

Tutorial 2

Correcting Thermal Focus Errors

This tutorial assumes that you have the results of Tutorial 1 available for use.

In this tutorial you will learn:

- how to calculate the effects of thermal expansion or contraction of the housing

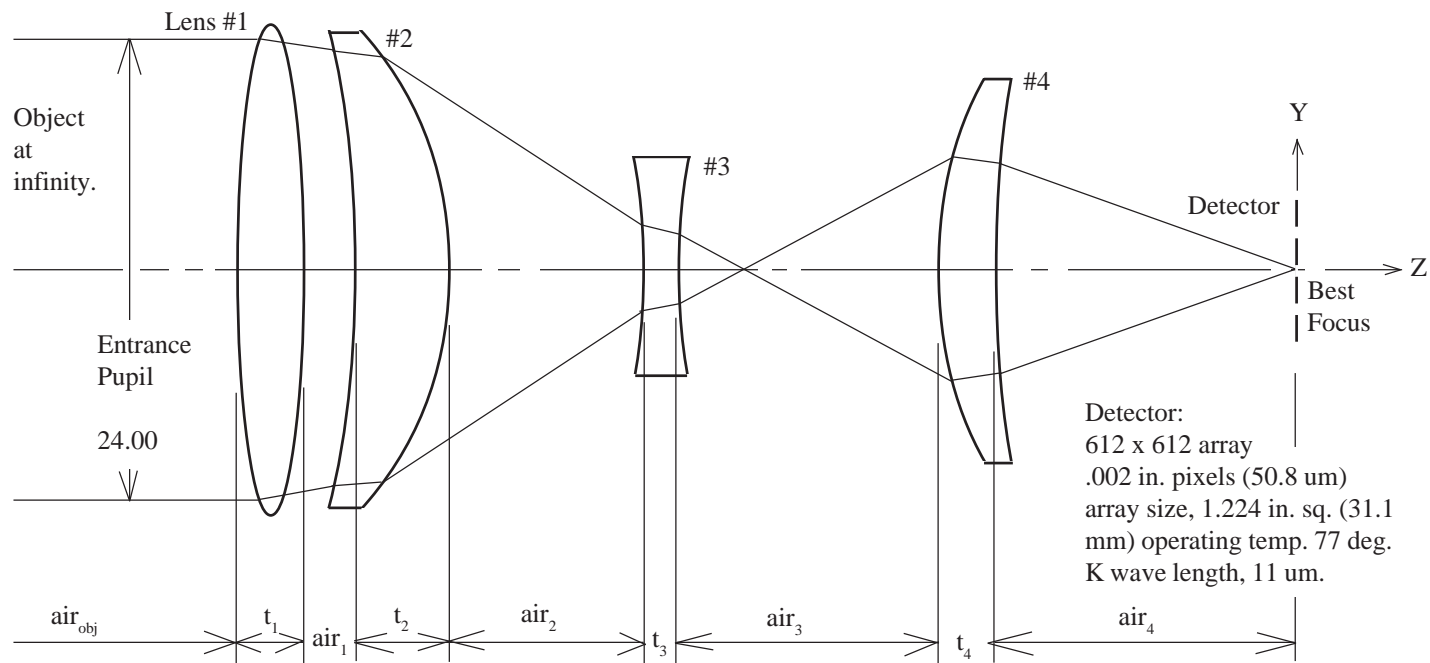
- how to calculate the thermal change in focal length of a lens

- how to calculate the focus error caused by thermal effects on the lenses and the housing

- how to specify an adjustment mechanism to correct the focus errors

AEH.

Optomechanics



Your project, an infrared receiver defined in Tutorial 1, is concerned about the sensitivity of the focus to changes in temperature.

Task 1:

Determine the focus shift caused by a temperature change of ± 10 C degrees, assuming the housing is aluminum.

AEH.

Optomechanics

In Tutorial 1 you ran Ivory to create the Optomechanical Constraint Equations. You then opened them in Excel and calculated the focus shift from the anticipated assembly tolerances. You will now open that Excel file from Internet Explorer:

The screenshot shows an Internet Explorer window titled 'IRREC' displaying a file explorer for the directory 'C:\11\IvoryTutorials\2\IRREC'. The file list includes 'IRREC1.DAT', 'IRREC.DAT', 'IRREC.IND', 'IRREC.OUT', and 'IRREC.OUT.xls'. Below the file explorer, an Excel spreadsheet is open, displaying the following data:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Output	from	-											
2		IVORY	Optomech	Modeling Tools										
3		Version	2.4											
4		Copyright 2010,	Alson	E.	Hatheway Inc.									
5														
6	This	Product	has	been	licensed	to	Alson	E.	Hatheway Inc.	for	one	user(s).		
7														
8	PROJECT	NAME:	'IRREC'	TIME	AND	DATE:	18:02:35	#####						
9														
10	PHYSICAL	PRESCRIP	ECHO											
11														
12		Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4			
13		1	obj	inf	1	inf	obj	1	0	0	0			
14		2	1	-300	4.0026	2	LENS	0	0	0	0			
15		3	1	300	1	5.3566	LENS	0	0	0	0			
16		4	2	110	4.0026	3.45	LENS	0	0	0	0			
17		5	2	55	1	17.775	LENS	0	0	0	0			
18		6	3	310	4.0026	2	LENS	0	0	0	0			
19		7	3	-215	1	11.9417	LENS	0	0	0	0			

AEH.

Optomechanics

You will re-name the first sheet from “IRREC” to “Tolerances”, add a second sheet and name it “Thermal.”

Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4
1	obj	inf		1 inf	obj	1	0	0	0
2	1	-300	4.0026	2	LENS	0	0	0	0
3	1	300	1	5.3566	LENS	0	0	0	0
4	2	110	4.0026	3.45	LENS	0	0	0	0
5	2	55	1	17.775	LENS	0	0	0	0
6	3	310	4.0026	2	LENS	0	0	0	0
7	3	-215	1	11.9417	LENS	0	0	0	0

You will then copy the contents of the first sheet, Tolerances, onto the second sheet, Thermal. On the Thermal sheet erase all the calculations that were copied from the Tolerances sheet so you have only the Ivory output file data on the Thermal sheet.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	
29	ELE	F	H1	H2	P	F/FAIR	PHI	THETA	TYPE																			
30	obj		0	0	0	inf	0	0	obj																			
31	1	50.0819	-0.2505	0.25046	1.49907	7.25347	0	0	LENS																			
32	2	34.9885	-1.6464	-0.8232	2.6268	17.246	0	0	LENS																			
33	3	-42.16	-0.2942	0.20405	1.50175	11.9058	0	0	LENS																			
34	4	6.64703	0.33998	0.67996	1.16002	21.1527	0	0	LENS																			
35	dot		0	0	0	0	0	0	dot																			
36																												
37	SYSTEM	-51.579	265.293	-72.045	381.362	-51.573																						
38																												
39																												
40	OBJECTS IMAGES AND																											
41																												
42	ELE	F	S	S'	M	PHI	THETA	TYPE	offT _{ax}																			
43	obj	inf	0	0	1	0	0	obj																				
44	1	50.0819	inf	-50.082	0	0	0	LENS	+0.00D+00																			
45	2	34.9885	-42.829	-19.257	0.4496	0	0	LENS	+1.29D-02																			
46	3	-42.16	-2.0108	-2.1115	1.0501	0	0	LENS	-2.49D-02																			
47	4	6.64703	9.6943	-21.146	-2.1813	0	0	LENS	-3.28D-01																			
48	dot	inf	+6.39D-0	+6.39D-0	1	0	0	dot																				
49																												
50																												
51	OPTOME CONSTR EQUATIO (ABSOLL VALUES																											
52																												
53	REGISTR VARIABLES																											
54																												
55		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LD _{dev} /var																		
56																												
57	Tx	0	0	0	0	0	0	0	0	0	Dt																	
58	Ty	0	0	0	0	0	0	0	0	0	DR1																	
59	Tz	0	0	0	0	0	0	0	0	0	DR2																	
60	Rx	0	0	0	0	0	0	0	0	0	Dn																	
61	Ry	0	0	0	0	0	0	0	0	0																		
62	Rz	0	0	0	0	0	0	1	0	0																		
63	Df,p	0	0	0	0	0	0	0	0	0																		
64	SYSTEM-OBJECT																											
65																												
66	Tx	-1.0299	0	0	0	0	0	0	0.06277	Dt																		
67	Ty	0	-1.0299	0	0	0	0	0	-0.0833	DR1																		

Copy first sheet
onto second sheet.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
29	ELE	F	H1	H2	P	F/FAIR	PHI	THETA	TYPE																		
30	obj		0	0	0	inf	0	0	obj																		
31	1	50.0819	-0.2505	0.25046	1.49907	7.25347	0	0	LENS																		
32	2	34.9885	-1.6464	-0.8232	2.6268	17.246	0	0	LENS																		
33	3	-42.16	-0.2942	0.20405	1.50175	11.9058	0	0	LENS																		
34	4	6.64703	0.33998	0.67996	1.16002	21.1527	0	0	LENS																		
35	dot		0	0	0	0	0	0	dot																		
36																											
37	SYSTEM	-51.579	265.293	-72.045	381.362	-51.573																					
38																											
39																											
40	OBJECTS IMAGES AND																										
41																											
42	ELE	F	S	S'	M	PHI	THETA	TYPE	offT _{ax}																		
43	obj	inf	0	0	1	0	0	obj																			
44	1	50.0819	inf	-50.082	0	0	0	LENS	+0.00D+00																		
45	2	34.9885	-42.829	-19.257	0.4496	0	0	LENS	+1.29D-02																		
46	3	-42.16	-2.0108	-2.1115	1.0501	0	0	LENS	-2.49D-02																		
47	4	6.64703	9.6943	-21.146	-2.1813	0	0	LENS	-3.28D-01																		
48	dot	inf	+6.39D-0	+6.39D-0	1	0	0	dot																			
49																											
50																											
51	OPTOME CONSTR EQUATIO (ABSOLL VALUES																										
52																											
53	REGISTR VARIABLES																										
54																											
55		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LD _{dev} /var																	
56																											
57	Tx	0	0	0	0	0	0	0	0	0	Dt																
58	Ty	0	0	0	0	0	0	0	0	0	DR1																
59	Tz	0	0	0	0	0	0	0	0	0	DR2																
60	Rx	0	0	0	0	0	0	0	0	0	Dn																
61	Ry	0	0	0	0	0	0	0	0	0																	
62	Rz	0	0	0	0	0	0	1	0	0																	
63	Df,p	0	0	0	0	0	0	0	0	0																	
64	SYSTEM-OBJECT																										
65																											
66	Tx	-1.0299	0	0	0	0	0	0	0.06277	Dt																	
67	Ty	0	-1.0299	0	0	0	0	0	-0.0833	DR1																	

Clear the old calculations
on this second sheet.

AEH.

Optomechanics

The temperature change affects the focus of the system through thermal expansion or contraction of the aluminum housing, through the thermal expansion or contraction of the lenses and changes in the index of refraction of the lens material. The changes in the aluminum housing primarily affect the air spacing of the elements whereas the changes to the elements primarily affect their focal lengths. You will need the material properties for the aluminum and the germanium:

	dl/dT (per C)	dn/dT (per C)
aluminum	23.4×10^{-6}	---
germanium	5.5×10^{-6}	4.0×10^{-4}

The first column is the coefficient of thermal expansion (CTE). The second column is the thermal coefficient of refractive index (TCRI).

Record these values at the top of the Thermal spreadsheet for future use.

See the next page for the results.

AEH.

Optomechanics

Material properties

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	Output	from	-																					
2		IVORY	Optomech	Modeling	Tools																			
3		Version	2.4																					
4		Copyright	2010,	Alson	E.	Hathewa	Inc.																	
5																								
6	This	Product	has	been	licensed	to	Alson	E.	Hathewa	Inc.	for	one	user(s).											
7																								
8	PROJECT	NAME:	'IRREC'	TIME	AND	DATE:	18:02:35	#####																
9																								
10	PHYSICAL	PRESCRIP	ECHO																					
11																								
12		Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4													
13		1	obj	inf	1	inf	obj	1	0	0	0													
14		2	1	-300	4.0026	2	LENS	0	0	0	0													
15		3	1	300	1	5.3566	LENS	0	0	0	0													
16		4	2	110	4.0026	3.45	LENS	0	0	0	0													
17		5	2	55	1	17.775	LENS	0	0	0	0													
18		6	3	310	4.0026	2	LENS	0	0	0	0													
19		7	3	-215	1	11.9417	LENS	0	0	0	0													
20		8	4	-11	4.0026	1.5	LENS	0	0	0	0													
21		9	4	-22	1	20.4727	LENS	0	0	0	0													
22		10	det	inf	1	0	det																	
23																								
24	INDEXES	OF	REFRACTIVE	INDEX	RELATIVE	TO	THE	VALUE	OF	1.00029														
25																								

Note:
We are assuming the vertex of lens #1 as the Z axis datum plane.

Next you need to calculate the length of the aluminum between the lenses that control the air spaces. You may *initially assume* the length between two lenses to be the distance between their first vertices. Calculate these distances on the spreadsheet next to the physical prescription data.

Then calculate the total distance of each lens from lens #1.

Of course you may wish to revisit any (or all) your assumptions later.

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Optomechanics

Fourth, calculate the Z axis displacement per C of lens 2:

$$Tz \text{ per C} = (Z \text{ distance})(\text{aluminum's CTE})$$

51	OPTOMECH	CONSTRAINT	EQUATION	(ABSOLUTE VALUES)	SMALLER THAN	0	ARE	PRINTED	AS	(0,0)			
53	REGISTERED VARIABLES												
54		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDasVar	Disp Vector per C	Dims	Material Properties
73	ELEMENT-1												
75	Tx	-1.2607	0	0	0	0	0	0	-0.4558	Dt			
76	Ty	0	-1.2607	0	0	0	0	0	-0.2895	DR1			
77	Tz	0	0	4.18598	0	0	0	-0.3214	1.24372	DR2	1.72E-04	7.3566 Z	2.34E-05 al CTE
78	Rx	0	-6.0168	0	-1.2607	0	0	0	-11.78	Dn		3.45 =t	5.50E-06 ge CTE
79	Ry	6.01684	0	0	0	-1.2607	0	0	0			110 =R1	5.50E-06 ge CTE
80	Rz	0	0	0	0	0	0	0	0			55 =R2	5.50E-06 ge CTE
81	Df,p	0	0	-1.5893	0	0	0	0.13289	0		-1.87E-02	4.0026 =n	4.00E-04 ge TCRI
82	ELEMENT-2												
84	Tx	0.10925	0	0	0	0	0	0	0.06007	Dt			

$$(R2)(CTE)(df/dR2)$$

example of calculations

Fifth, calculate the change in focal length per C:

$$\Delta f \text{ per C} = (t)(CTE)(df/dt) + (R1)(CTE)(df/dR1) + (R2)(CTE)(df/dR2) + (n)(TCRI)$$

The change in focal length per C is the sum of the contributions from the four lens design variables: the thickness, the first radius, the second radius and the index of refraction, as shown in the equation.

AEH.

Optomechanics

Now, to get the contribution of lens 2 to the image motion at the detector you multiply the influence coefficients for lens 2 by the displacement vector for lens 2, as shown.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
74																										
75	Tx	-1.2607	0	0	0	0	0	0	0	-0.4558	Dt															
76	Ty	0	-1.2607	0	0	0	0	0	0	-0.2895	DR1															
77	Tz	0	0	4.18598	0	0	0	0	-0.3214	1.24372	DR2	1.72E-04	7.3566	Z		2.34E-05	al	CTE								
78	Rx	0	-6.0168	0	-1.2607	0	0	0	0	-11.784	Dn		3.45	=t		5.50E-06	ge	CTE								
79	Ry	6.01684	0	0	0	-1.2607	0	0	0	0			110	=R1		5.50E-06	ge	CTE								
80	Rz	0	0	0	0	0	0	0	0	0			55	=R2		5.50E-06	ge	CTE								
81	Df,p	0	0	-1.5893	0	0	0	0	0.13289	0			-1.87E-02	4.0026	=n		4.00E-04	ge	TCRI							
82	ELEMENT-2																									
83																										

influence coefficients x displacement vector = image motion contributions

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
74																										
75	Tx	-1.2607	0	0	0	0	0	0	0	-0.4558	Dt							0	0	0	0	0	0	0	0	0
76	Ty	0	-1.2607	0	0	0	0	0	0	-0.2895	DR1							0	0	0	0	0	0	0	0	0
77	Tz	0	0	4.18598	0	0	0	0	-0.3214	1.24372	DR2	1.72E-04	7.3566	Z		2.34E-05	al	CTE	0	0	0.00072	0	0	0	-6E-05	
78	Rx	0	-6.0168	0	-1.2607	0	0	0	0	-11.784	Dn		3.45	=t		5.50E-06	ge	CTE	0	0	0	0	0	0	0	
79	Ry	6.01684	0	0	0	-1.2607	0	0	0	0			110	=R1		5.50E-06	ge	CTE	0	0	0	0	0	0	0	
80	Rz	0	0	0	0	0	0	0	0	0			55	=R2		5.50E-06	ge	CTE	0	0	0	0	0	0	0	
81	Df,p	0	0	-1.5893	0	0	0	0	0.13289	0			-1.87E-02	4.0026	=n		4.00E-04	ge	TCRI	0	0	0.02968	0	0	0	-0.0025
82	ELEMENT-2																									
83																										

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	
51	OPTOMECH CONSTRAIN EQUATION (ABSOLUTE VALUES SMALLER THAN 0 ARE PRINTED AS 0.0)																										
52																											
53	REGISTRAR VARIABLES											Disp Vector (per C)		Dims		Material Properties											
54																											
55		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDesVar								TX	TY	TZ	RX	RY	RZ	DM/M			
56																											
57	Tx	0	0	0	0	0	0	0	0	0 Dt																	
58	Ty	0	0	0	0	0	0	0	0	0 DR1																	
59	Tz	0	0	0	0	0	0	0	0	0 DR2																	
60	Rx	0	0	0	0	0	0	0	0	0 Dn																	
61	Ry	0	0	0	0	0	0	0	0	0																	
62	Rz	0	0	0	0	0	0	1	0	0																	
63	Df,p	0	0	0	0	0	0	0	0	0																	
64	SYSTEM-OBJECT																										
65																											
66	Tx	-1.0299	0	0	0	0	0	0	0	0.06277 Dt								0	0	0	0	0	0	0	0	0	
67	Ty	0	-1.0299	0	0	0	0	0	0	-0.0833 DR1								0	0	0	0	0	0	0	0	0	
68	Tz	0	0	1.06068	0	0	0	0	-0.0653	0.08326 DR2		0.00E+00	0	Z	2.34E-05	al CTE		0	0	0	0	0	0	0	0	0	
69	Rx	0	-1.5439	0	-1.0299	0	0	0	0	-16.669 Dn					2	t	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
70	Ry	1.54389	0	0	0	-1.0299	0	0	0	0					-300	R1	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
71	Rz	0	0	0	0	0	0	0	0	0					300	R2	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
72	Df,p	0	0	-1.0607	0	0	0	0.08531	0	0								0	0	0	0.02802	0	0	0	0	-0.0023	
73	ELEMENT-1																										
74																											
75	Tx	-1.2607	0	0	0	0	0	0	0	-0.4558 Dt								0	0	0	0	0	0	0	0	0	
76	Ty	0	-1.2607	0	0	0	0	0	0	-0.2895 DR1								0	0	0	0	0	0	0	0	0	
77	Tz	0	0	4.18598	0	0	0	0	-0.3314	1.24372 DR2		1.72E-04	7.3566	Z	2.34E-05	al CTE		0	0	0	0.00073	0	0	0	0	-6E-05	
78	Rx	0	-6.0168	0	0	-1.2607	0	0	0	0								0	0	0	0	0	0	0	0	0	
79	Ry	6.01684	0	0	0	0	0	0	0	0					110	=R1	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
80	Rz	0	0	0	0	0	0	0	0	0					55	=R2	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
81	Df,p	0	0	-1.5893	0	0	0	0.13289	0	0								0	0	0	0	0	0	0	0	0	
82	ELEMENT-2																										
83																											
84	Tx	0.10925	0	0	0	0	0	0	0	0.06007 Dt								0	0	0	0	0	0	0	0	0	
85	Ty	0	0.10925	0	0	0	0	0	0	-0.0569 DR1								0	0	0	0	0	0	0	0	0	
86	Tz	0	0	-0.4885	0	0	0	0	0.0586	0.11602 DR2		6.69E-04	28.5816	Z	2.34E-05	al CTE		0	0	-0.0003	0	0	0	0	0	3.9E-05	
87	Rx	0	-3.2758	0	0.10925	0	0	0	0	14.051 Dn					2	=t	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
88	Ry	3.27578	0	0	0	0.10925	0	0	0	0					310	=R1	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
89	Rz	0	0	0	0	0	0	0	0	0					-215	=R2	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
90	Df,p	0	0	0.0119	0	0	0	2.01503	0	0								0	0	0	-0.0003	0	0	0	0	4.5E-05	
91	ELEMENT-3																										
92																											
93	Tx	3.1813	0	0	0	0	0	0	0	0.417 Dt								0	0	0	0	0	0	0	0	0	
94	Ty	0	3.1813	0	0	0	0	0	0	-1.4525 DR1								0	0	0	0	0	0	0	0	0	
95	Tz	0	0	-3.7581	0	0	0	0.32816	0.24406 DR2		9.95E-04	42.5233	Z	2.34E-05	al CTE			0	0	-0.0037	0	0	0	0	0	0.00033	
96	Rx	0	0	0	0	0	0	0	0	-2.265 Dn					1.5	=t	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
97	Ry	-1.16	0	0	0	0	3.18131	0	0	0					-11	=R1	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
98	Rz	0	0	0	0	0	0	0	0	0					-22	=R2	5.50E-06	ge CTE		0	0	0	0	0	0	0	0
99	Df,p	0	0	0	0	0	0	0	0	0								0	0	0	0.03633	0	0	0	0	-0.0017	
100	ELEMENT-4																										
101																											
102	Tx	-1	0	0	0	0	0	0	0	0 Dt								0	0	0	0	0	0	0	0	0	
103	Ty	0	-1	0	0	0	0	0	0	0 DR1								0	0	0	0	0	0	0	0	0	
104	Tz	0	0	-1	0	0	0	0	0	0 DR2		1.51E-03	64.496	Z	2.34E-05	al CTE		0	0	-0.0015	0	0	0	0	0	0	
105	Rx	0	0	0	-1	0	0	0	0	0 Dn					0	=t	5.50E-06	ge CTE		0	0	0	0	0	0	0	
106	Ry	0	0	0	0	-1	0	0	0	0					inf	=R1	5.50E-06	ge CTE		0	0	0	0	0	0	0	
107	Rz	0	0	0	0	0	-1	0	0	0								0	0	0	0	0	0	0	0	0	
108	Df,p	0	0	0	0	0	0	0	0	0					0	1	=n	5.50E-06	ge CTE		0	0	0	0	0	0	0
109	DETECTOR																										
110																			0	0	0.0889	0	0	0	0	-0.0061	
111	Thank	you	for	using	IVORY(tm)	to	prepare	the	Optomech	Constrain	Equations	for	'IRREC'					TX	TY	TZ	RX	RY	RZ	DM/M			
112																											
113																											

The calculations for lens #2 were performed on the previous three pages.

Perform the calculations for the other elements (copy the functions from lens 2 and paste them into positions for the other elements).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z					
51	OPTOMECONSTR	EQUATION	ABSOLUT	VALUES	SMALLER	THAN		O	ARE	PRINTED	AS	0.0)																			
52		REGISTRA	VARIABLES									Disp																			
53												Vector	Dims																		
54												(per C)																			
55		TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDesVar										TX	TY	TZ	RX	RY	RZ	DM/M					
56																															
57	Tx	0	0	0	0	0	0	0	0.06277	Dt									0	0	0	0	0	0	0	0					
58	Ty	0	0	0	0	0	0	0	0	DR1									0	0	0	0	0	0	0	0					
59	Tz	0	0	0	0	0	0	0	0	DR2									0	0	0	0	0	0	0	0					
60	Rx	0	0	0	0	0	0	0	0	DR									0	0	0	0	0	0	0	0					
61	Ry	0	0	0	0	0	0	0	0										0	0	0	0	0	0	0	0					
62	Rz	0	0	0	0	0	0	0	0										0	0	0	0	0	0	0	0					
63	Df,p	0	0	0	0	0	0	0	0										0	0	0	0	0	0	0	0					
64	SYSTEM-OBJECT																														
65																															
66	Tx	-1.0299	0	0	0	0	0	0	0.06277	Dt									0	0	0	0	0	0	0	0					
67	Ty	0	-1.0299	0	0	0	0	0	0	DR1									0	0	0	0	0	0	0	0					
68	Tz	0	0	1.06068	0	0	0	0	-0.0653	0.08326	DR2								0.00E+00	0	Z	2.34E-05	al	CTE	0	0	0				
69	Rx	0	-1.5439	0	-1.0299	0	0	0	0	-16.669	Dn								2	t	5.50E-06	ge	CTE	0	0	0	0				
70	Ry	1.54389	0	0	0	-1.0299	0	0	0	0									-300	R1	5.50E-06	ge	CTE	0	0	0	0				
71	Rz	0	0	0	0	0	0	0	0	0									300	R2	5.50E-06	ge	CTE	0	0	0	0				
72	Df,p	0	0	-1.0607	0	0	0	0.08531	0	0									-2.64E-02	4.0026	n	4.00E-04	ge	TCRI	0	0	0.02802	0	0	0	-0.0023
73	ELEMENT-1																														
74																															
75	Tx	-1.2607	0	0	0	0	0	0	-0.4558	Dt									0	0	0	0	0	0	0	0					
76	Ty	0	-1.2607	0	0	0	0	0	0	-0.2895	DR1								0	0	0	0	0	0	0	0					
77	Tz	0	0	4.18598	0	0	0	0	-0.3214	1.24372	DR2								1.72E-04	7.3566	Z	2.34E-05	al	CTE	0	0	0.00072	0	0	0	-6E-05
78	Rx	0	-6.0168	0	-1.2607	0	0	0	0	-11.784	Dn								3.45	=t	5.50E-06	ge	CTE	0	0	0	0	0	0	0	
79	Ry	6.01684	0	0	0	-1.2607	0	0	0	0									110	=R1	5.50E-06	ge	CTE	0	0	0	0	0	0	0	
80	Rz	0	0	0	0	0	0	0	0	0									55	=R2	5.50E-06	ge	CTE	0	0	0	0	0	0	0	0
81	Df,p	0	0	-1.5893	0	0	0	0.13289	0	0									-1.87E-02	4.0026	=n	4.00E-04	ge	TCRI	0	0	0.02968	0	0	0	-0.0025
82	ELEMENT-2																														
83																															
84	Tx	0.10925	0	0	0	0	0	0	0.06007	Dt									0	0	0	0	0	0	0	0					
85	Ty	0	0.10925	0	0	0	0	0	0	-0.0559	DR1								0	0	0	0	0	0	0	0					
86	Tz	0	0	-0.4885	0	0	0	0.0586	0.11602	DR2									6.69E-04	28.5816	Z	2.34E-05	al	CTE	0	0	-0.0003	0	0	0	3.9E-05
87	Rx	0	-3.2758	0	0.10925	0	0	0	0	14.0513	Dn								2	=t	5.50E-06	ge	CTE	0	0	0	0	0	0	0	
88	Ry	3.27578	0	0	0	0.10925	0	0	0	0									310	=R1	5.50E-06	ge	CTE	0	0	0	0	0	0	0	0
89	Rz	0	0	0	0	0	0	0	0	0									-215	=R2	5.50E-06	ge	CTE	0	0	0	0	0	0	0	0
90	Df,p	0	0	-0.0119	0	0	0	2.01E-03	0	0									2.23E-02	4.0026	=n	4.00E-04	ge	TCRI	0	0	-0.0003	0	0	0	4.5E-05
91	ELEMENT-3																														
92																															
93	Tx	3.18131	0	0	0	0	0	0	-0.4112	Dt									0	0	0	0	0	0	0	0					
94	Ty	0	3.18131	0	0	0	0	0	0	-1.152	DR1								0	0	0	0	0	0	0	0					
95	Tz	0	0	-3.5991	0	0	0	0.181	0.1306	DR2									3.18E-01	31.8131	Z	2.34E-05	al	CTE	0	0	-0.0037	0	0	0	0.00033
96	Rx	0	1.16002	0	3.18131	0	0	0	0	-2.2651	Dn								1.5	=t	5.50E-06	ge	CTE	0	0	0	0	0	0	0	0
97	Ry	-1.16	0	0	0	3.18131	0	0	0	0									-11	=R1	5.50E-06	ge	CTE	0	0	0	0	0	0	0	0
98	Rz	0	0	0	0	0	0	0	0	0									-22	=R2	5.50E-06	ge	CTE	0	0	0	0	0	0	0	0
99	Df,p	0	0	-10.121	0	0	0	0.47861	0	0									-3.59E-03	4.0026	=n	4.00E-04	ge	TCRI	0	0	0.03633	0	0	0	-0.0017
100	ELEMENT-4																														
101																															
102	Tx	-1	0	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0					
103	Ty	0	-1	0	0	0	0	0	0	0									0	0	0	0	0	0	0	0					
104	Tz	0	0	-1	0	0	0	0	0	0									1.51E-03	64.496	Z	2.34E-05	al	CTE	0	0	-0.0015	0	0	0	0
105	Rx	0	0	0	-1	0	0	0	0	0									0	=t	5.50E-06	ge	CTE	0	0	0	0	0	0	0	0
106	Ry	0	0	0	0	-1	0	0	0	0									inf	=R1	5.50E-06	ge	CTE	0	0	0	0	0	0	0	0
107	Rz	0	0	0	0	0	-1	0	0	0									0	=R2	5.50E-06	ge	CTE	0	0	0	0	0	0	0	0
108	Df,p	0	0	0	0	0	0	0	0	0									0	1	=n	5.50E-06	ge	CTE	0	0	0	0	0	0	0
109	DETECTOR																														
110																				0	0	0.0889	0	0	0	0	-0.0061				
111	Thank	you	for	using	IVORY(tm)	to	prepare	the	Optomec	Constrain	Equations	for	'IRREC'							TX	TY	TZ	RX	RY	RZ	DM/M					
112																															
113																															

Add titles at the top and bottom of the columns for the registration variables...

...then sum all of the Tz contributions vertically...
 ...to get the net focus error at the detector per C.



Looking more closely at the net registration error we see that a 1 deg C increase causes the image to fall in front of the detector by 0.0889 inches. It also causes a 0.61% reduction in image size. Therefore for a ± 10 deg C change in temperature the focus will shift ± 0.889 inches.

			0	0	0	0	0	0	0
			0	0	0	0	0	0	0
2.34E-05	α CTE		0	0	-0.0015	0	0	0	0
			0	0	0	0	0	0	0
			0	0	0	0	0	0	0
			0	0	0	0	0	0	0
			0	0	0	0	0	0	0
			0	0	0.0889	0	0	0	-0.0061
			TX	TY	TZ	RX	RY	RZ	DM/M
			ΔT=±		10 deg C				
			Tz(image)=±		0.88905 inches				

Answer to Task 1:

T_z of the image = ± 10 deg C x ± 0.0889 inches per deg C = ± 0.889 inches.

AEH.

Optomechanics

Task 2: Specify the requirements of an actuator to move Lens 3 the correct the thermal focus errors.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
85	Ty	0	0.10925	0	0	0	0	0	-0.0559	DR1								0	0	0	0	0	0	0	0	
86	Tz	0	0	-0.4885	0	0	0	0.0586	0.11602	DR2		6.69E-04	28.5816	Z	2.34E-05	al CTE		0	0	-0.0003	0	0	0	3.9E-05		
87	Rx	0	-3.2758	0	0.10925	0	0	0	14.0513	Dn				2	=t	5.50E-06	ge CTE		0	0	0	0	0	0	0	
88	Ry	3.27578	0	0	0	0.10925	0	0	0	0				310	=R1	5.50E-06	ge CTE		0	0	0	0	0	0	0	
89	Rz	0	0	0	0	0	0	0	0	0				-215	=R2	5.50E-06	ge CTE		0	0	0	0	0	0	0	
90	Df,p	0	0	-0.0119	0	0	0	2.01E-03	0	0		2.23E-02	4.0026	=n	4.00E-04	ge TCRI		0	0	-0.0003	0	0	0	4.5E-05		
91	ELEMENT-3																									
92																										
93	Tx	3.18131	0	0	0	0	0	0	-0.4112	Dt								0	0	0	0	0	0	0	0	
94	Ty	0	3.18131	0	0	0	0	0	-1.1525	DR1								0	0	0	0	0	0	0	0	
95	Tz	0	0	-3.7581	0	0	0	0.32816	0.24606	DR2		9.95E-04	42.5233	Z	2.34E-05	al CTE		0	0	-0.0037	0	0	0	0.00033		
96	Rx	0	1.16002	0	3.18131	0	0	0	-2.2651	Dn				1.5	=t	5.50E-06	ge CTE		0	0	0	0	0	0	0	
97	Ry	-1.16	0	0	0	3.18131	0	0	0	0				-11	=R1	5.50E-06	ge CTE		0	0	0	0	0	0	0	
98	Rz	0	0	0	0	0	0	0	0	0				-22	=R2	5.50E-06	ge CTE		0	0	0	0	0	0	0	
99	Df,p	0	0	-10.121	0	0	0	0.47861	0	0		-3.59E-03	4.0026	=n	4.00E-04	ge TCRI		0	0	0.03633	0	0	0	-0.0017		
100	ELEMENT-4																									
101																										
102	Tx	-1	0	0	0	0	0	0	0	Dt								0	0	0	0	0	0	0	0	
103	Ty	0	-1	0	0	0	0	0	0	DR1								0	0	0	0	0	0	0	0	
104	Tz	0	0	-1	0	0	0	0	0	DR2		1.51E-03	64.496	Z	2.34E-05	al CTE		0	0	-0.0015	0	0	0	0	0	
105	Rx	0	0	0	-1	0	0	0	0	Dn				0	=t			0	0	0	0	0	0	0	0	
106	Ry	0	0	0	0	-1	0	0	0	0				inf	=R1			0	0	0	0	0	0	0	0	
107	Rz	0	0	0	0	0	-1	0	0	0					=R2			0	0	0	0	0	0	0	0	
108	Df,p	0	0	0	0	0	0	0	0	0		0	1	=n				0	0	0	0	0	0	0	0	
109	DETECTOR																									
110																			0	0	0.0889	0	0	0	-0.0061	
111	Thank	you	for	using	IVORY(tm)	to	prepare	the	Optomech	Constrain	Equations	for	'IRREC'						TX	TY	TZ	RX	RY	RZ	DM/M	
112																										
113																										
114																										
115																										
116																										
117																										
118																										
119																										
120																										

Answer to Task 2:

Stroke at Lens 3 = $2 \times 0.889 / 0.4885 = 3.640$ inches

Accuracy = 0.0167 inches (same as for Tolerances, Tutorial 1)

AEH.

Optomechanics