)	50 µm	12 µm	2.5 µm
Concentricity (if part must be removed from chuck between cuts)	200 µm	100 µm	25 µm
Concentricity (cuts made without de-chucking part)	200 µm	25 µm	5 µm

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Zemax tolerance analysis

- Zemax conducts an analysis of the tolerances using one of these three tools:
  - Sensitivity analysis
  - Inverse sensitivity analysis
  - Monte Carlo analysis

Sensitivity analysis

- “Forward” analysis
- Considers each defined tolerance sequentially and independently.
- Parameters are adjusted to the limits of the tolerance range, and then the optimum value of each compensator is determined.
- A table is generated listing the contribution of each tolerance to the performance loss.

Inverse sensitivity analysis

- “Backwards” analysis
- Iteratively computes the tolerance limits on each parameter when the maximum degradation in performance is defined.

Monte Carlo

- All tolerances are considered at once.
- Random systems are generated using the defined tolerances.
- Every parameter is randomly perturbed using appropriate statistical models. All compensators are adjusted and then the entire system is evaluated with all defects considered.

Zemax example

- Let's open Zemax file DOUBLET.ZMX
- Presenting in Zemax

DOUBLET.ZMX