DEVELOPMENT OF MWIR CONTINUOUS ZOOM WITH LARGE ZOOM RANGE

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ABSTRACT

A thermal imaging zoom system has been developed for the mid wave infrared band with greater than 30X zoom range. The zoom system provides continuous changes in the field of view from the narrow field of view to the wide field of view. Athermalization was also a key feature included in the design. An active thermal compensation approach is being used to cover a broad thermal range. A preloaded rail approach is used to maintain boresight and vibration requirements. The final optical layout and mechanical design resulted in a system suitable for tactical and other harsh environments. The current design is very compact for the extremely large zoom range but, the lens layout also provides adequate space for folding. In this way the zoom system can be easily configured for applications with compact space claims such as small turrets or gimbals. The fundamental optical design has also been found to be capable of accommodating different camera formats (focal plane array size and F number).

Keywords: Optical design, Zoom lens, Infrared Lens, MWIR, Diffractive optics

1. INTRODUCTION

In a prior paper we reported the design of a MWIR continuous zoom with significant zoom range (>30X)[1]. Here we look at what it takes to tolerance and build a system of this complexity. In the prior paper, there were several challenges that were addressed in the design phase. These challenges also needed to be handled in the tolerancing and building of the zoom assembly.

The largest constraint that existed was developing a strategy that would allow the zoom focus to be continuous. The large zoom range created the condition of the zoom groups moving through the 1X magnification case. Discontinuities about this point have been well documented in the literature. Some of the aspects of the mechanical design needed to achieve the final optical system are also discussed.

2. ACTUAL DESIGN

With many IR optical designs we need to base the design on a particular camera. The cold stop of the camera needs to act as the aperture stop of the optical system. With the camera specifications fixed the optical prescription was easily migrated to a final design. We employed some newer design tools and actually removed several aspheric surfaces from the earlier design. This helped to reduce the cost and complexity of the design.

The zoom system presented here is based upon the specification presented in table 1. The design form can be migrated to other camera specifications by decreasing the F/# and image plane size. The design also accommodates mirror placements for different packaging requirements.

Table 1. Characteristics of the optical design presented

Characteristics	Value
Zoom Range	> 30X
Focal Length Range	15.25 - 456mm
Spectrum	3 - 5 μm
F/#	4.5
Image Plane Diagonal	12.3mm
Pixel size	30 μm
Front Element Diameter	120mm
Total Track	353mm
Distortion	< 0.5%
Transmission	> 70%
Number of Diffractives	1

The zoom range listed here is 30X, but the limitation is not mechanical. The focus and MTF performance is maintained for wider fields of view, but the Narcissus and illumination uniformity will begin to dominate.

The design contains 1 diffractive and several aspheric surfaces. Because the optics are diamond turned, the use of aspheres is not cost prohibitive. For this type of zoom system, they are vital to the performance given the small overall length[2].
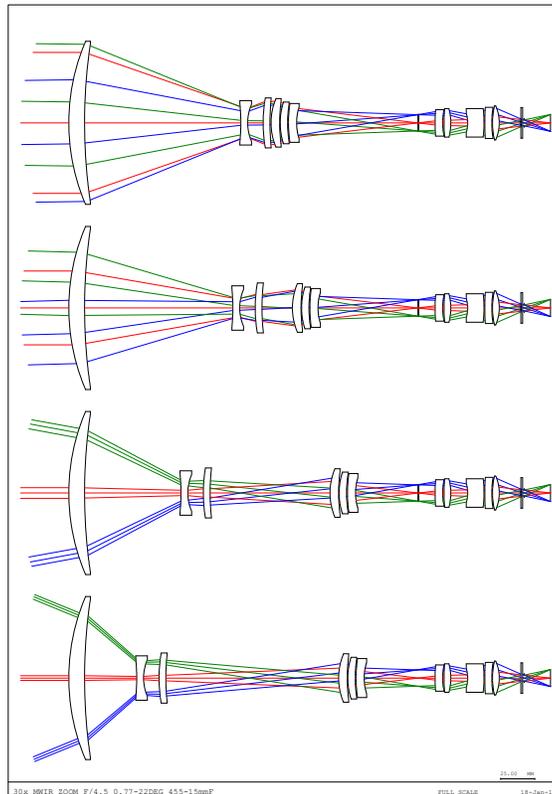

Figure 1. The layout shows the smooth path of the zoom groups throughout the range. It also shows that the WFOV is not limited by any glass to glass collisions.

2.1 Performance

The nominal system is nearly diffraction limited across the zoom range and has very low distortion. As presented prior, the design form was controlled to set up favorable conditions to have low sensitivities. Through proper tolerancing the degradation of the wavefront will not change significantly from the nominal design.
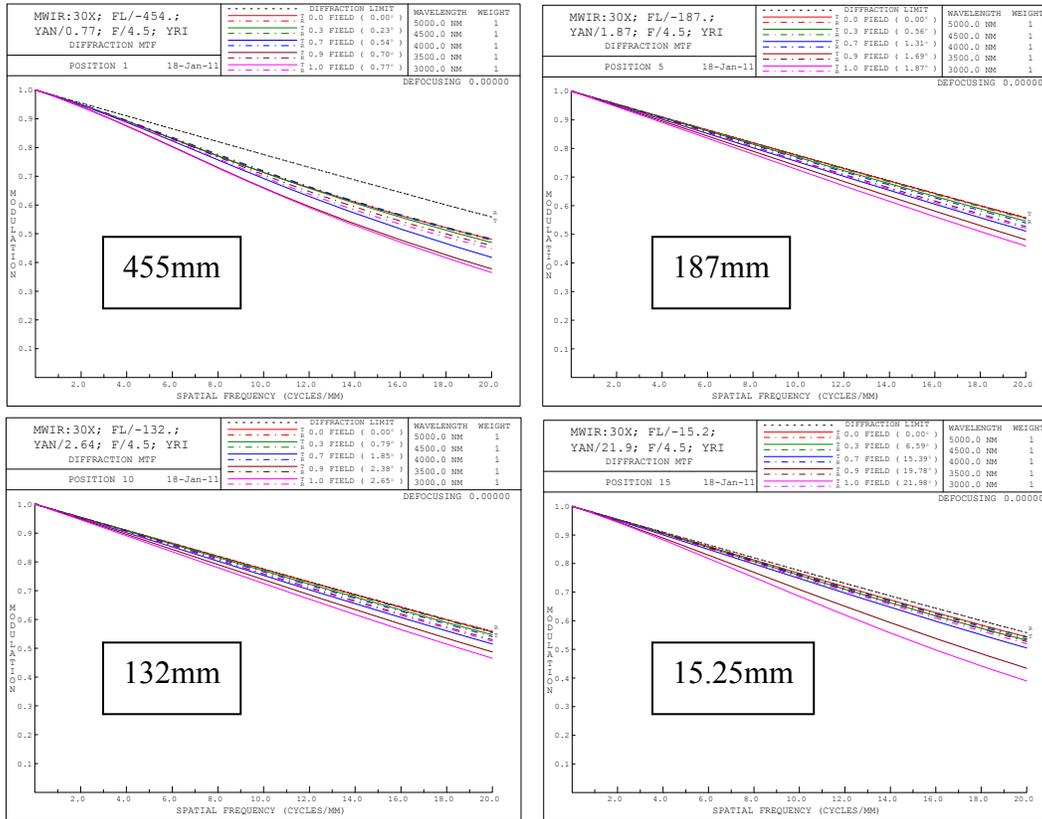
Figure 2. The MTF plots shown are out to Nyquist of the designed camera. The system is close to the diffraction limit for the entire zoom range and for the full field.

Furthermore, the distortion of this zoom system is under 0.5% for the entire 30X range. Figure 5 shows the distortion across the full focal length range.
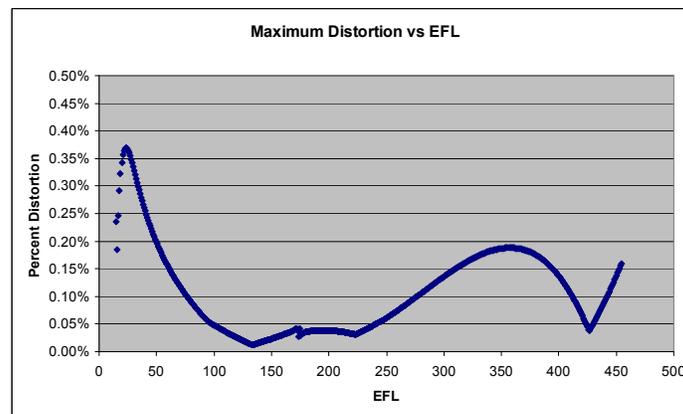
Figure 3. The distortion of the system is low through the entire zoom range.

2.2 Close Focus Range

Close focus was a requirement for this system. With the ability to move both moving groups independently this was not a large concern of the design. It was found that the WFOV had no loss of contrast at a target 25meters away. For the NFOV, this target range could be achieved with a shift of one of the zoom groups.

2.3 Thermal Compensation

As presented in the prior paper, the optical system was designed to handle a thermal range from -40°C to +60°C. The performance over this thermal range was preserved by repositioning of the zoom groups.

3. TOLERANCING

3.1 Predicted results

An optical designer must always consider the sensitivities of the design. A nominal design with high sensitivities may not be as good as a design which has a lower nominal performance but low sensitivities. We were able to control the aberrations throughout the design process which resulted in a system with good manufacturability.

In tolerancing of the zoom system, we knew that we would be driving each zoom group independently. This allowed us to have 2 free compensators. We looked for the building and compensation of the system to be as simple and straight forward as possible. We accomplished this by treating the objective and zoom as separate entities from the re-imager group.

3.2 Maintaining Continuous Focus

As mentioned in the prior paper, the design achieved a continuous zoom range by very carefully examining the 1st order of the zoom groups and thorough examination about the 1X magnification positions. This care needed to be continued in the tolerancing and build process. Since the tolerances on the individual surfaces and center thickness would result in a change to the 1st order of the zoom, we needed to carefully consider how to compensate for these changes.

With the change in focal length of each of the zoom groups we needed to be able to handle building a continuous zoom system even though the 1st orders of each system would be slightly different. We found that this could be accomplished without using measured element data in a design program or measuring the focal lengths of each of the zoom groups. This will allow the build process to move smoother. The build strategy actually will take into account optical effects when the zoom groups are moved through their nominal paths to determine how adjustments should be made.

3.3 Controlling Boresight

One important requirement of most IR zoom systems, is very good boresight. With a significant zoom range and zoom groups moving axially up to 75mm, this was a significant challenge. The tolerances and alignment scheme have allowed the boresight to be less than ½ a pixel, without any internal compensation. With compensation, this error will be able to be reduced further.

4. MECHANICAL DESIGN

The housing is made of upper and lower halves, each supporting one of the two drive mechanisms. A camera adaptor can be made to fit nearly any mount type or the housing design can be easily modified for special applications.

Figure 4a-b. Envelope dimensions.

The IR lenses are bonded in their cells with athermalizing bond gaps. Both movable lens groups use a similar carriage design, guided by two rails each. Each primary rail locates the carriage by a collinear pair of linear bearings. The secondary rail and single linear bearing prevents the carriage subassembly from rotating about the first rail. The rails are aligned as necessary during assembly.
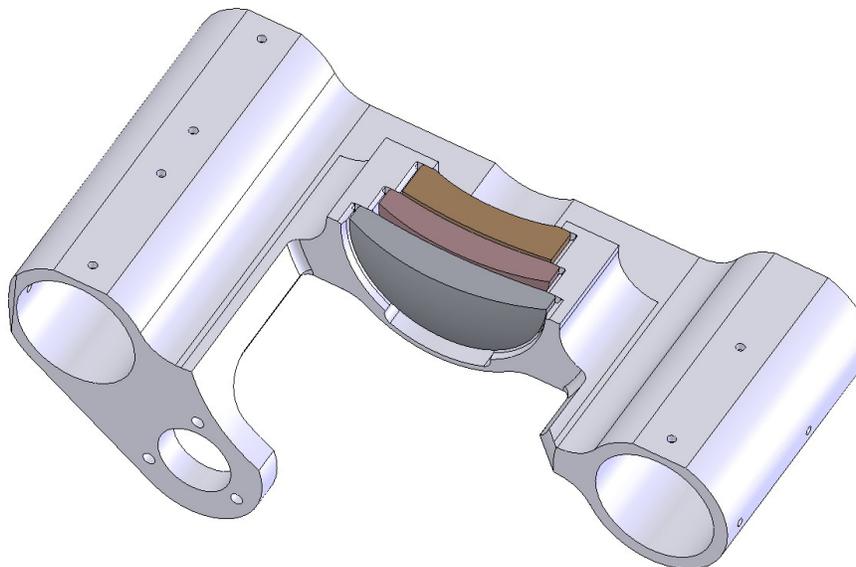

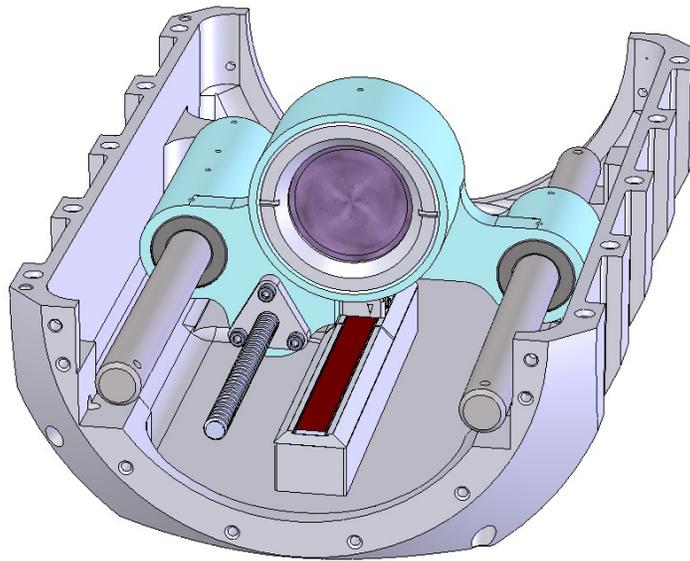Figure 5. Integral lens cell and carriage.

Figure 6. Rail guides and lead screw drive, which is similar for both moving lens groups.

The carriages are each positioned along the optical axis by a lead screw and anti-backlash lead nut which is flange-mounted to the carriage. The lead screw is supported by a pair of preloaded duplex bearings at the driven end, while the other end is radially constrained by the lead nut. The lead dimension, motor size and gear reduction are selected to balance actuation speed and electrical requirements with positioning accuracy. The actuators can operate at 100% duty cycle with <25°C temp rise of the motor.
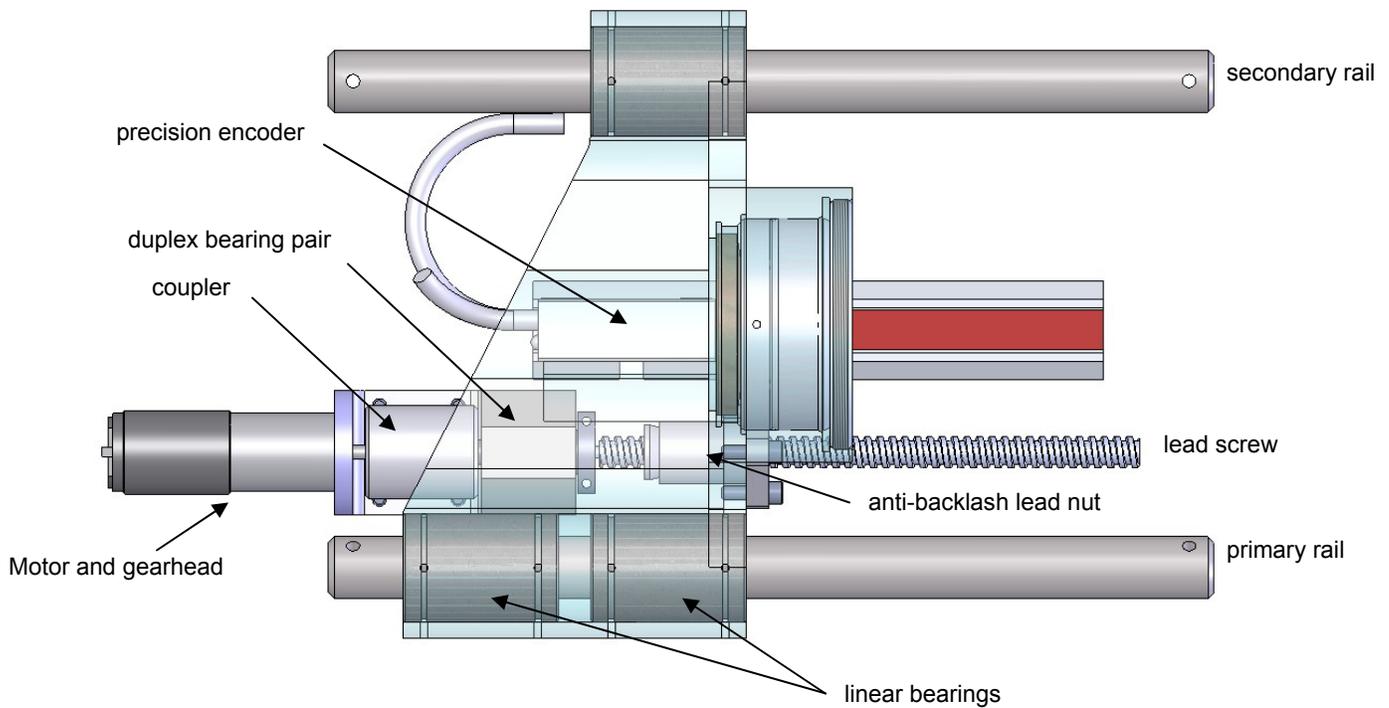

Figure 7. Major components for half of the zoom mechanism.

5. SUMMARY

Through sound design principals we have demonstrated a manner to build a MWIR zoom system which has a very large zoom range with continuous focus. The system was toleranced with the build strategy in mind. The mechanical and electrical designs have produced a system to meet the customer's needs.

REFERENCES

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