Design, Fabrication, and Testing of a 3D-Printed Optomechanical Assembly for MIFEDS Coil Characterization

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1. Abstract

Engineering design principles were developed to provide an inexpensive and rapid production method for optomechanical assemblies using 3D-printing technology. The ultimate goal is to establish principles through the development of an optomechanical housing. Several iterations led to optic holders that maintain the axial and radial location of individual optics. Future research will integrate these holders into a monolithic structure.

2. Introduction

The Magneto Inertial Fusion Electrical Discharge System (MIFEDS)[1] produces high-intensity magnetic fields for plasma physics and astrophysics experiments at the University of Rochester Laboratory for Laser Energetics (LLE). Figure 1 shows the MIFEDS device with a closeup of its coil. The MIFEDS device stores 400 Joules of electrical energy in capacitors and then rapidly discharges a 20 kV, 50 kA pulse into a ~1 cm diameter coil.

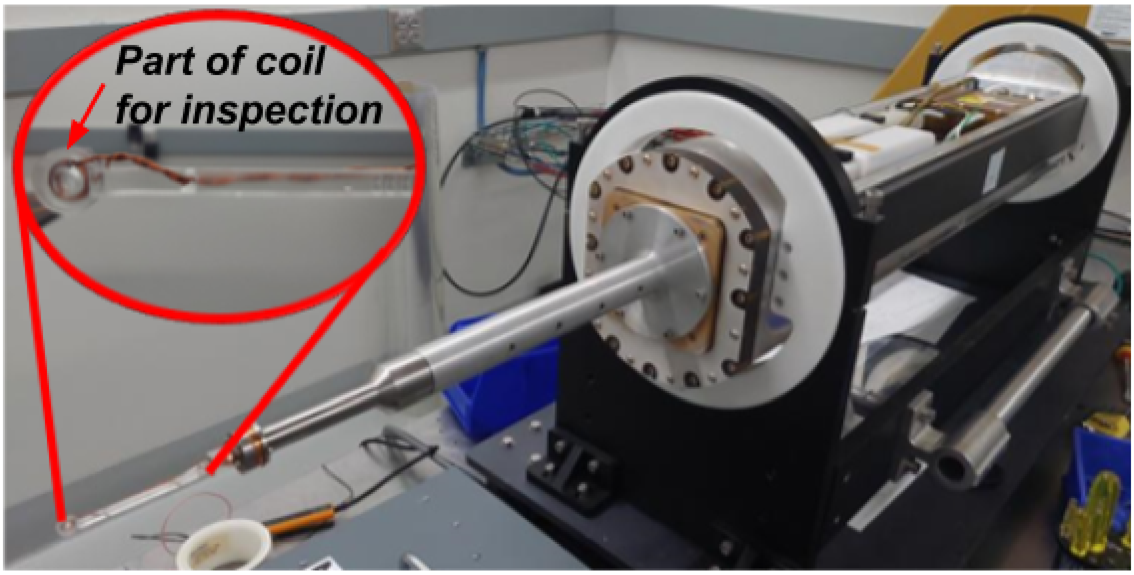

Figure 1 - A MIFEDS diagnostic with close up coil view

MIFEDS coils occasionally fail to meet dimensional specifications, causing interference with laser beams and compromising other aspects of an experiment. These deficiencies need to be identified prior to an experimental campaign to prevent delays and compromised performance. A coil inspection station is being built that will allow for pass-fail dimensional inspection of coils. The inspection station requires two optomechanical assemblies to be built in order to image a coil assembly from two nearly orthogonal axes. Each assembly houses a telecentric lens assembly, consisting of two lenses and a field stop, one or more mirrors and beam splitters, a camera, and an illumination source. A telecentric lens maintains a constant magnification over an extended depth of field, allowing accurate measurements to be taken from resulting images.

The goal of this work was to develop design principles for the fabrication of high-precision monolithic 3D-printed optomechanical structures and apply them to this system. Monolithic is defined as “consisting of or constituting a single unit” (Merriam Webster 2c) and is a design principle that allows for quick assembly. As these principles are further refined, they will provide an inexpensive and rapid production method for optomechanical assemblies.

3. Optical Layout

Figure 2 shows the telecentric lens system[2] design being packaged. A linear beam path is too long for practical use so a folded design was pursued. The four optical components in the folded setup are lens 1 (50 mm diameter), lens 2, mirror, and beamsplitter (all 25 mm diameter). A field-stop aperture located at the beam-waist is required to achieve telecentric performance. Figure 3 shows the folded arrangement[3], including the camera position. This design is shorter and permits a coaxial illumination source behind the beamsplitter to be injected through it or a ring illuminator in front of the 50mm lens.

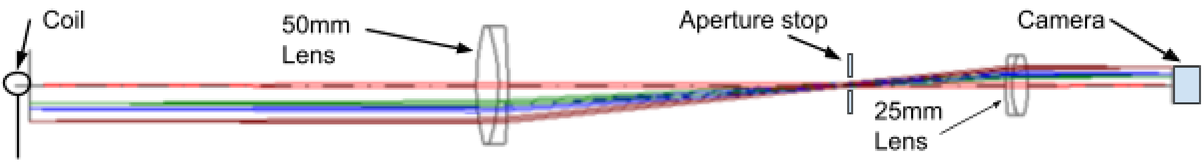

Figure 2 - An optical model created using CODE-V software showing the location of key elements in the telecentric lens assembly

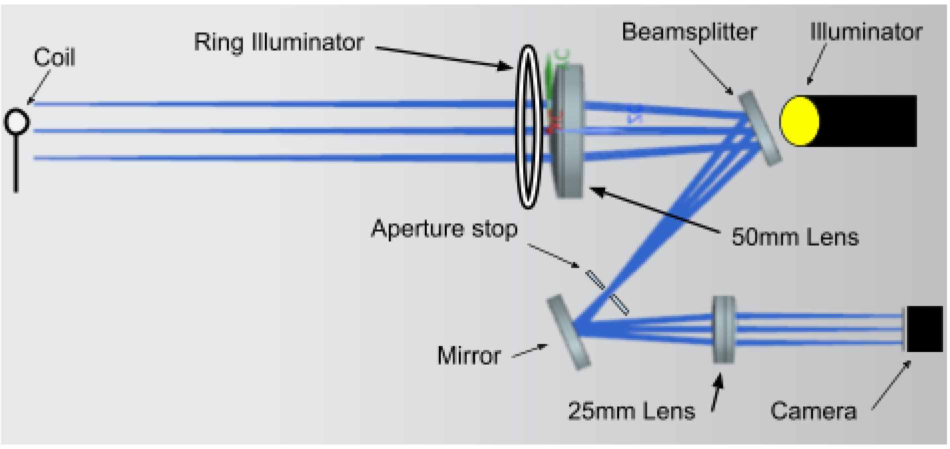

Figure 3 - Preliminary folded layout of optical assembly

4. Stereolithographic 3D-printing And Design Challenges

3D-printing is an additive manufacturing process that forms three-dimensional objects one layer at a time. Stereolithography (SLA) is a photopolymerization printing method. A build plate is lowered into a vat of liquid resin where a laser "writes" a pattern, causing the resin to solidify into a thin layer of hardened plastic. The plate is then raised a small distance (e.g., 0.05 mm) and the process repeats. LLE has Formlabs™ SLA printers which suit this project given their high resolution and accuracy. SLA printing creates the first actual layers of a part after establishing a base "raft" on the build plate. The layers which form the raft sacrifice dimensional accuracy for adhesion. The printer then creates "support structures" which support the part during the printing process. Once the print is complete, the supports are broken or cut from the final part. These supports leave remnants where they were connected to

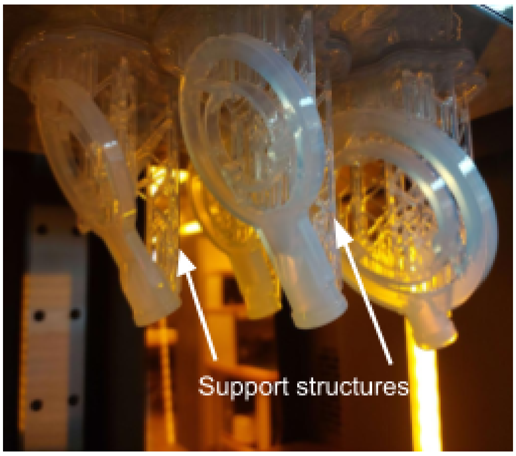

Figure 4 - Supports added by slicer software on a 3D-printed part made with SLA printing

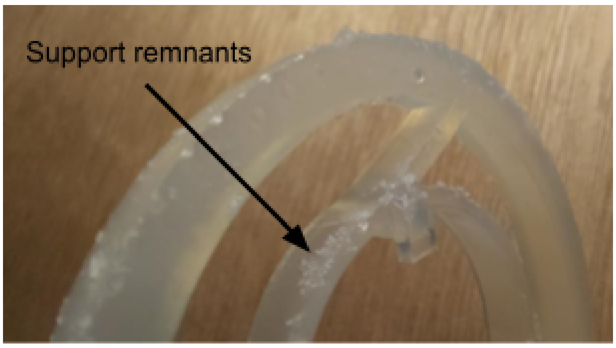

Figure 5 - A close view of support remnants on a printed part

the part. The designer must ensure that these remnants are located where they won't interfere with the functional requirements of the part. Supports are added to a part in a pre-print program known as a "slicer", which slices a model into layers. The slicer used with Formlabs printers is "PreForm"; supports can be added and optimized manually or automatically. Supports are required for any overhanging feature or otherwise unsupported surface. Figure 4 depicts three optic holders with SLA supports that are added to the parts. Figure 5 displays remnants of these supports after removal. These remnants can be smoothed out with the sacrifice of dimensional accuracy.

5. Optic Holder Design Iterations

Figure 6 is a computer-aided design (CAD) model of the first optic holder design. This was inspired by an aluminum optic mount designed by Mark Romanofsky[4]. Three (3) contact points constrain the optic radially; two of these are "fixed" and one flexes to create a radial "clamping" force. In this design, the center line of the supported optic changes for varying diameter components. This is suitable for plano optics (e.g., flat mirrors & windows) as they have large centering tolerance, unlike curved optics (e.g., lenses).

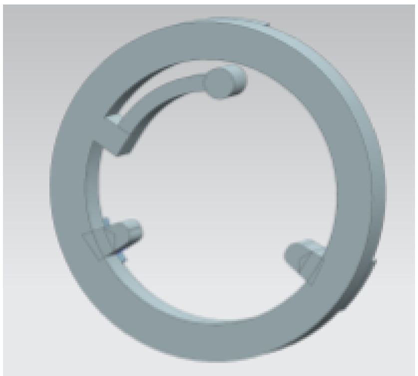

Figure 6 - Design with two stationary contact points and one flexure point

Optical performance depends on precisely aligning the optic axis of all lenses. Figure 7 depicts a design consisting of three "flexure points"; the inner ring deforms symmetrically about its center point upon optic installation. This design maintains the center line regardless of optic tolerance and was used for all components given its versatility. This design was adequate for early development work, facilitating easy installation and removal of optics, but it doesn't constrain the part axially and instead

Figure 7 - Design with three contact points flexing symmetrically with respect to the center of the optic

depends on friction at the three contact points to retain the optic. An option explored later uses 3 screws with plastic washers to properly retain the optic.

Axial stops are needed to locate the critical surface of an optic (e.g., the reflective face of a mirror). These features must accommodate component curvature when applied to lenses while flat mirrors need no such consideration. Figure 8 shows a spring-clip concept that both constrains axial placement and retains the optic.

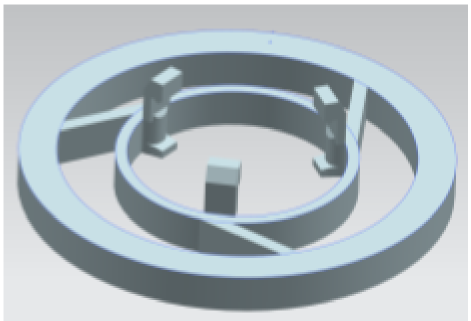

Figure 8 - Design that constrains the optic axially and radially

5.1 Component Holder Variations

Each component requires a unique variation of the holder design. Unlike the lenses, the mirror and beam splitter feature flat surfaces on both sides. Figure 9 is the design of the beam splitter and mirror holder. The beam splitter differs from the mirror as it has a 0.5° wedge to direct reflections from the back of the beam splitter out of the imaging path. This holder iteration uses friction to hold optics in place and has three flat stop points along with extrusions indicating the location of the thickest point on the beam splitter.

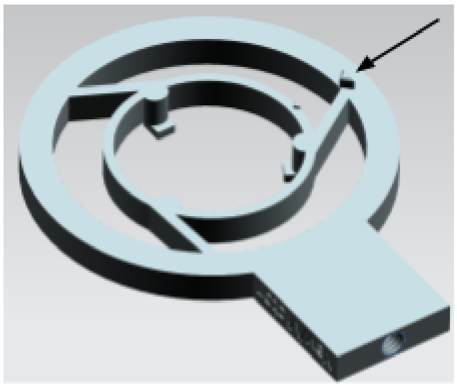

Figure 9 - Beamsplitter and mirror design with arrow to the beamsplitter thickest point indicator

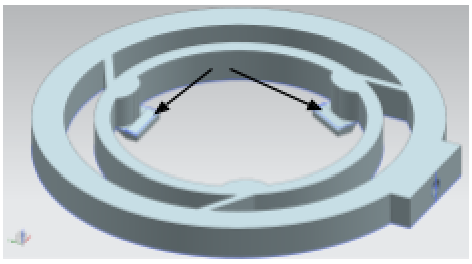

Figure 10a - 50mm optic holder design with arrow to the backstops

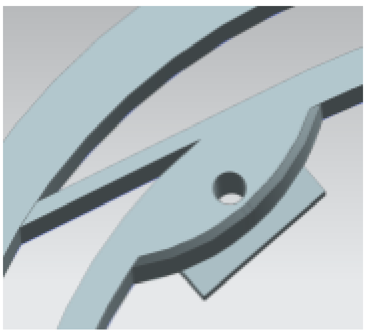

Figure 10b - 50 mm optic holder screw hole

The two lens holders accommodate lens curvature and define the edge position. Figure 10a displays the optic holder for the 50 mm lens. The optic holder for the 25 mm lens follows the same design concept. Figure 10b shows a recent design developed that has a screw hole to facilitate optic retention using a screw and washer. Figure 10b, because of the simpler design, requires no supports on working surfaces.

The individual component holders need to be mounted to a breadboard for testing. Figure 11 shows a design created to be compatible with a commercial breadboard clamp allowing for breadboard testing. This feature was added to all component holders to locate the optic axis at the correct height.

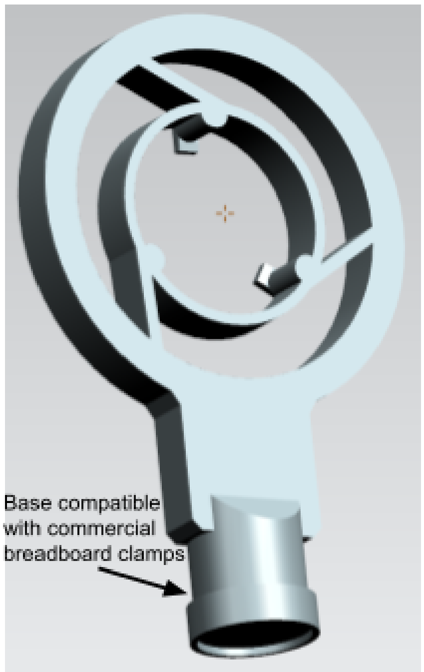

Figure 11 - Commercial breadboard clamp design

6. **Preliminary Breadboard Testing**

Using the optical layout depicted in Figure 12, a breadboard prototype was constructed following the layout from Figure 3 using either a monochromatic red coaxial illuminator or a white-LED ring illuminator[5] in front of the first lens (a.k.a. front-side illumination). Several problems were encountered in the preliminary tests. The coaxial illuminator scattered light in the translucent resin, causing poor image contrast. Scattering also renders a translucent aperture stop ineffective.

An image taken of a test MIFEDS coil using the ring illuminator (Figure 13) was far superior. After the preliminary testing, it was found that the 50 mm lens was mounted backward, which likely contributed to poor image quality along with the lack of the aperture stop.

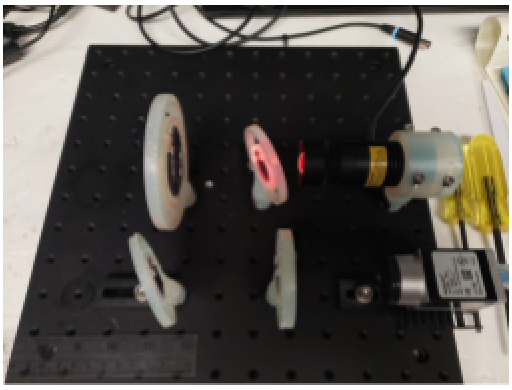

Figure 12 - Breadboard Setup. The components match those shown schematically in Figure 3.

Figure 13 - Image from breadboard setup using ring illuminator

7. Conclusion

Engineering design principles for 3D-printed optical mounts were developed to provide an inexpensive and rapid production method for optomechanical assemblies. Optic holders were successfully produced which met all desired criteria.

8. Future Research

Illumination issues will be resolved through the testing of front-side and coaxial illumination separately and in tandem. Due to light scattering in translucent 3D-printing material, opaque alternatives, and their qualities will be tested. Optimization is required on the optic holder design to minimize size by reducing the flexure arm length as well as the thickness of all features. A method for retaining each optic in its mount must be chosen. The option currently being pursued uses three thread-forming screws positioned near the three points of contact to press plastic washers against the optics. The feasibility of using low-cost, rapid-production 3D-printing for optomechanical systems will thus be demonstrated by the integration of all optic holders into a monolithic assembly. Mounting features need to be designed to install the two optical assemblies into the characterization station. A rail mount system is being considered.

9. Acknowledgments

I thank Dr. Craxton for organizing this program, which provides such amazing opportunities for my fellow students, and my advisor, Dr. Doug Jacob-Perkins, for all the time dedicated to my project this summer. Additionally, I thank Mike Bradley for teaching me SLA 3D-printing and techniques as well as Dave Weiner and Sam O'Conner for sharing their knowledge and expertise on optics. Also, many thanks to the other students in the program for their help and their hard working attitudes.

10. References

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