

Environmental Modeling and Athermalizing for Imaging Lens Design

Using CODE V Multi-Environment Coupling (MECo)

Introduction

As requirements for image quality increase and lens application areas diversify, consideration of environmental factors in the design process has become more important than ever. Imaging lenses, as precision optical components, are significantly affected by ambient temperature and pressure. These effects not only directly impact image quality but also influence the overall performance of imaging systems.

For example, industrial lenses must operate under high- or low-temperature conditions. Lenses used in outdoor surveillance or automotive applications must withstand substantial temperature variations. Lenses used in space, aerospace, or underwater environments must adapt to both extreme temperatures and pressure variations.

Multi-Environment Coupling (MECo) is a powerful feature of CODE V specifically developed for optical designers. This capability enables designers to construct various temperature and pressure environments, perform analysis and optimization under these conditions, and design lenses that maintain high performance across diverse operating environments.

Seamless and Intuitive Workflow

The operation of MECo is designed to be highly streamlined, allowing designers to easily set up and analyze multiple environments. Figure 1 illustrates the workflow of this feature.

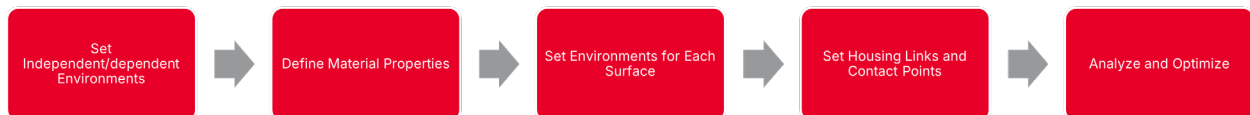


Figure 1. Seamless and intuitive workflow

- **Independent/Dependent environment setup:**

First, set the nominal temperature and pressure of the lens, typically corresponding to manufacturing conditions. Then, multiple dependent environments can be added simultaneously.

- **Material property definition:**

Enter Coefficients of Thermal Expansion (CTE) and refractive index temperature dependence (dn/dT) for user-defined materials or to modify default materials. CODE V automatically loads CTE and dn/dT data for built-in materials, which users can easily input or modify. This improves ray tracing accuracy across different temperatures.

- **Environment assignment for each surface:**

Specify temperature and pressure for each lens element or space. Housing regions may have different temperatures depending on the optical materials.

- **Housing link and contact point definition:**

Define the positions of contact points for mounts or spacers on lens surfaces. Contact points can be extended along curved or planar surfaces within the clear aperture. Extensions such as notches or flanges can be defined to implement various optomechanical models.

Example Model

Using tools integrated within the MECo feature, designers can rapidly configure multiple temperature and pressure conditions and automatically construct multi-environment coupling models to analyze lens performance under various environmental conditions. Different temperatures and pressures can be assigned to each lens element and space. This flexibility enables more accurate simulation of real operating environments.

Using a three-element lens as an example, the overall ambient temperature range is set from -80°C to 120°C . MECo allows the use of either spacer-based or seat-based mechanical links. The links and contact points are visualized in a 3D viewer, helping designers examine thermal expansion and contraction of mechanical components caused by temperature variations.

Figures 2 and 3 show spacer-based and seat-based mechanical links, respectively. The upper images are schematic representations, and the lower images show corresponding 3D views in CODE V.

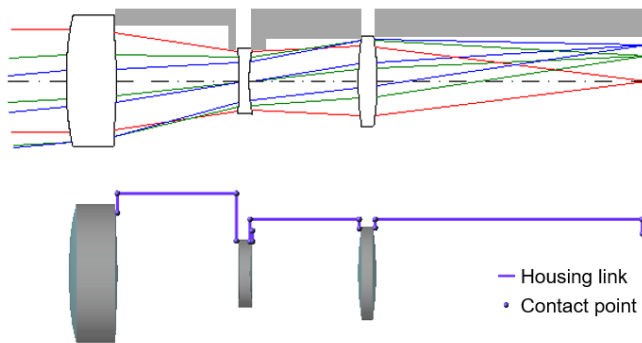


Figure 2. Spacer-based mechanical links

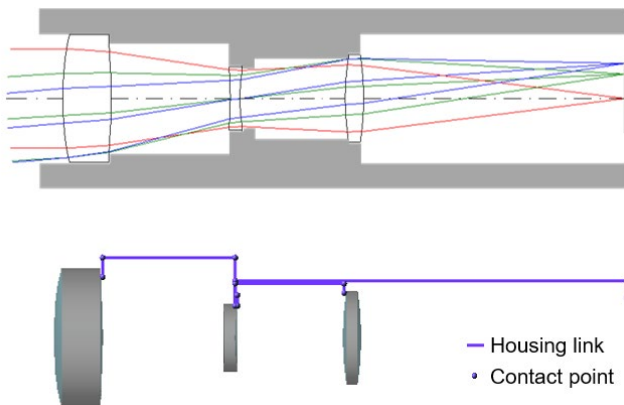


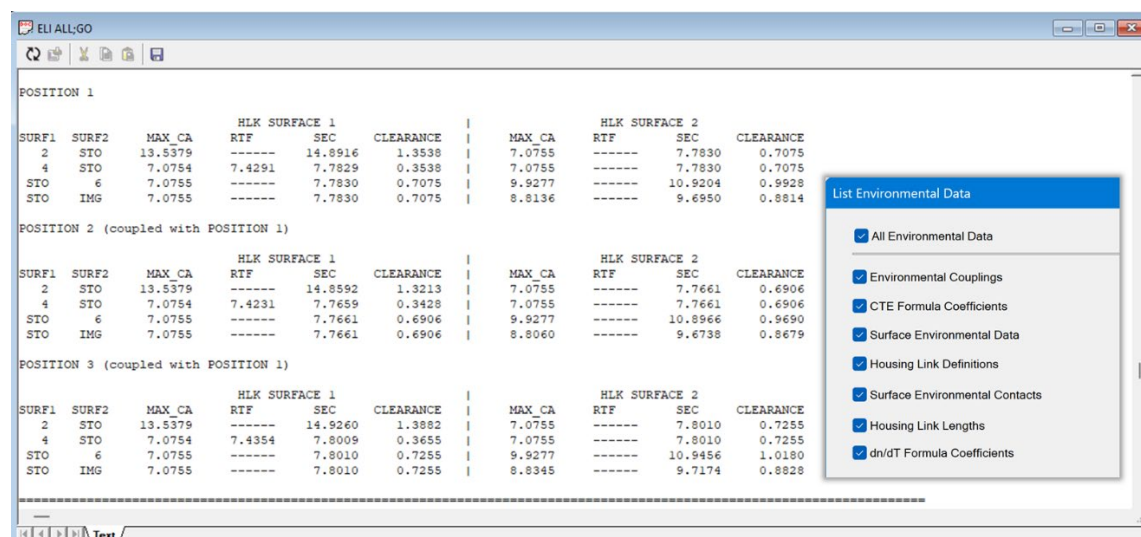
Figure 3. Seat-based mechanical links

MECo allows polynomial definitions for the Coefficients of Thermal Expansion (CTE) of both mechanical and optical materials (Figure 4). It uses exponential calculations to model thermal expansion and contraction, providing higher accuracy than other commercial optical design software.

	Material	Reference	T0 (deg C)	C0	C1	C2	C3	C4	C5
1	NLAK12_SCHOTT	Catalog	20.0000	7.6000e-06	1.2143e-08	0.0000	0.0000	0.0000	0.0000
2	'A6061MH'	Default	0.0000	2.2217e-05	2.1564e-08	-7.3320e-11	5.6732e-13	-1.6890e-15	1.5745e-18
3	SF57HTULTRA_SCHOTT	Catalog	20.0000	8.3000e-06	6.4286e-09	0.0000	0.0000	0.0000	0.0000
4	NLAK33B_SCHOTT	Catalog	20.0000	5.8300e-06	8.7857e-09	0.0000	0.0000	0.0000	0.0000
*									

Figure 4. Polynomial definitions for the CTE of mechanical and optical materials

MECo also provides detailed environmental data tables (Figure 5), which allow designers to examine the specific mechanical changes at each surface for each environmental configuration.



The screenshot shows the ELI ALL.GO software interface. The main window displays three positions of environmental data. Position 1 is the base position. Position 2 is coupled with Position 1. Position 3 is also coupled with Position 1. Each position shows a table of environmental data for two surfaces (SURF1 and SURF2). The data includes MAX_CA, RTF, SEC, and CLEARANCE for each surface. A 'List Environmental Data' dialog box is open on the right, showing a list of environmental parameters that can be selected for display. The parameters include All Environmental Data, Environmental Couplings, CTE Formula Coefficients, Surface Environmental Data, Housing Link Definitions, Surface Environmental Contacts, Housing Link Lengths, and dn/dT Formula Coefficients.

POSITION 1	SURF1	SURF2	MAX_CA	RTF	SEC	CLEARANCE	SURF1	SURF2	MAX_CA	RTF	SEC	CLEARANCE
2	STO	13.5379	-----	14.8516	1.3538	7.0755	-----	7.7830	0.7075			
4	STO	7.0754	7.4291	7.7829	0.3538	7.0755	-----	7.7830	0.7075			
STO	6	7.0755	-----	7.7830	0.7075	9.9277	-----	10.9204	0.9928			
STO	IMG	7.0755	-----	7.7830	0.7075	8.8136	-----	9.6950	0.8814			

POSITION 2 (coupled with POSITION 1)	SURF1	SURF2	MAX_CA	RTF	SEC	CLEARANCE	SURF1	SURF2	MAX_CA	RTF	SEC	CLEARANCE
2	STO	13.5379	-----	14.8592	1.3213	7.0755	-----	7.7661	0.6906			
4	STO	7.0754	7.4231	7.7659	0.3428	7.0755	-----	7.7661	0.6906			
STO	6	7.0755	-----	7.7661	0.6906	9.9277	-----	10.8966	0.9690			
STO	IMG	7.0755	-----	7.7661	0.6906	8.8060	-----	9.6738	0.8679			

POSITION 3 (coupled with POSITION 1)	SURF1	SURF2	MAX_CA	RTF	SEC	CLEARANCE	SURF1	SURF2	MAX_CA	RTF	SEC	CLEARANCE
2	STO	13.5379	-----	14.9260	1.3882	7.0755	-----	7.8010	0.7255			
4	STO	7.0754	7.4354	7.8009	0.3655	7.0755	-----	7.8010	0.7255			
STO	6	7.0755	-----	7.8010	0.7255	9.9277	-----	10.9456	1.0180			
STO	IMG	7.0755	-----	7.8010	0.7255	8.8345	-----	9.7174	0.8828			

Figure 5. Environmental data lists

Finally, using CODE V's proprietary **Glass Expert** tool, designers can athermalize lenses to improve performance. The following figures show results before and after athermalization of a seat-based mechanical link model, demonstrating significant performance improvements. Figure 6 shows transverse ray aberration with a maximum scale of 0.02 mm, and Figure 7 shows the Modulation Transfer Function (MTF) up to a maximum spatial frequency of 42 cycles/mm.

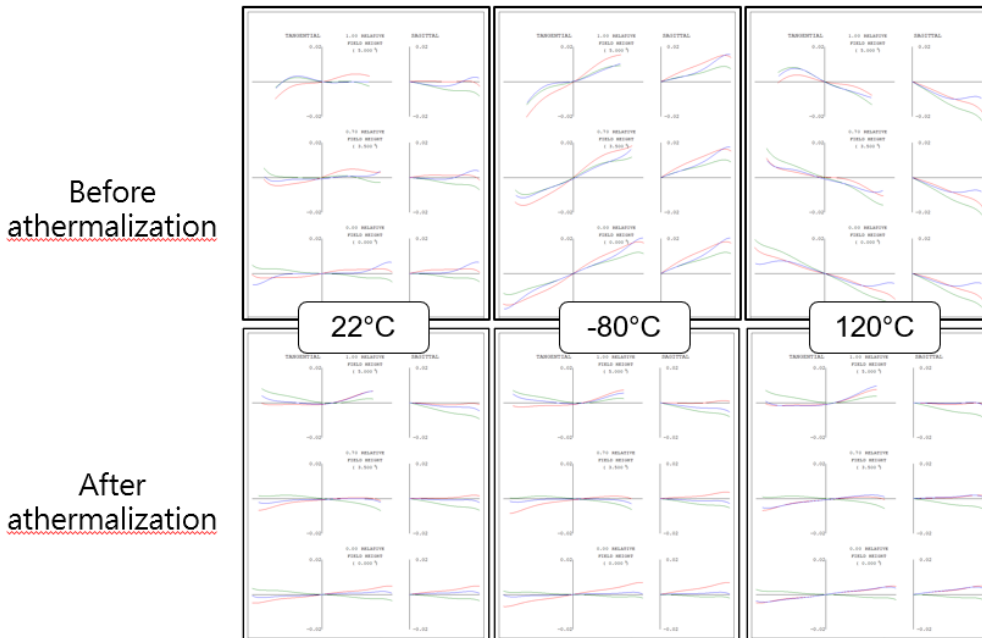


Figure 6. Transverse ray aberration with a maximum scale of 0.02 mm

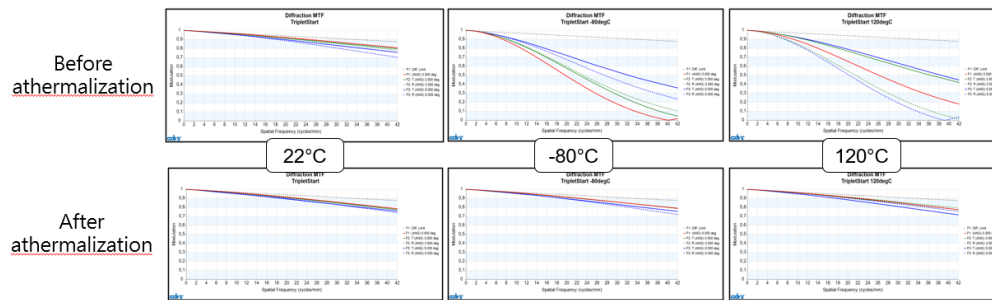


Figure 7. MTF with a maximum spatial frequency of 42 cycles/mm

Summary

MECo provides a powerful and user-friendly platform for designing thermally stable or environmentally compensated lenses. By incorporating environmental factors into the design process, MECo ensures that lenses deliver excellent image quality under various conditions. This is particularly important in fields requiring high performance and reliability, such as automotive, aerospace, and industrial manufacturing.

By leveraging the CODE V MECo capability, optical designers can effectively address environmental challenges and develop high-performance optical systems.

Keysight enables innovators to push the boundaries of engineering by quickly solving design, emulation, and test challenges to create the best product experiences. Start your innovation journey at www.keysight.com.