#### ZEMAX Users' Knowledge Base - <u>http://www.zemax.com/kb</u> How to Analyze Your Tolerance Results

http://www.zemax.com/kb/articles/109/1/How-to-Analyze-Your-Tolerance-Results/Page1.html By Dan Hill Published on 19 June 2006

Many times it is useful to analyze your tolerances in detail. In ZEMAX's tolerance analysis, you may save the tolerance results for each Monte Carlo file, or you may save each tolerance in the sensitivity analysis indidvidually in ZEMAX file format. This article describes how to take a closer look at what ZEMAX does internally to model each and every tolerance in your design.

### Introduction

ZEMAX offers a built-in tolerancing feature which you may use to perform a complete and accurate tolerance analysis of your optical system.

Although ZEMAX performs the calculation of each tolerance "behind the scenes," ZEMAX also gives you the option to view what it is doing more closely; the operation of the tolerance feature is not always transparent.

There are two different methods to saving the modifications that ZEMAX made to your lens file to calculate the change in criteria as a function of the specified tolerance(s).

The first option may be defined in the Tolerance Data Editor as a tolerance control operand. The SAVE tolerance control operand can be used after any tolerance you would like to inspect in more detail. For example, suppose that you had a tolerance operand TEDX (tolerance on element decenter in X) in the Tolerance Data Editor. After reviewing the resulting sensitivity analysis, the results did not appear to make sense.

As a result, you may edit the Tolerance Data Editor by adding a SAVE command after the TEDX operand. The next time the tolerance analysis is run, ZEMAX will save the file used to compute the TEDX tolerance, which you may view as a ZEMAX lens file.

# **Applying the SAVE Tolerance Control Operand**

To demonstrate, consider a single element for which you would like to know how the RMS Spot Radius changes for a tilt tolerance about the X axis.

FILE: Single Element Lens.ZMX (attached to last page of article)

TETX is the operand for tolerance on element tilt about the X axis. In this case, the single element has a tilt tolerance of +/-0.5 degrees.

00 T	olerar	nce Data Edi	itor				
Edit	Tools	Help					
	Oper	#	-	Nominal	Min	Max	Comment
	1	(TETX)	-	0.0000	-0.5000	0.5000	
<						1000	0

Running the tolerance with the following settings (note that Paraxial Focus is set as the compensator):

🚺 Tolera	ncing				
Mode: # Monte Ca	Sensitivity	2 50.000000 Save Monte Carlo Runs: 0			
Criteria: Sampling: Comp: Fields: Script:	RMS Spot Radius     2   Paraxial Focus   Y-Symmetric   DDUZ2.TSC	MTF Frequency:   30.000000     Config:   1 / 1     Cycles:   Auto     Separate Fields/Configs     Force Ray Aiming On			
Show E Show C Statistics:	Descriptions Compensators	Overlay MC Graphics   Hide All But Worst   Show Worst:   10			
	Cancel Terminate	Save Load Reset			

In the Sensitivity Analysis of the tolerance output, we can see the criteria value as well as the change in criteria as a function of our TETX tolerance.

<b>01 2:</b> T	ext '	Viewer					
Update	Sett	ings <b>Prin</b>	t Window				
Test W	lave.	length	: 0.5500				~
Fields	- Y	Symmetry	ric Angle in d	enrees			
#	X	-Field	Y-Field	Weight	VDX	VDY	Ţ
1 0	. 00	DE+000	0.000E+000	1.000E+000	0.000	0.000	0.C
a							
Sensit	101	ty Analy	7515:				
			1	Minimu	<u>m</u>		
Type			Valu	e Crit	eria	C	hang
TETX	l	2	-0.5000000	0 0.04397	6541	3.4911	E-OC
Worst	off	anders					
Type	011.	ender s.	Valu	e Crit	eria	c	hanc
TETX	1	2	-0.50000000	0 0.04397	6541	3.4911	E-OC
TETX	1	2	0.5000000	0 0.04397	6541	3.4911	E-OC
Estima	ted	Perform	mance Changes 1	based upon P	loot-Sum	-Square	met
Nomina	I RI	MS Spot	Radius :	0.043973049		1999 - Total State (1999) 1999 - Total State (1999) 1999 - Total State (1999)	
Estima	ted	change		3.4911E-006			
Estime	ted	RMS Spo	ot Radius:	0.043976541			
							~
<							> .

In this case, the tilt did not affect the RMS Spot Radius very much, but we can review what ZEMAX has done more closely by saving the file ZEMAX internally constructed to perform this perturbation.

In the Tolerance Data Editor, under the TETX line, insert a SAVE tolerance control operand.

<b>01</b> 1	olerar	nce Data Ed	litor				
Edit	Tools	Help					
	Oper	#	Туре	File#	8	=	Nominal 📥
	1	(TETX)	TETX	1	2	-	0.0
	2	(SAVE)	SAVE	5	-	-	
		150	694 (1)	16	190	197	~
<							> .::

The SAVE command allows you to save the previous tolerance to a ZEMAX Lens File with the specified "File #." A file will be saved for both the maximum and minimum tolerance. The file names will be TSAV\_MIN\_xxxx.ZMX and TSAV\_MAX\_xxxx.ZMX for the min and max tolerance analysis, respectively, where xxxx is the integer number specified in the Int1 column. In this case, the integer number is 5, so the minimum tolerance file will be TSAV\_MIN\_0005.ZMX. Note that the saved file is saved into the same directory as the current lens file.

Run the tolerance analysis once more with the SAVE operand in place (use the same tolerance settings).

Once the analysis is complete, open the TSAV\_MIN\_0005.ZMX file from the appropriate directory. Note the modifications made to the Lens Data Editor. To tilt the element about the X axis, ZEMAX inserted a pair of Coordinate Break Surfaces with the appropriate solves and values. ZEMAX even places text in the Comment column to indicate which tolerance each surface represents. Also note the marginal ray height solve on surface 6. Remember, we chose to have Paraxial Focus as our compensator when performing the tolerance analysis! With this choice, ZEMAX compensates for tolerance perturbations by moving the image surface in such a way that the perturbed system has the same amount of paraxial defocus as the original system. Thus, the marginal ray height solve on surface 6 brings surface 7 to paraxial focus, and the thickness of surface 7 maintains the paraxial defocus present in the original system.

Edit	Solves Options H	elp						
	Surf:Type	Comment	Radius	Thickness		Glass		Semi-
OBJ	Standard		Infinity	Infinity				
1	Coordinate	+TETX 1 2		0.0000				
TO*	Standard	32470	6.0500	1.7500		SF5		
3*	Standard		Infinity	-1.7500	Т			
4	Coordinate	-TETX 1 2		1.7500	P	-		
5	Standard		Infinity	7.3902			P	
6	Standard		Infinity	0.5012	M		P	
7	Standard		Infinity	-0.5012			P	
IMA	Standard		Infinity	5 <u>1</u>				

01 L	ens Data Editor					
Edit	Solves Options I	Help				
	Surf:Type	Decenter Y	Tilt About X	Tilt About Y	Tilt About Z	c 🔨
OBJ	Standard					
1	Coordinate	0.0000	-0.5000	0.0000	0.0000	
STO*	Standard					
3*	Standard					
4	Coordinate	0.0000	0.5000	0.0000	0.0000	
5	Standard					
6	Standard					
7	Standard					
IMA	Standard					
<					· ·	×

With this capability, we can clearly review what ZEMAX has done to ensure any given tolerance is performed the way we expect. Most importantly, we can thoroughly investigate any tolerance which we find to produce curious results.

In the saved file, it is also possible to review the merit function which ZEMAX constructed to evaluate the RMS Spot Radius criteria. The Merit Function Value is equivalent to the criteria value reported in the tolerance output:

🔲 Merit Fu	nction Edit	or 4.397	654E-002					
Edit Tools I	Help							
Oper #	Ty	7pe				15		^
1 D	MFS	DMFS						a
2 B	LNK	BLNK	Default merit	function:	RMS	spot radius c	entroid GQ 2 :	rings 4 a
ЗВ	LNK	BLNK	No default ai	ir thickness	bou	ndary constra	ints.	
4 B	LNK	BLNK	No default gl	lass thickne:	ss b	oundary const	raints.	
5 B	LNK	BLNK	Operands for	field 1.			<i>.</i>	
6 T	RAC	TRAC			1	0.0000	0.0000	
7 T	RAC	TRAC			1	0.0000	0.0000	
8 T	RAC	TRAC			1	0.0000	0.0000	v
<				Þ				> .:

01 2:	Text	Viewer					
Updab	e Sett	ings Prir	it Window				
Test	Wave.	length	: 0.5500				^
Fiel	ds: Y	Symmet	ric Angle in	degrees			
#	X	-Field	Y-Field	Weight	VDX	VDY	Ţ,
1	0.00	0E+000	0.0008+000	1.000E+000	0.000	0.000	0.C
Sens	itivi	ty Anal	ysis:				
			1	Minimu	ա		
Type			Val	ue Crit	eria	C	hang
TETX	1	2	-0.500000	00 0.04397	6541	3.4911	E-OC
Wors	t off	enders:					
Type			Val	ue Crit	eria	C	hang
TETX	1	2	-0.5000000	00 0.04397	6541	3.4911	E-OC
TETX	1	2	0.500000	00 0.04397	6541	3.4911	.E-0C
Esti	mated	Perfor	mance Changes	based upon I	loot-Sum	-Square	. met
Nomi	nal N	MS Spot	Radius :	0.043973049		8000 <b>-</b> 8402 - 86	10.000
Esti	mated	change	8 12	3.4911E-006			
Esti	mated	RMS Sp	ot Radius:	0.043976541			
22000			1221 022202202020202				×
<							>

# **Saving Monte Carlo Tolerance Files**

Much like the SAVE tolerance control operand (which is useful for evaluating one tolerance at a time), you may also save each individual Monte Carlo file generated during the tolerance analysis. This option exists in the Tolerancing dialog. In the top-most portion of the dialog, you may choose to specify how many Monte Carlo runs to perform as well as how many of these Monte Carlo files you would like to save for viewing after the analysis is complete.

()) Tolerancing					[	
Mode:	Sensitivity				? 50.00000	
# Monte Ca	arlo Runs:	20		Save Monte Carlo	Runs: 0	
Criteria:	RMS Spot R	adius	-	MTF Frequency:	30,000000	
Sampling:	2		-	Config:	1/1	•
Comp:	Paraxial Focu	s	-	Cycles:	Auto	-
Fields:	XY-Symmetrie	D	-	🔲 Separate Fields/Configs		
Script:	ODUZ2.TSC		~	Force Ray Aim	ing On	
G Show E	escriptions)			🔲 Overlay MC Gr	aphics	
□ Show C	Compensators			Hide All But W	orst	
Statistics:	Norm	ial	-	Show Worst:	10	•
Status:	Idle					
ОК	Cancel	Tem	ninate	Save	Load	Reset

The benefits to saving the Monte Carlo files are the same to that of the SAVE tolerance control

operand. However, the Monte Carlo analysis simulates the effect of *all* perturbations simultaneously. Thus, the saved files will contain the modified Lens Data Editor with possibly many changes/additions (depending upon the number of tolerance operands you have for your system).

Saved Monte Carlo files are also saved to the directory of the nominal lens file and any number of Monte Carlo files may be saved. The lens files are named MC\_T000x.zmx, where x is the value 1 through the maximum number of specified Monte Carlo files to be saved.

🗀 Tolerance Analysis of Singl	e Element Lens		
File Edit View Favorites Too	ols Help		<u></u>
🌀 Back 🔹 🕥 🕤 🏂 🔎	Search 😥 Folders 🛄 🗸		
Address 🛅 C:\Tolerance Analysis of	Single Element Lens		🖌 🄁 Go
	Name 🔺	Size	Туре
File and Folder Tasks 🏾 🏝	MC_T0001.ZMX	10 KB	ZEMAX Lens File
C Mala a saw faldar	MC_T0002.ZMX	10 KB	ZEMAX Lens File
Make a new rolder	MC_T0003.ZMX	10 KB	ZEMAX Lens File
Publish this folder to	MC_T0004.ZMX	10 KB	ZEMAX Lens File
C Share this folder	MC_T0005.ZMX	10 KB	ZEMAX Lens File
	MC_T0006.ZMX	10 KB	ZEMAX Lens File
	MC_T0007.ZMX	10 KB	ZEMAX Lens File
Other Places	MC_T0008.ZMX	10 KB	ZEMAX Lens File
	MC_T0009.ZMX	10 KB	ZEMAX Lens File
🥪 Local Disk (C:)	MC_T0010.ZMX	10 KB	ZEMAX Lens File
A My Documents	Single Element Lens.SES	13 KB	ZEMAX Session File
😡 My Computer	Single Element Lens.ZMX	7 KB	ZEMAX Lens File
My Network Places	v <		

In most cases, it isn't necessary or desirable to review each individual saved Monte Carlo file. You may use the Monte Carlo Analysis output to help pick out any specific trial that you would like to later review in ZEMAX format:

WI Z: Text Viewer		
Update Settings Print Windo	W	
Estimated change	: 3.4911E-006	~
Estimated RMS Spot Radi	ius: 0.043976541	
Compensator Statistics:	8	
Change in back focus:		
Minimum :	0.00000	
Maximum :	0.00000	
Mean :	0.00000	
Standard Deviation :	0.000000	
Monte Carlo Analysis:		
Number of trials: 20		
Initial Statistics: Nor	mal Distribution	
Trial Criteria	Change	
1 0 043975471	2 4214E-006	
2 0.043973356	3 06898-007	
3 0.043973056	6 54918-009	
4 0.043973516	4 66728-007	
5 0.043973852	8 03028-007	
6 0.043973100	5 09108-008	
7 0 043973162	1 12908-007	
8 0.043973072	2 27888-008	
9 0.043975039	1 98948-006	
10 0.043973532	4 83028-007	
11 0 043973832	7 82838-007	
12 0.043976305	3 25558-006	
13 0.043973083	3 37348-008	
14 0.043974039	9 89258-007	
15 0.043972075	2 50968-009	13
16 0.043973078	1 81398-008	
17 0.043973697	6 47788-007	
18 0.043974955	1 90558-006	
19 0.043973541	4 91478-007	
20 0.043973695	6.4599B-007	
Nominal 0.043973049		
Best 0.043973056	Trial 3	
Worst 0.043976305	Trial 12	
Mean 0.043973822		
Std Dev 8.9384E-007		
		×
		2

### **Summary and References**

When tolerancing and optical system, it is very important that you analyze and understand the results of the tolerance analysis. Sometimes, a certain tolerance or Monte Carlo run might produce suspicious results, requiring further in-depth analysis. The SAVE tolerance control operand and the ability to save Monte Carlo files make this job much easier and give you full access to what ZEMAX has done to the compute the tolerance analysis.

#### REFERENCES

ZEMAX Optical Design Program User's Guide, ZEMAX Development Corporation