Teaching lens, optical systems and optomechanical systems design at the Irvine Center for Applied Competitive Technologies (CACT)

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ABSTRACT

For well over a decade, the Laser Electro-Optics Technology (LET) program has been teaching introductory laser and optics classes at Irvine Valley College (IVC). At the beginning of the telecom boom, the Irvine CACT was established to teach optics fabrication to support the many optics fabrication businesses in Southern California. In the past few years, these two programs have merged – with some help from the Optics Institute of Southern California (OISC) - and grown under the newly established Advanced Technology and Education Park (ATEP). IVC and ATEP are both operated by the South Orange County Community College District (SOCCCD). This year a new program of three courses was established to teach, in sequence, lens, optical systems and optomechanical systems design. This paper reviews the reasons for establishing these courses and their content, the students' motivations for taking them and their employers' incentives for encouraging the students.

Keywords: Lens design, optical system design, optomechanical design

1. INTRODUCTION

This new three course optical instrument design program was established to meet the growing needs of the local optics industry and is filling a need to have trained engineers and designers skilled in the art of design and associated analysis of lenses, advanced optical systems and optomechanical systems. Traditionally and currently, there are many firms who have very good and experienced lens and optical systems designers and engineers and also mechanical designers and engineers; however, many times there seems to be a gap between the two groups. This programs aims to fill that gap by training students on both sides of the equation. Student prequalification for entrance into this program includes a solid fundamental knowledge of optics. For students who have not completed this type of education Irvine CACT also offers introductory optics fundamentals, lasers and fiber optics courses.

The optical instrument design program starts with an introductory hands-on lens design course which provides three basic skills: *manual, design code,* and *design philosophy***.** Manual skills include first and third order calculations by hand, *design code* skills include prescription entry, optimization and design analysis and *design philosophy* is about selecting a starting point and developing a plan of the design. The second course covers advanced optical systems design and analysis beginning with modeling coordinate breaks, multi-configurations, systems analysis and tolerancing and athermalization. The third course covers optomechanical systems design and bridges the gap between the optical and the mechanical systems. The students learn how to evolve their optical design into the mechanical design environment which includes material selection, tolerancing, vibration isolation, the assembly and alignment strategies; including alignment jigs and fixtures design.

This paper will describe by examples the philosophy of hands-on teaching, problem solving and developing sophisticated designer skills that are highly sought in today's optics based companies.

2. TEACHING PHILOSOPHY AND IMPLEMENTATION

The teaching philosophy of the CACT courses and programs are to fuse the 'lectures' with the hands-on learning by doing implementation. The courses in this program last 16 weeks and meet once each week for 3 hours. In the fundamental optics courses, the lectures are at most half of the class period and the hands-on labs are at least half the class period. For example, if a class runs three hours per day, then at most 1.5 hours will be lecture and the rest of the time the students will be working with lenses and mirrors and light sources. For these optical design program courses, the students each have a computer and design environment (like ZEMAX Lens Design software or 3D SolidWorks) in which to follow the instructor as she introduces new concepts, terminology and design approaches. The students also learn about navigating around in their new design environments and where many of the key levers are located and how they function. During each class period, the students are given design problems to work on during the class and explore and express their own creativity and design approaches under the guidance of the instructor. By the end of each class period the students have had the hands-on experience that they can use to complete their homework problems and take their new knowledge back to their daytime work place and use.

3. OPTICAL INSTRUMENT DESIGN PROGRAM - COURSE 1: LENS DESIGN

This course is intended for students who took the CACT Fundamentals of Optics course or who have a good working knowledge of geometric optics (Hecht's Optics or Jenkins and White's Fundamentals of Optics). This is an introductory hands-on lens design course. Until recently, lens design was a skill reserved for a few professionals, but today with readily available commercial design software and powerful personal computers, it is accessible to the general optical engineering community. Consequently some skill in lens design is now expected by a wide range of employers who utilize optics in their products. Lens design is, therefore, a strong component of a well-rounded education in optics, and a skill valued by industries employing optical engineers and technicians.

Course curriculum

The course curriculum for the lens design course is outlined in table 1.

First-order optics
- Refraction and reflection
- Glass definition and properties
- Image formation and ray tracing
- Stops, pupils, marginal and chief rays

Aberration theory
- Aberration descriptions
- Identifying aberrations
- Aberration balancing

Lens design with *ZEMAX*
- How optical design programs model lenses
- Surface, field, wavelength, system data
- Apertures, f-numbers
- Use of solves and variables
- Spot diagrams
- 2D, 3D, wireframe, and solid model layouts
- MTF plots
- Diffraction effects
- Other diagnostic tools

Singlet design
- Merit function construction
- Using optimization, setting variables
- Boundary constraints

Achromat design
- Magnification, EFL, spacings
- Correcting chromatic aberrations
- Glass selection and optimization

Multi-element lenses
- Cooke triplet
- Collimation
- Beam expanders
- Designing with stock lenses
- Double Gauss
- Zoom lens design
- Scanning systems

Table 1. Optical Instrument Design Program Course 1: Lens Design course curriculum.

An example of teaching aberration identification and balancing

Starting with a 150 mm focal length doublet we introduce the students to their new working environment in ZEMAX software. They learned that technical information about optical elements is described by their surfaces; which include surface curvature, thickness and medium refractive indices. They are taught how to enter prescriptions, assign variables and the order in which these and other tasks can be accomplished. Figure 1 shows a typical ZEMAX screen with the Lens Data Editor on top, a 3D Layout on the right and a Spot Diagram on the left. This is the beginning of how the students are taught to use extensive analysis capability of ZEMAX to evaluate the quality of their design and whether it meets the specifications.

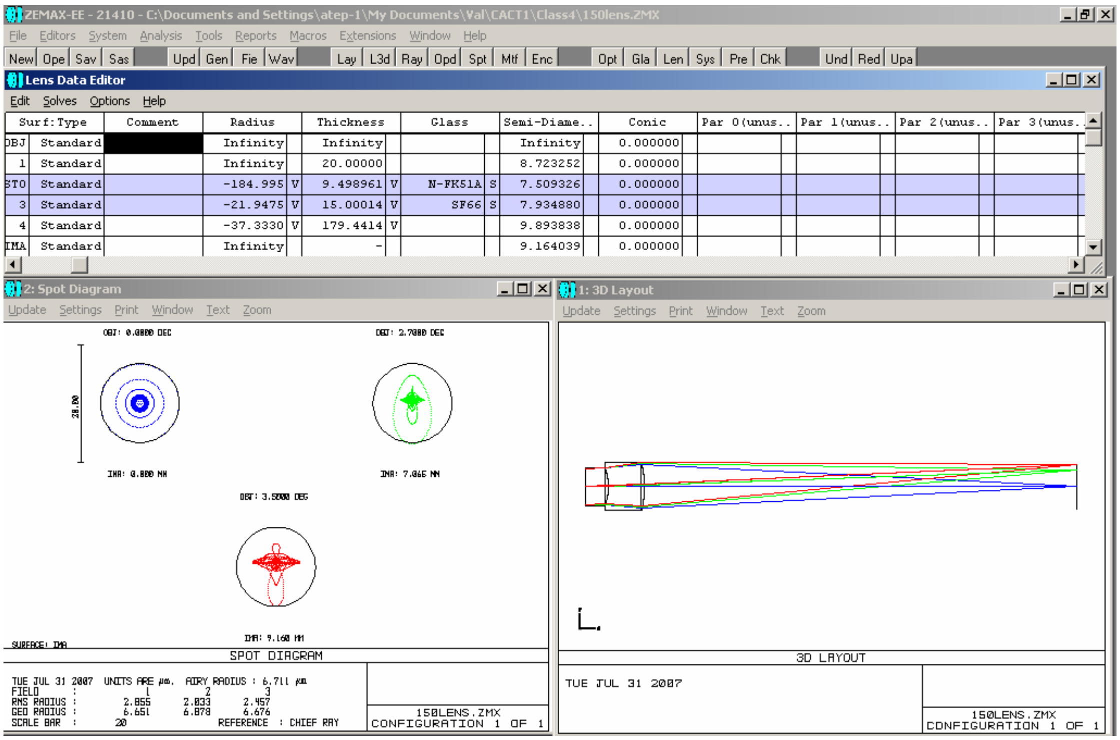

Fig. 1. A typical ZEMAX screen showing the Lens Editor, 3D Layout and Spot Diagrams

A new diagram showing relative amounts of the various coefficients of the five Seidel aberrations is shown in figure 2, illustrating the importance of balancing these aberrations at the final (imaging) surface.

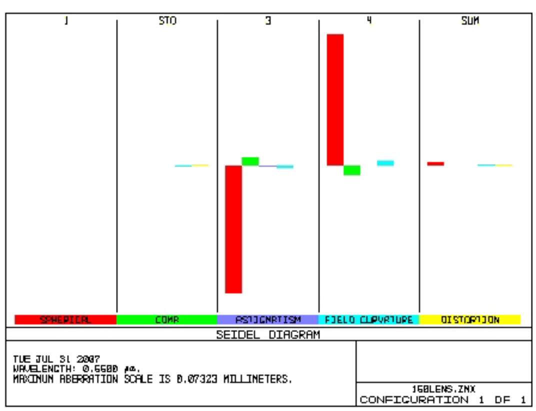

Fig. 2. Seidel Diagram.

Multi-element lens design: The Cooke Triplet

A standard in lens design classes is the Cooke triplet. Here we use three elements to teach the students about setting the aperture stop, F#, Merit function construction, optimization and setting variables. In figure 3 we show the Layout, the RMS Wavefront Error vs. Field position, Modulation Transfer Function (MTF) and the Transverse Ray Fan Plot.

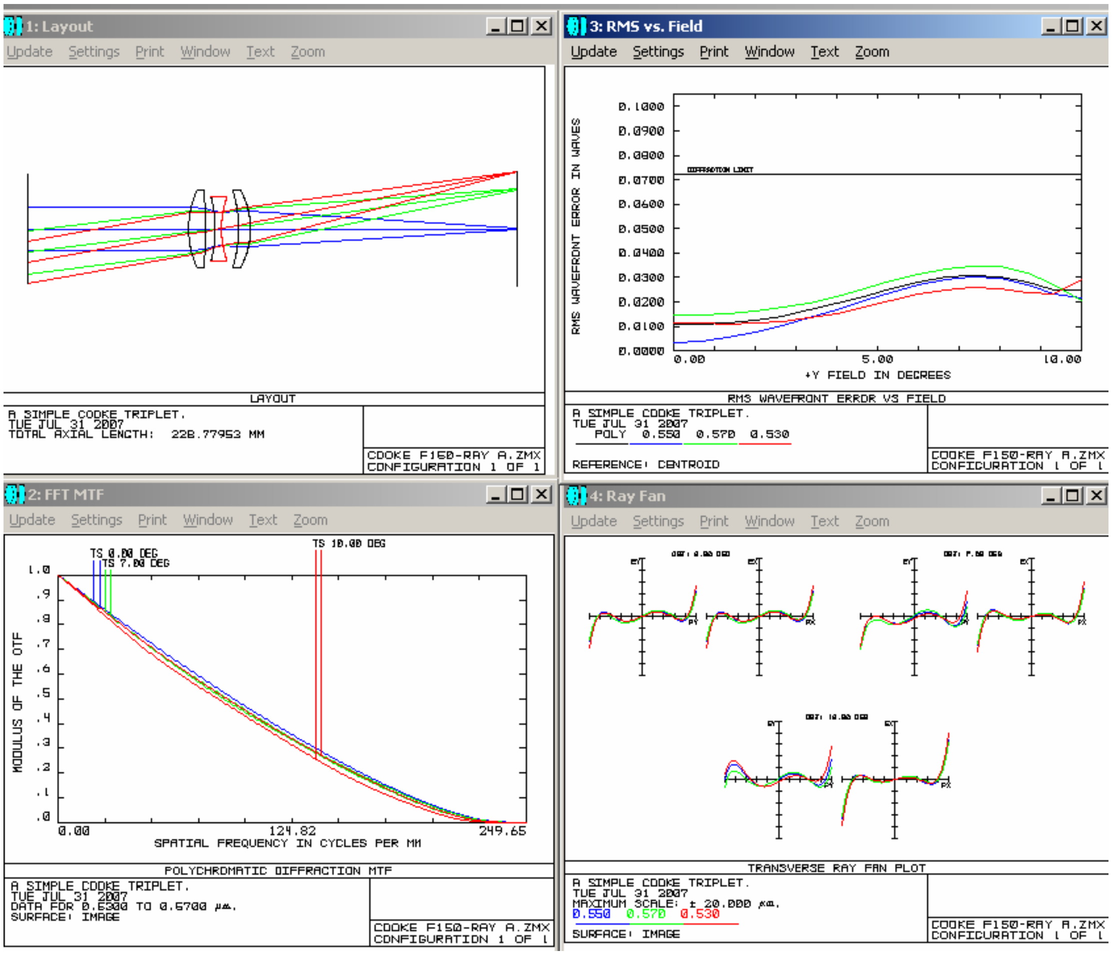

Fig. 3. Multi-element design: The Cooke Triplet

4. OPTICAL INSTRUMENT DESIGN PROGRAM - COURSE 2: ADVANCED OPTICAL SYSTEMS DESIGN AND ANALYSIS

By the end of Course 1: Lens Design, students are comfortably transitioned to the concept of optical systems design. This course then begins with modeling using coordinate breaks so that students can model components such as beam splitters, mirrors, tilts and decenters.

Course curriculum

The detailed outline of the course curriculum is shown in table 2.

Modeling with coordinate break:

- Prisms, beamsplitters, fold mirrors;
- Off axis designs;
- Tilting and de-centering object, lens, image;
- Multiple apertures

Modeling with multi-configurations;

- Interferometers,
- Multi channel systems;
- Zoom lens;
- Scanning Systems
- Gradient index lenses

- Double pass system

Optimization of multi-configured systems:

- Default and custom merit function design for multi-configured systems
- Optimization with MTF, RMS, and PTV
- Boundary constrains and control
- Hammer optimization
- Global Search
- Ray aiming

System Analysis:

- Geometrical and diffraction optics analysis;
- Spot size, Ray Fan, OPD diagrams, field curvature/distortion, aberrations;
- PSF, MTF,
- Gaussian beam;

- Thermal Analysis and system Athermalization
- Tool for system analysis
- Interferograms, wave front analysis

System tolerancing

- Error budget and tolerances
- Construction and assembly errors
- Passive and active compensators
- Monte Carlo statistical tolerance analysis
- Test plates fitting
- Alignment design and analysis

Physical Optics

- Gaussian beam propagation, analysis and control
- Beam characterization

Table 2: Optical Instrument Design Program Course 2: Advanced Optical Systems Design course curriculum

An example of modeling a 2 channel system using coordinate breaks and multi-configurations

Figure 4 shows a typical 2 channel system modeled using coordinate breaks and the multi-configurations editor. This particular design helps the students learn about using wavelength sensitive dichroic beam splitters to separate two wavelengths ranges in an optical system sending each wavelength range down a different optical path, in this case perpendicular to each other. The lens data editor shown in figure 4 is controlled by the multi-configuration editor shown in figure 5. The third column in the multi-configuration editor shows the values of the parameters of the first configuration; including the wavelength, lens surface curvatures, thicknesses and the optical element materials. The forth column shows the values for the second configuration.

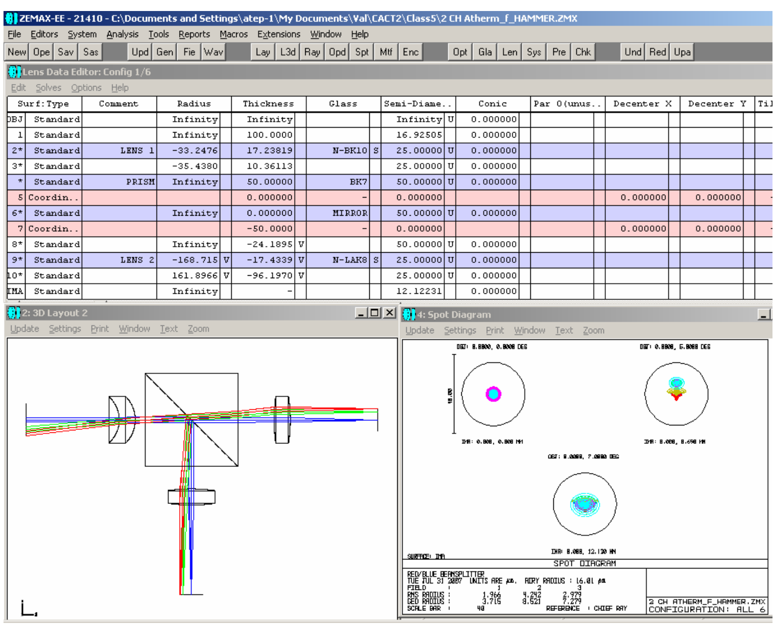

Fig. 4. A 2 channel system using coordinate breaks multi-configurations.

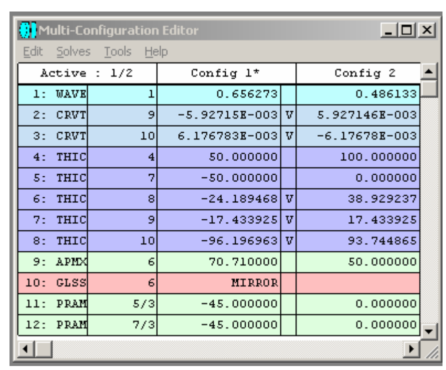

Fig.5. Multi-configurations editor controls the lens data editor.

Thermal analysis and system athermalization

Once students are familiar with the use of multi-configurations in optical modeling they are introduced to the concepts of thermal analysis of optical components and athermalization of optical systems. An example is shown in figure 6 where the multi-configuration editor represents the system prescription shown in figure 4 for the temperature range from 0˚ C to 40˚ C.

Multi-Configuration Editor

Edit Solves Tools Help

Active : 1/6		Config 1*		Config 2		Config 3		Config 4		Config 5		Config 6	
1: TEMP	0	20.000000		20.000000		0.000000		40.000000		0.000000		40.000000	
2: WAVE	1	0.656273		0.486133		0.656259	T	0.656284	T	0.486123	T	0.486141	T
3: PRES	0	1.000000		1.000000		1.000000		1.000000		1.000000		1.000000	
4: CRVT	2	-0.030077		-0.030077		-0.030081	T	-0.030074	T	-0.030081	T	-0.030074	T
5: CRVT	3	-0.028218		-0.028218		-0.028222	T	-0.028215	T	-0.028222	T	-0.028215	T
6: CRVT	9	-5.92715E-003	V	5.927146E-003	P	-5.92781E-003	T	-5.92648E-003	T	5.927810E-003	T	5.926482E-003	T
7: CRVT	10	6.176783E-003	V	-6.17678E-003	P	6.177475E-003	T	6.176091E-003	T	-6.17747E-003	T	-6.17609E-003	T
8: THIC	1	100.000000		100.000000		100.001994	T	99.998007	T	100.001994	T	99.998007	T
9: THIC	2	17.238189		17.238189		17.236189	T	17.240189	T	17.236189	T	17.240189	T
10: THIC	3	10.361135		10.361135		10.361333	T	10.360931	T	10.361333	T	10.360931	T
11: THIC	4	50.000000		100.000000		49.992900	T	50.007100	T	99.985800	T	100.014200	T
12: THIC	7	-50.000000		0.000000		-50.000000	T	-50.000000	T	0.000000	T	0.000000	T
13: THIC	8	-24.189468	V	38.929237	V	-24.179219	T	-24.199717	T	38.912355	T	38.946119	T
14: THIC	9	-17.433925	V	17.433925	P	-17.431973	T	-17.435878	T	17.431973	T	17.435878	T
15: THIC	10	-96.196963	V	93.744865	V	-96.154338	T	-96.239587	T	93.703344	T	93.786385	T
16: GLSS	2	N-BK10	S	N-BK10	P	N-BK10	P	N-BK10	P	N-BK10	P	N-BK10	P
17: GLSS	4	BK7		BK7		BK7	P	BK7	P	BK7	P	BK7	P
18: GLSS	9	N-LAK8	S	N-LAK8	P	N-LAK8	P	N-LAK8	P	N-LAK8	P	N-LAK8	P
19: SDIA	2	25.000000		25.000000		24.997100	T	25.002900	T	24.997100	T	25.002900	T
20: SDIA	3	25.000000		25.000000		24.997100	T	25.002900	T	24.997100	T	25.002900	T
21: SDIA	4	50.000000		50.000000		49.992900	T	50.007100	T	49.992900	T	50.007100	T
22: SDIA	6	50.000000		50.000000		49.992900	T	50.007100	T	49.992900	T	50.007100	T
23: SDIA	8	50.000000		50.000000		49.977500	T	50.022500	T	49.977500	T	50.022500	T
24: SDIA	9	25.000000		25.000000		24.997200	T	25.002800	T	24.997200	T	25.002800	T
25: SDIA	10	25.000000		25.000000		24.997200	T	25.002800	T	24.997200	T	25.002800	T
26: APMX	6	70.710000		50.000000		70.710000	P	70.710000	P	50.000000	P	50.000000	P
27: GLSS	6	MIRROR				MIRROR		MIRROR					
28: PRAM	5/3	-45.000000		0.000000		-45.000000	P	-45.000000	P	0.000000	P	0.000000	P
29: PRAM	7/3	-45.000000		0.000000		-45.000000	P	-45.000000	P	0.000000	P	0.000000	P

Fig.6. The multi-configuration editor represents the prescription of the system in figure 4.

The first configuration in figure 6 is a nominal configuration modeled for a wavelength of 656nm at 20˚ C and pressure of 1 Atmosphere. The third and forth configurations show the thermal effect on the optical system, at 656 nm, when the temperature is at 0˚ C or 40˚ C respectively. The second configuration in figure 6 is a nominal configuration modeled for a wavelength of 486 nm at 20˚ C and pressure of 1 Atmosphere. The fifth and sixth configurations show the thermal effect on the optical system, at 486 nm, when the temperature is at 0˚ C or 40˚ C respectively.

Merit functions

One of the most important optical modeling skills the students learn is the design of merit functions. A sample of a merit function editor is shown in figure 7. The specifications given to the students for this system were to obtain diffraction limited images for each wavelength path; and to have equal magnification for both channels in the specified temperature.

This particular merit function was constructed to solve the described problem including the athermalization of the optical system shown in figure 4. The operand #3 controls the focal length of the system for the 656 nm wavelength optical path as defined in the multi-configuration editor. Operand #10 locks the position of the image plane for the marginal rays of optical paths, 656 nm and 486 nm, at nominal temperature of 20˚C, so that for the same field angles in each wavelength path, the images of both configurations have the same magnification in each respective image plane (except that one is inverted). Operands # 20, 21, 30, 31, 32 and 33 control the athermal behavior of the optical system for both channels. The default merit function follows operand #34 (not shown.)

Merit Function Editor: 1.846324E+001

Edit Tools Help

Oper #	Type		Wave					Target	Weight	Value	% Contrib
1 CONF	CONF	1									
2 EFFL	EFFL		1					0.000000	0.000000	99.999687	0.000000
3 REAY	REAY	11	1	0.000000	1.000000	0.000000	0.000000	0.000000	1.000000	12.119834	0.525812
4 REAY	REAY	11	1	0.000000	0.700000	0.000000	0.000000	0.000000	0.000000	8.517329	0.000000
5 RGLA	RGLA	1	11	0.000000	0.000000	0.000000		0.020000	0.100000	0.020000	0.000000
6 BLNK	BLNK	Blue @20									
7 CONF	CONF	2									
8 REAY	REAY	11	1	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	12.119663	0.000000
9 REAY	REAY	11	1	0.000000	0.700000	0.000000	0.000000	0.000000	0.000000	8.523008	0.000000
10 DIFF	DIFF	3	8					0.000000	1.000000	1.708E-004	1.044E-010
11 DIFF	DIFF	4	9					0.000000	1.000000	-5.68E-003	1.154E-007
12 BLNK	BLNK	Red @0									
13 CONF	CONF	3									
14 REAY	REAY	11	1	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	12.118999	0.000000
15 REAY	REAY	11	1	0.000000	0.700000	0.000000	0.000000	0.000000	0.000000	8.516734	0.000000
16 BLNK	BLNK	Red@40									
17 CONF	CONF	4									
18 REAY	REAY	11	1	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	12.120639	0.000000
19 REAY	REAY	11	1	0.000000	0.700000	0.000000	0.000000	0.000000	0.000000	8.517904	0.000000
20 DIFF	DIFF	3	14					0.000000	1.000000	8.351E-004	2.496E-009
21 DIFF	DIFF	3	18					0.000000	1.000000	-8.05E-004	2.321E-009
22 BLNK	BLNK	Blue@0									
23 CONF	CONF	5									
24 REAY	REAY	11	1	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	12.119492	0.000000
25 REAY	REAY	11	1	0.000000	0.700000	0.000000	0.000000	0.000000	0.000000	8.522868	0.000000
26 BLNK	BLNK	Blue @40									
27 CONF	CONF	6									
28 REAY	REAY	11	1	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	12.119789	0.000000
29 REAY	REAY	11	1	0.000000	0.700000	0.000000	0.000000	0.000000	0.000000	8.523116	0.000000
30 DIFF	DIFF	8	24					0.000000	1.000000	1.711E-004	1.049E-010
31 DIFF	DIFF	8	28					0.000000	1.000000	-1.26E-004	5.696E-011
32 DIFF	DIFF	9	25					0.000000	1.000000	1.399E-004	7.002E-011
33 DIFF	DIFF	9	29					0.000000	1.000000	-1.08E-004	4.201E-011
34 BLNK	BLNK										

Fig. 7. Merit function editor for optical system

Tolerancing of the Optical System

Students are taught about manufacturing and assembly tolerances of optical systems. This is very important for them to understand as they need to be able to choose appropriate manufacturing and assembly tolerances so that the completed system meets the specifications. System performance is evaluated using Monte Carlo statistical tolerance analysis where every optical surface, thickness, material and optical element assigned a tolerance range.

The outcome of the tolerance analysis is that the appropriate tolerances are chosen so that system elements can be manufactured, assembled and aligned to meet the overall optical system performance specification during final testing.

A typical tolerance data editor to perform Monte Carlo statistical tolerance analysis is shown in figure 8. Here, some of the operands are: #1 the compensator on the back focus, #2 the test wavelength and #3-6 are for the radii tolerances. The tolerances on the surfaces and the element positioning are also included in the tolerance data editor. Worst case system performance spot diagram for 9 field angles for the system shown in figure 4 is derived from the Monte Carlo statistical tolerance analysis. The tolerance range used in the analysis is as shown in figure 8.

Tolerance Data Editor

Edit Tools Help

Oper #	Type	Surf	-	-	Nominal	Min	Max	Comment
1 (COMP)	COMP	10	0	-	0.000000	-5.000000	5.000000	Default compensator on back focus.
2 (TWAV)	TWAV	-	-	-	-	0.632800	-	Default test wavelength.
3 (TRAD)	TRAD	2	-	-	-33.246028	-0.100000	0.100000	Default radius tolerances.
4 (TRAD)	TRAD	3	-	-	-35.581261	-0.100000	0.100000	
5 (TRAD)	TRAD	9	-	-	-156.46700	-0.100000	0.100000	
6 (TRAD)	TRAD	10	-	-	196.610510	-0.100000	0.100000	
7 (TTHI)	TTHI	1	3	-	100.000000	-0.050000	0.050000	Default thickness tolerances.
8 (TTHI)	TTHI	2	3	-	17.152327	-0.050000	0.050000	
9 (TTHI)	TTHI	3	8	-	10.031992	-0.050000	0.050000	
10 (TTHI)	TTHI	4	8	-	50.000000	-0.050000	0.050000	
11 (TTHI)	TTHI	5	8	-	0.000000	-0.050000	0.050000	
12 (TTHI)	TTHI	6	8	-	0.000000	-0.050000	0.050000	
13 (TTHI)	TTHI	7	8	-	-50.000000	-0.050000	0.050000	
14 (TTHI)	TTHI	8	10	-	-26.234115	-0.050000	0.050000	
15 (TTHI)	TTHI	9	10	-	-17.986224	-0.050000	0.050000	
16 (TSDX)	TSDX	2	-	-	0.000000	-0.025000	0.025000	Default surface dec/tilt tolerances 2.
17 (TSDY)	TSDY	2	-	-	0.000000	-0.025000	0.025000	
18 (TSTX)	TSTX	2	-	-	0.000000	-0.100000	0.100000	
19 (TSTY)	TSTY	2	-	-	0.000000	-0.100000	0.100000	
20 (TSDX)	TSDX	3	-	-	0.000000	-0.025000	0.025000	Default surface dec/tilt tolerances 3.
21 (TSDY)	TSDY	3	-	-	0.000000	-0.025000	0.025000	
22 (TSTX)	TSTX	3	-	-	0.000000	-0.100000	0.100000	
23 (TSTY)	TSTY	3	-	-	0.000000	-0.100000	0.100000	
24 (TSDX)	TSDX	4	-	-	0.000000	-0.025000	0.025000	Default surface dec/tilt tolerances 4.
25 (TSDY)	TSDY	4	-	-	0.000000	-0.025000	0.025000	
26 (TSTX)	TSTX	4	-	-	0.000000	-0.100000	0.100000	
27 (TSTY)	TSTY	4	-	-	0.000000	-0.100000	0.100000	
28 (TSDX)	TSDX	6	-	-	0.000000	-0.025000	0.025000	Default surface dec/tilt tolerances 6.
29 (TSDY)	TSDY	6	-	-	0.000000	-0.025000	0.025000	
30 (TSTX)	TSTX	6	-	-	0.000000	-0.100000	0.100000	
31 (TSTY)	TSTY	6	-	-	0.000000	-0.100000	0.100000	
32 (TSDX)	TSDX	8	-	-	0.000000	-0.025000	0.025000	Default surface dec/tilt tolerances 8.
33 (TSDY)	TSDY	8	-	-	0.000000	-0.025000	0.025000	
34 (TSTX)	TSTX	8	-	-	0.000000	-0.100000	0.100000	
35 (TSTY)	TSTY	8	-	-	0.000000	-0.100000	0.100000	
36 (TSDX)	TSDX	9	-	-	0.000000	-0.025000	0.025000	Default surface dec/tilt tolerances 9

Fig. 8. Tolerance editor for system shown in figure 4.

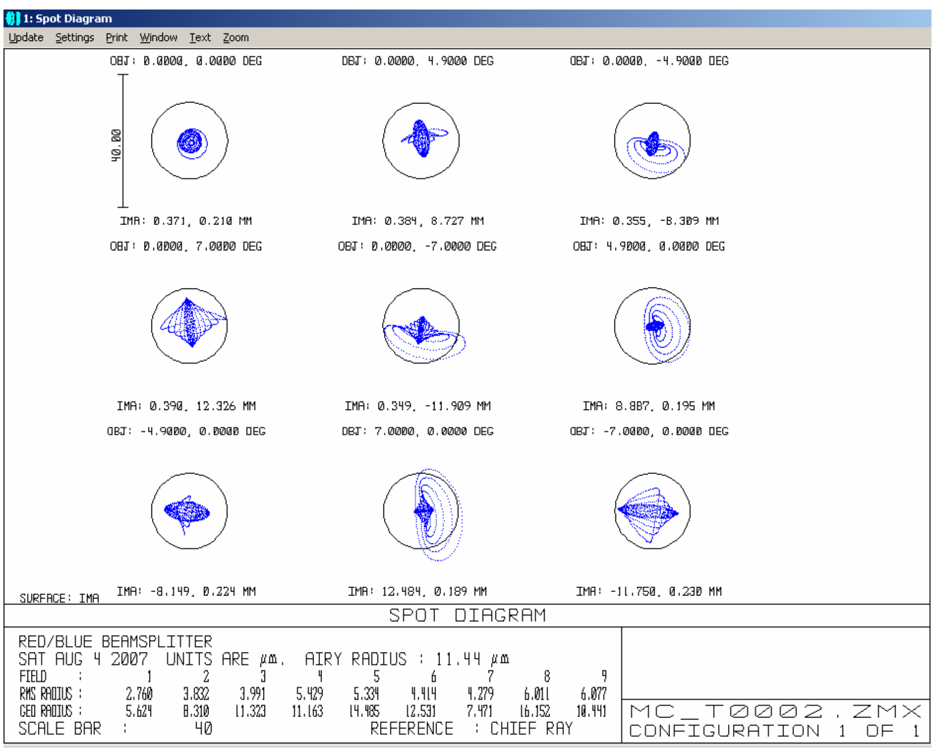

Fig. 9. Worst case performance spot diagram for 9 field angles of the optical system shown in figure 4.

Physical Optics

Modern day optical systems include the use of Gaussian beams from, for example, lasers and fiber optics based systems. Students learn how to model and control theoretical Gaussian beam propagation in optical systems. An example of a 16X Galilean beam expander is shown in figure 10. The physical optics propagation total irradiance plot is illustrated on the bottom right in the figure and shows the irradiance distribution and beam size on the test surface; the waist size and position.

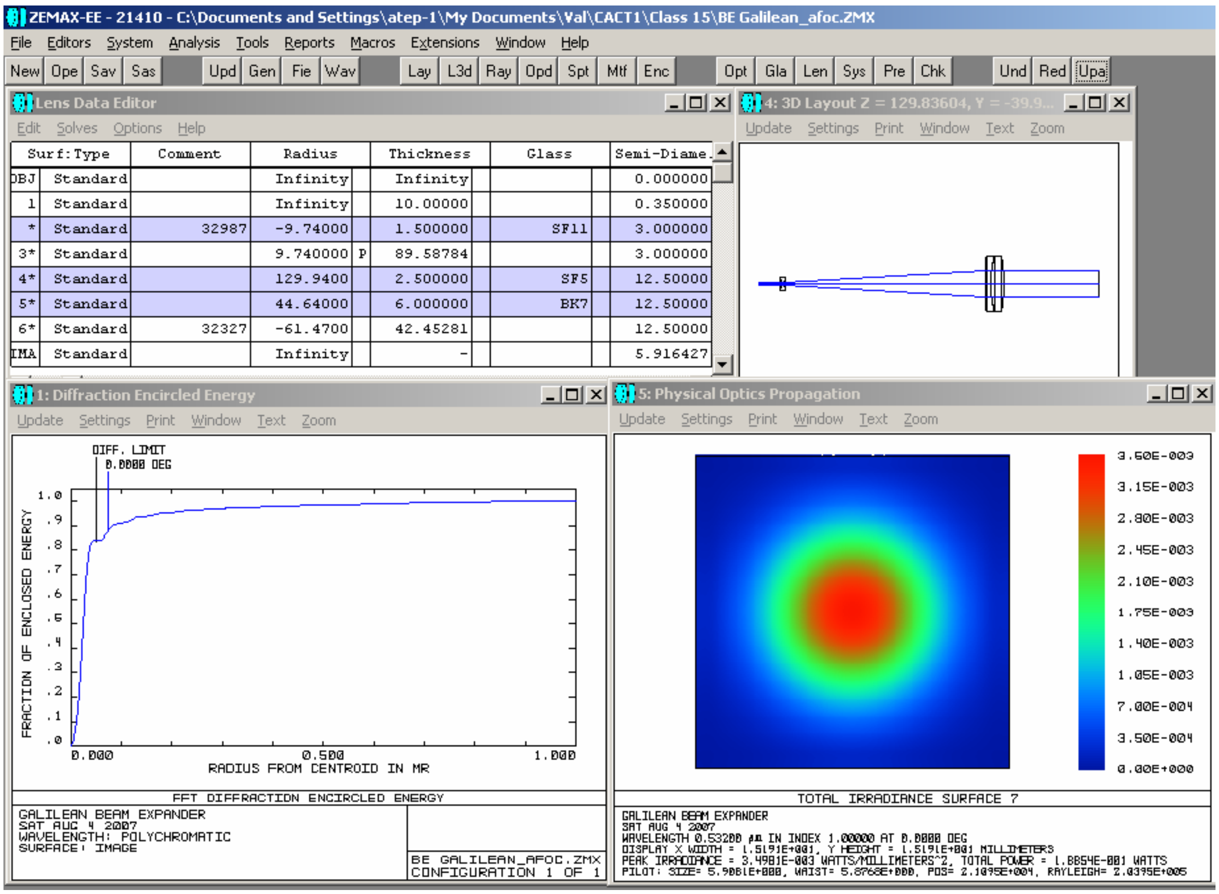

Fig. 10. Physical optics propagation of a 16X Galilean beam expander.

5. OPTICAL INSTRUMENT DESIGN PROGRAM - COURSE 3: OPTOMECHANICAL DESIGN

Current state-of-the-art optical and mechanical system design engineering tools like ZEMAX™ and 3D SolidWorks™ are used at Irvine CACT to bring our students to the level of professionalism required by employers. It is rare to find a person skilled in both optical and optomechanical engineering, which is a growing demand of employers, especially those in small companies and start-ups. This CACT Optical Design Program is aimed to fill that need. Once students finish Course 2, they are smoothly transitioned into Course 3 by way of a short introductory course in 3D SolidWorks in the middle of Course 2. Thus students can integrate the concept of tolerancing of optical and mechanical components as one complete integrated system.

Course curriculum

The detailed outline of the course curriculum is shown in table 3.

Introduction to optomechanical design

- Performance specifications
- Preliminary design
- Error budgets and tolerancing

Integration of optical and mechanical designs

- Export optical model to 3D SolidWorks
- Thermal Analysis
- Material selection for optical and mechanical components

Optical components mounting techniques

- Mounting:
  - Lenses
  - Prisms
  - Mirrors
  - Filters
  - Windows
- Multi-components assembly design
- Glass to metal interfaces
- Lens assemblies with moving parts
- Adhesive selection

System design and top level assembly

- Consideration of centered optics
- Establishing the optical axis
- ‘Wrapping’ mechanics around optical model
- Stray light considerations
  - Black anodizing
  - Placement of baffles
- Packaging and enclosure considerations

Instrument alignment strategy and procedure

- Alignment procedures
- Selection of alignment jigs
- Design of alignment jigs

System test

- Final system test considerations

Table 3: Optical Instrument Design Program Course 3: Optomechanical Design course curriculum

Integration of the optical design into the optomechanical model

Students are taught how to effectively design the optical instrument based on the known environmental operating, shipping and storage conditions. The instrument mechanical design evolves during the Monte Carlo statistical tolerance analysis; where a material can be chosen for the base plate, and lens housings if applicable, by applying an appropriate thermal coefficient of expansion (TCE) into the ZEMAX model in the spaces between the optical components. An example of this is shown in column 13 of the Lens Data Editor in figure 11. Here, surfaces 3, 8 and 10 are the air gaps which will be affected by the thermal environment between the optical elements.

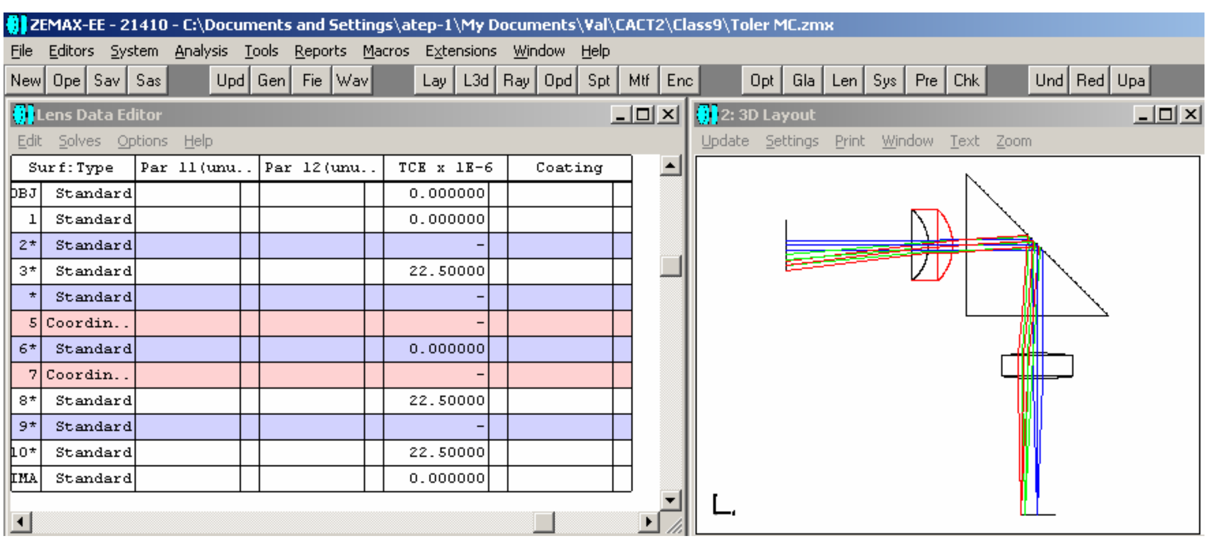

Fig. 11. Example of Lens Data Editor showing thermal coefficient of expansion (TCE).

Integration of modern engineering tools of ZEMAX and SolidWorks significantly increases the efficiency of the optical instrument design process; drastically reducing human error and cost. By the time the students have finished the optical system design and completed the associated analysis; such as athermalization and Monte Carlo statistical tolerance analysis; they have the design plan including: 1) the prescription for the individual optical components with the tolerances, 2) the optical system tolerances, 3) the material and the tolerances for optical component mounts and 4) the alignment strategy based on the chosen compensator(s) (Operand 1 in figure 8).

The ray trace of the optical system with all the optical components gets exported from ZEMAX as a STEP file into 3D SolidWorks; as shown in figure 12.

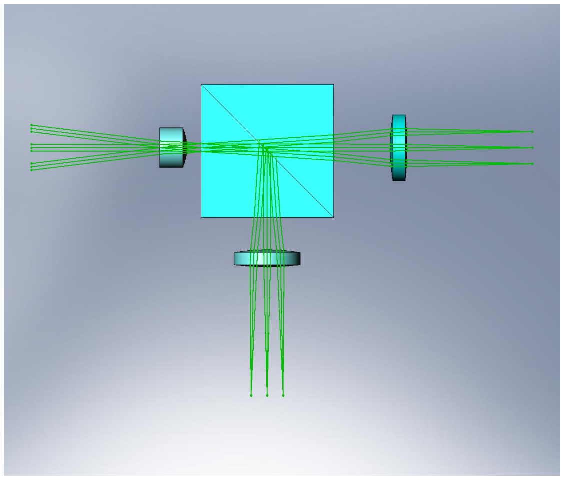

Fig. 12. The 3D SolidWorks model of the ray trace and the optical components of the system shown in figure 4.

System design and top level assembly

Having all the optical components at the right distances from each other, it is very straight forward to wrap the mechanical design around the optics with a clear vision of how the assembly unfolds and avoids possible overlap of mechanical components. An example of this is shown in figure 13.

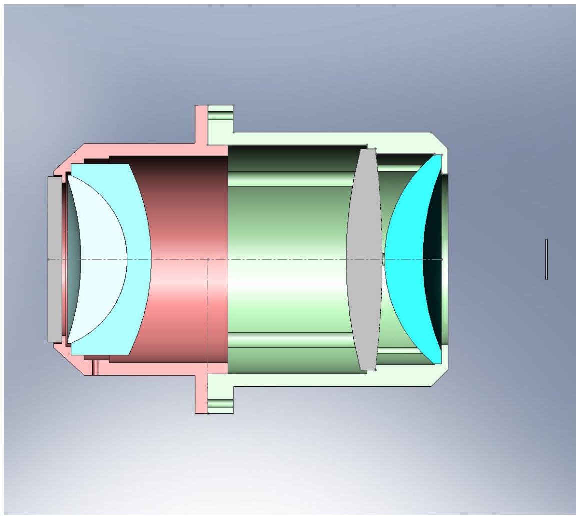

Fig. 13. A lens housing assembly design based on the optical components imported from ZEMAX.

The top level assembly is shown in figure 14 with the optical components imported from ZEMAX. The lens holders designed around the lenses with the appropriate tolerances derived from the Monte Carlo statistical tolerance analysis. The compensators were derived from this statistical tolerance analysis and are realized by the jigs shown in figure 14. Particularly; the lenses in the red and blue housings have two jigs each with 1 or 2 degrees of freedom physically controlled by the fine adjustment screws and spring plungers.

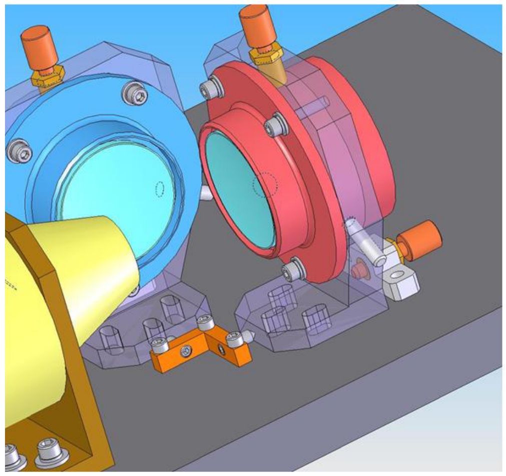

Fig. 14. Top level assembly showing alignment jigs on two lens holders.

6. CONCLUSIONS

While lens design, optical systems design and optomechanical systems design has been taught for many years at many distinguished educational institutions, we believe that this new Optical Instrument Design program of three courses at the Irvine CACT is unique for many reasons. It provides a hands-on educational and design experience for students in the optics industry; and for students with different technical backgrounds, we offer additional assistance. As an example, the Irvine CACT offers an Optics Fundamental course in the fall semester and this Optical Instrument Design program from January through December; so a student could take these four courses in sequence.

The first course in this program is an introductory hands-on lens design course which provides three basic skills: *manual, design code,* and *design philosophy***.** The second course covers advanced optical systems design and analysis beginning with modeling coordinate breaks, multi-configurations and evolving into systems analysis, tolerancing and athermalization. The third course covers optomechanical systems design and integrates the optical and the mechanical systems to perform effectively.

These courses and the others at the Irvine CACT have been developed and implemented to fill the growing needs of local optics companies and companies using optics. Technicians and engineers completing these courses can help produce better optical instruments in shorter time cycles and reduced costs.

From this program the students learn that effectively engineered optical instruments are the result of the successful integration of optical and mechanical designs derived and analyzed from the given specifications.

7. PROGRAMS AND COURSES

Current programs and courses

Currently, the Irvine CACT offers the following programs and courses:

- CACT 20 Introduction to Lasers
- CACT 21 Fundamentals of Optics
- CACT 22 Introduction to Fiber Optics
- CACT 101 Optics Fabrication I
- CACT 102 Optics Fabrication II
- CACT 105 Optical Interferometry/Metrology
- CACT 120 Lens Design
- CACT 121 Advanced Optical Systems Design and Analysis
- CACT 122 Optomechanical Design

Future programs and courses

In the next 6 to 18 months, the Irvine CACT will be developing courses in spectroscopy, telescope making and a teen optics club. In the following 12 to 24 months, we are planning to develop a program in Advanced Optics / Instrumentation Design.

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