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Progress Towards Alignment of Multi-Order Diffractive Engineered (MODE) Lens Segments using the Kinematically-Engaged Yoke System (KEYS) for Optical Performance Testing

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ABSTRACT

The continued development of multi-order diffractive engineered (MODE) lens technology that utilizes both multi-order diffractive surfaces and a diffractive Fresnel lens surface[1–3] allows for the conception and development of future applications of the technology such as lightweight large aperture telescope primary lenses. Manufacturing methods being developed for this technology use glass compression molding to create its unique optical surface features. However, to enable the design and development of larger apertures using the MODE lens, it is necessary to allow segmentation due to the size constraints of current glass molding technology. Previous proceedings presented the effectiveness of the Kinematically-Engaged Yoke System (KEYS) to align the segments of a 0.24-m, PMMA, monochromatic, MODE-like lens (having no diffractive Fresnel lens features). The KEYS alignment system consists of ball bearings with which the step-like features of MODE lens segments kinematically engage with. In previous iterations of the KEYS, these ball bearings were mounted on ultra-fine screws that are adjusted radially with flexures that occupy space in the transverse plane (perpendicular to the MODE lens's optical axis). We present a new iteration of KEYS in which these radially adjusting flexures have been modified to be located in planes that contain the MODE len's optical axis. The alignment and optical performance of the MODE lens are evaluated using deflectometry in order to determine its current resolution of lens segment adjustment. Improvement of the KEYS will allow optical performance testing of the aligned lens. This version of KEYS will be used to assemble a 0.24-m, compression molded, glass, segmented MODE lens.

Keywords: alignment, metrology, multi-segmented optics, MODE lens, optomechanics, kinematic constraint, flexures

1. INTRODUCTION

The use of segmented mirrors has long been the preferred method of creating large apertures for telescopes for astronomical observations. This includes both the largest terrestrial telescope, the Large Binocular Telescope with two 8.4-m segments and a collecting area of 111-m^2), and the largest space telescope, the JWST with 18 hexagonal segments with a collecting area of 111-m. Mirrors are used over lenses because their optical power is not dependent on their thickness (and therefore can be made lighter) and they are achromatic. Telescopes with greater diameters and collecting area are able to make observations with greater resolution and can observe celestial bodies that emit and radiate less light. However, with the drive to design and develop telescopes with larger apertures, the task of designing and developing mechanisms for aligning segmented mirrors becomes a

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much more difficult task due to the stringent alignment tolerances required for aligning mirror segments. While these strict alignment tolerances could be avoided by utilizing a segmented lens design should difficult qualities of lenses (bulky form factor and chromatism) could be overcome.

Fortunately, development continues rapidly on the multi-order diffractive (MODE) lens which is an optical element that utilizes a multi-order diffractive lens design in order to reduce the material and weight of the lens. It also has a diffractive Fresnel lens (DFL) on the back in order to correct for chromatism. Also, because it is a lens, if it were to be segmented, the misalignment and cophasing tolerances are less stringent than a mirror with similar optical power and size.[3] Due to the beneficial qualities of the MODE lens, it has the potential to be used as a primary lens for novel space telescope designs such as the Nautilus Deep Space Observatory, a proposed concept that consists of 35 observatories, each with an 8.4-m diameter aperture in which a MODE lens is used as the primary optical element. This concept can be seen in Fig. 1.[4] Technologies to prototype and qualify the suitability of the MODE lens technology for space observatories are under active development. This includes the development of glass compression molding to manufacture the MODE lens and the alignment of MODE lens segments. This paper discusses our method of aligning MODE lens segments. We do this using the Kinematically Engaged Yoke System (KEYS).

We present both a previous and current version of the KEYS alignment mechanism. See Fig. 2 and Fig. 3 for the previous and current iterations of the KEYS alignment mechanism. These prototypes were developed using a segmented MODE-like lens(no diffractive Fresnel lens surface on the back of the lens) made of diamond-turned PMMA and 0.24-m in diameter as seen in Fig. 4. The lens is divided into one central segment and 8 ring segments.

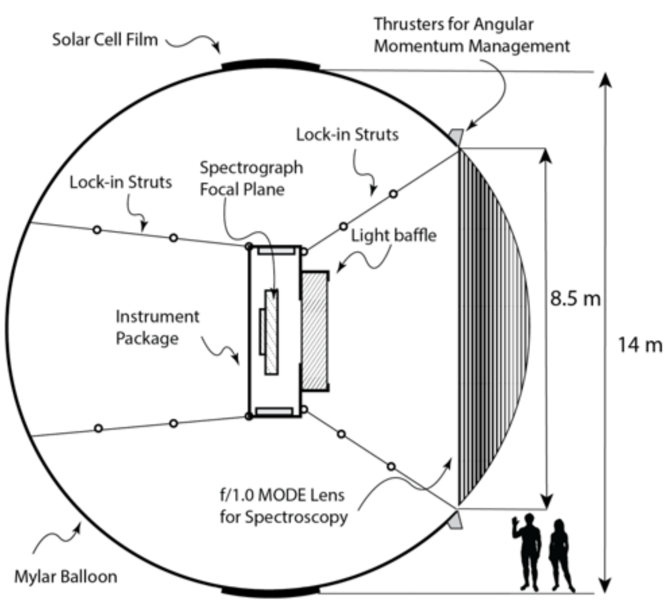

Figure 1. A diagram of one of the observatories that make up the Nautilus Deep Space Observatory.[4]

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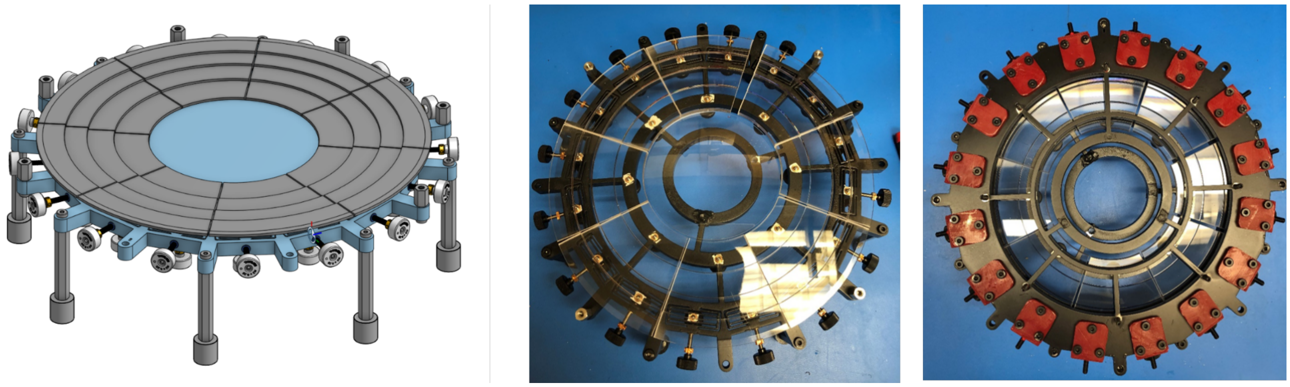

Figure 2. (left) A 3D model of the assembled KEYS system mounting the MODE segments without the top plate, (center) the assembled KEYS system without the top plate and (right) the assembly with the top plate. The top plate on which spring plungers are mounted for preloading the lens segments.[5]

Figure 3. (left) The new and current KEYS design with improved flexures for radial adjustment of the ring lens segments and magnetic preload.

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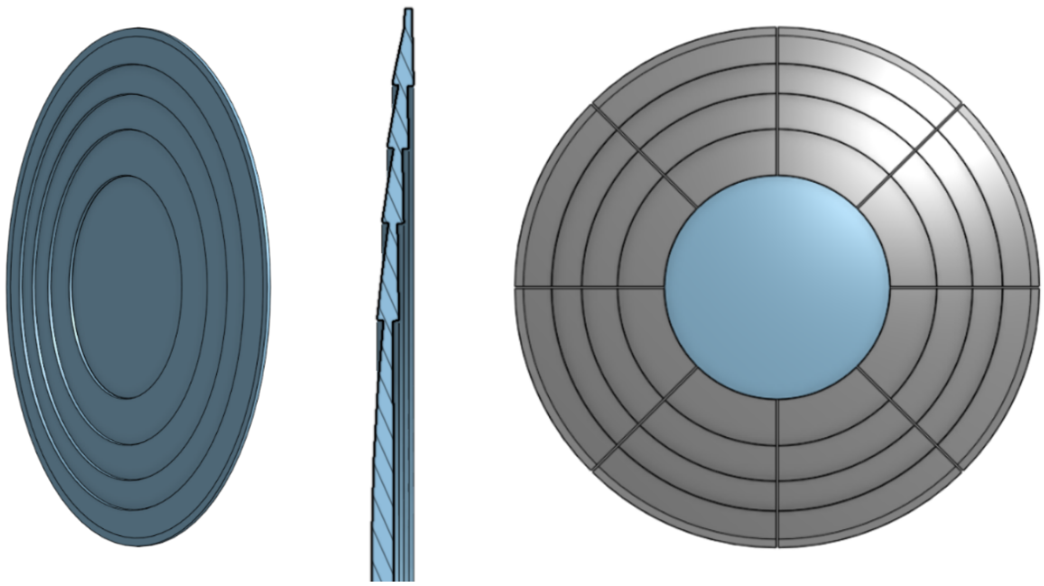

Figure 4. (left) A views of a 3D model of the prototype MODE-like lens before it was segmented, (center) a cross-section view showing the blaze profile of the MODE-like lens and (right) a top view showing how the MODE lens is segmented.[5]

2. DESIGN ELEMENTS OF KEYS

Both iterations of the KEYS alignment mechanism utilizes the step features of the blaze profile of the MOD (Multi-Order Diffractive) surface of the MODE lens in order to kinematically engage the lens segments. Each ring segment is constrained and adjustable in five degrees of freedom with the rotation about the optical axis left unconstrained. Three of the degrees of freedom (tip, tilt, and piston) are controlled using ultra-fine thread adjustment screws that move parallel to the optical axis at three different locations on the ring segment. As seen in Fig 5, two setscrews on the outermost blaze step contact the lens segment at two points while the set screw closer to the optical axis only contacts the segment at one point. This is a total of five points of contact and five degrees of freedom that are kinematically constrained. The ring segments are preloaded so that they remain in contact with the adjustment screws. The radial position of the wedge is controlled by moving the two outer setscrews per wedge radially. This is done using a flexure mechanism that is also adjusted with ultra-fine adjustment screws.[5] While these basic design elements are present in both the previous and current iterations of the KEYS alignment mechanism, the implementation of the radial flexures and preloading differs.

2.1 Previous Iteration of KEYS

The previous version of KEYS utilized a folded flexures to provide for radial adjustments. This is seen in Fig 6 which shows the base plate of the KEYS system on which the folded flexures are cut into. The base plate was made out of 7075 aluminum in order to use an easily manufacturable material with a high strength to stiffness ratio which is beneficial for compliant mechanisms such as folded flexures.[6] Preload is applied using spring plungers mounted on a top plate as can be seen in Fig. 2 (right).[5] While this iteration of KEYS worked adequately to adjust and mechanically align the MODE lens segments, it blocks quite a bit of light when testing the optical performance of the segment alignment and it became necessary to create a design that obscured less of the aperture. There were also some stiction issues with the spring plungers (used for preload) that were address in the current iteration of KEYS.

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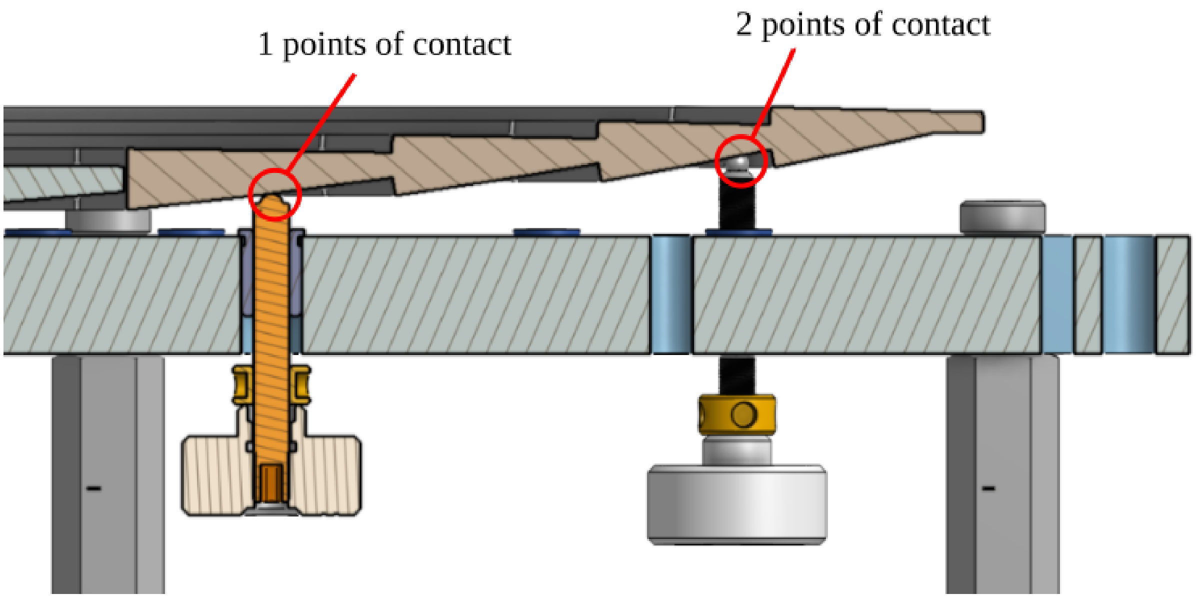

Figure 5. A section view of a 3D model of the KEYS system showing where the ball-ends of the set-screws contact the MODE-like lens segment. Note that the outer set of two setscrew ball-ends (one of which is not shown) contacts the lens at two points and the inner setscrew contacts it at one point. Note that this is a model of the previous iteration of the KEYS adjustment mechanism but the current iteration utilizes the same concept.[5]

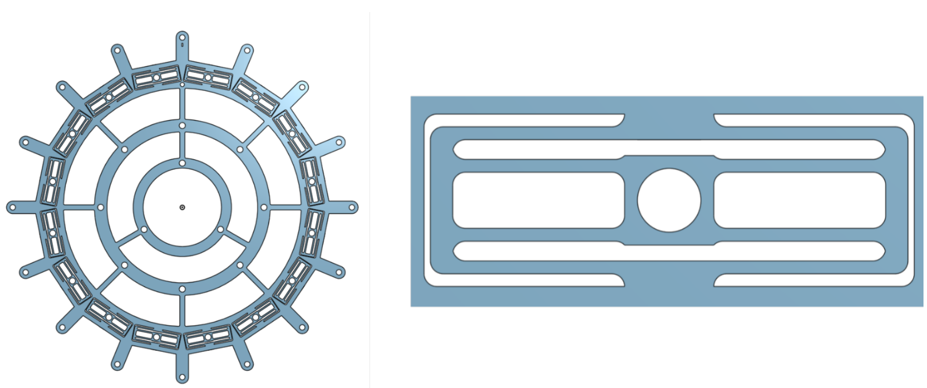

Figure 6. (left) The base plate of the KEYS system with 16 folded flexure elements (two per ring lens segment) that move the outer setscrews radially and (right) a close up view of a single folded flexure.[5]

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3. CURRENT KEYS DESIGN

The current KEYS design utilizes a simpler parallelogram flexure than the previous iteration. While the folded flexure design in the previous iteration does not exhibit parasitic motion like this design, the parasitic motion can be compensated for by adjustment using the tip/tilt/piston adjustment screws. The flexures are also separate subassemblies rather than all of them cut out of the same base plate. While this complicates the manufacturing and assembly process, it allowed the flexure subassembly to be rotated to reduce the obscuration of the aperture. The flexure blades are made of 1075 spring steel and the surrounding structure and flexure stages are made of stainless steel. The flexure was designed to have the same adjustment capabilities as the previous iteration.

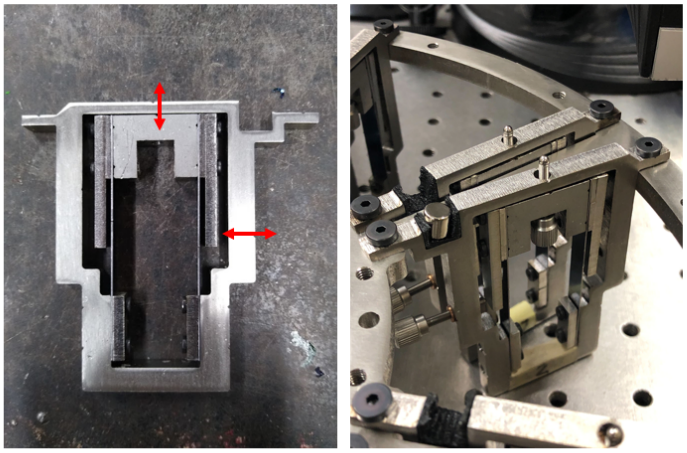

Figure 7. (left) A single radial flexure subassembly used int he current KEYS adjustment mechanism. Two flexures are used per ring segment. The horizontal red arrow indicates how an adjustment screw pushes on the flexure and the vertical red arrow indicates the direction of adjustment of the adjustment screw that is mounted on the flexure stage. (right) The flexure subassemblies mounted on the KEYS adjustment mechanism.

To further clear up the aperture, the spring plungers that applied preload but required a top plate to be mounted, were replaced by magnets. Each ring segment had four neodymium magnets (two on the below the ring segment and two on the top) that applied preload to the ring segment keep it in contact with the adjustment screws. The two magnets below the ring segment were bonded to the static flexure structure and the two magnets above the ring segment were mounted on custom 3D printed mounts that sat on top of the ring segment. The custom 3D printed magnet mount was printed out of PLA plastic but had rubber bonded to the bottom to prevent scratching on the ring segment.

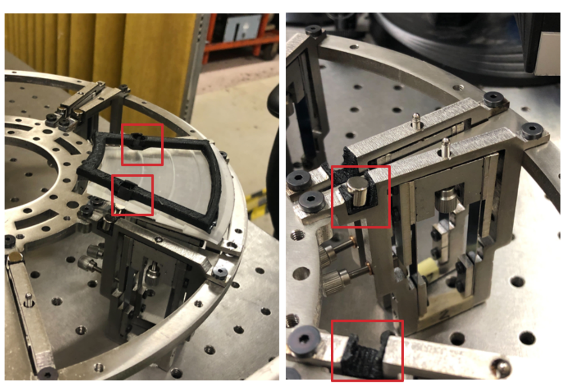

Figure 8. (left) The custom 3D printed magnet mounts that sit on top of the ring segments. The red boxes indicate where the magnets are mounted. (right) The magnets mounted below the ring segment.

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4. CONCLUSIONS AND FUTURE WORK

These design changes in the KEYS alignment mechanism increased the optical throughput of the system from 31% to 64% and makes optical testing during alignment much more feasible. While the magnetic preload worked satisfactorily to keep the ring segments in contact with the adjustable screws, it was found that while adjusting one lens segment, the magnet would affect the magnet on the neighboring lens segment. This can be seen in Fig. 9. A deflectometry metrology system[7] to measure the movement of each lens segment (the one being adjusted and the one that was not adjust but still moved slightly). Further improvements will be made to the KEYS adjustment mechanism to reduce this magnetic crosstalk.

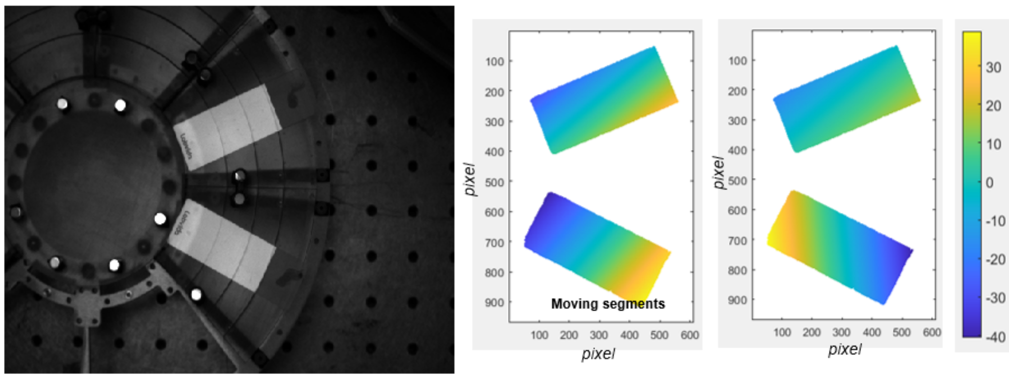

Figure 9. (left) Two ring segments being adjusted and measured using a deflectometry metrology system. Glass slides are placed on top of the ring segments to ensure proper specular reflection to get measurement. (right) The results of adjusting a ring lens segment. It can be seen that the neighboring segment also moves because of magnetic crosstalk.

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