Automated Mirror Cover for Telescope Application

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Midpoint Report

Document

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Problem Statement

The NPOI needs an automated mirror cover that can operate without interfering with current equipment while maintaining a nitrogen purge.

Introduction

The NPOI (Navy Precision Optical Interferometer) located at the top of Anderson Mesa in Flagstaff, Arizona, is a United States Naval Research Laboratory (NRL) facility. This facility uses a series of expensive aluminum coated mirrors to reflect starlight down vacuum tubes, where the starlight is then captured by sensors. The data is then analyzed by astronomers to produce a high resolution image of stars.

Background Research

The capstone's contact and client, James Clark, has been working at the NPOI since 1990. James Clark has become concerned about the potential safety risks associated with removing the mirror caps. The mirrors aluminum coating is only a few molecules thick, so the mirrors need to be covered when not in use or the coating can be damaged by moisture or debris. Currently the mirrors are protected by a Lexan cover with a nitrogen purge. The Lexan protects the mirrors from debris and the nitrogen purge maintains 10 psi of pressure that prevents moisture from condensing on the mirror. This requires NPOI employees to crawl into each siderostat housing, remove the mirror cap, and crawl out either late at night or before dawn with no light, this process can be very dangerous particularly in winter and is a major safety concern with the addition of 2 new taller siderostat housings.

The aluminum mirrors are re-coated once every three years. In order to lengthen the time between coatings, the mirrors are cleaned three to four times in three years. This practice ensures that no unnecessary contact with the mirror is made which can damage the coating. A protective dome closes to protect the siderostat and when the facility is not is use. Within the dome, there is a climate controlled environment which protects the mirror from harsh weather and debris. While the dome is closed, moisture can condense on the mirrors surface, if left uncovered, frost may form, significantly reducing the useable life of the mirror. In order to counteract this process, a Lexan cover was built with a purge that creates a nitrogen blanket on the mirror's surface.

Project Goal and Scope of Project

A solution for removing and replacing essential mirror dust covers must be found while maintaining functionality of existing equipment, and adding a minimum amount of mass to the system while incorporating autonomous and semi-autonomous operation during power loss situations.

Objectives

The new cover must operate remotely, from outside of the equipment housing, keeping observers out of potential danger and protecting the equipment from accidental impacts. The mirror must be kept in a nitrogen environment in order to displace moisture. In order to do this, an orifice, 4 thousands of an inch in diameter must allow 10 psi of nitrogen to be injected through the mirror cover, purging atmospheric air. The nitrogen flow needs to automatically shut off when the cover is open. In addition, the equipment must maintain balance so that motor components are not exposed to excess stress during rotation. The new equipment should enhance the performance of the equipment that is in place and should in no way hinder the operations of the equipment.

Constraints

The cover must not block any light from the mirror's lens. The full range of motion of the siderostat must be maintained after installation of the automated cover. This includes a vertical tilt from -10 to 60 degrees and a horizontal pan of -60 to 60 degrees. The cover must be able to close in the event of a power failure.

The siderostats are precision instruments that use small movements to track celestial objects while the Earth is rotating. Anything that is mounted on them cannot interfere with this task. The facility is located at the top of Anderson Mesa, which experiences high winds therefore a low profile cover is required. It has been requested by the sponsor that no fabric folds be exposed to the wind, as this type of system may act as a sail, disrupting observation. All of the moving components need to have tight tolerance, allowing essentially zero unanticipated movement.

The cover must be able to open and close while the dome is closed, allowing maintenance to be performed at any time. The critical clearances that must be accommodated are the clearance between the bottom of the mirror cell and the base as well at the clearance between the top of the mirror cell and the dome when it is closed. The top and bottom clearances are measured to be 10 inches and 4 inches respectively.

The siderostats are outside so the cover must be able to operate in the temperature range of -40ºC to 40ºC. The mirror cell is made of cast aluminum and anything mounted to the mirror cell must account for the motion of the cell due to thermal expansion. Cast aluminum is expensive, and the cover will be constructed out of any available polymer, so the mounting points will be slotted to account for stress from the expanding mirror cell. The cover will be mounted using existing threaded holes in the mirror cell where the current cover is attached.

The only grease that is allowed near the mirror is high specific weight grease because if the grease evaporates then the vapor can get on to the mirror and jeopardize the mirrors resolution. This option is out of the project budget because this grease cost approximately $600 per ounce therefore any cover cannot use grease.

If a polymer is used, it must be able to withstand small to moderate amounts of ultraviolet radiation without ceasing to function. The plastic must not be hydroscopic, such as nylon. It will be exposed to moisture and a hydroscopic material may swell and could cease to function properly.

The Iris Design

This design satisfied all of the design constraints and solved many of the issues of previous design concepts. The small area occupied by the iris will reduce the wind's ability to move the siderostat during observation. Figures 1, shows the iris in different modes of operation.

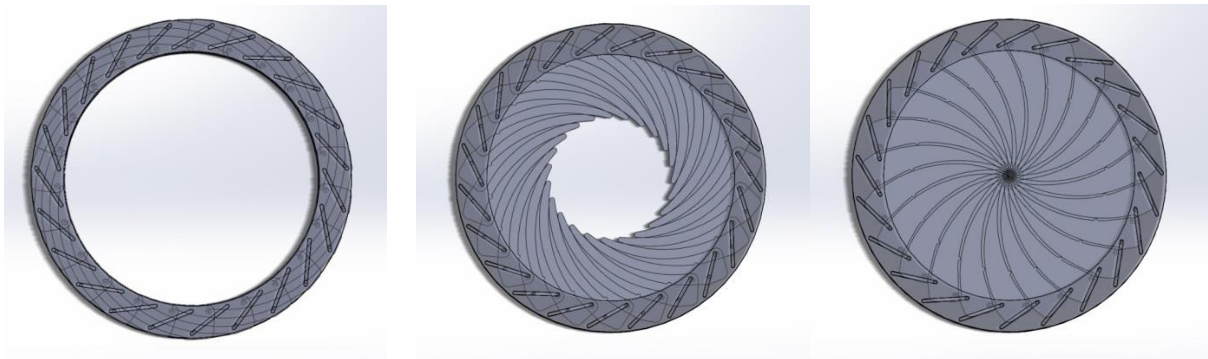


Figure 1 – The Iris Mechanism

Opening and closing the iris requires that the outer ring be rotated approximately 19 degrees. In order to produce this motion, a motor will be mounted to the top of the mirror cell. The motor will drive the ring utilizing a friction drive. The Iris consistent of four essential components; the outer ring, the lower ring, pins and the blades. When the outer ring is rotated it forces pins attached to the blades down a cut out track that then either opens or closed the iris. A video of this process is available online at the capstone project website.

Manufacturing Process

The scaled Iris prototype was manufactured in the Northern Arizona University Machine Shop in building 98C with the help of the machinist, Tom Cothrun. The process of manufacturing starts with developing a G-code through the WLPM1000. G-code is a numerical control programming language which tells a machine what to make and how to make it. At NAU, the computer numerical control program used to develop codes and simulate each code is the WLPM1000 program. Since the scaled prototype is 8 inches in diameter, the actual machining must be completed by the use of the Supermax which has a machining table that fits our prototype dimensions. The Supermax uses a different computer numerical control program called Mach 3. The G-code from WLPM1000 has to be transferred over to the Mach 3 program and from there the G-code needs to be modified as needed. Once the G-code is complete, the components can now be machined out of the proper material using the Supermax.

The Iris Blades

Due to the scaled down size of the blades it was determined a stamp would save time in manufacturing the 23 blades needed for the design. The stamp was machined using the Supermax at the NAU machine shop and programed using G-code. With the guidance of the shop technicians the profile of the female and male parts where cut into the steel bar stock. The rest of the material was removed by manually manipulating the CNC machine. Originally, it was planned to have a set of pins set in the female end to punch the required holes out. However, due to an oversight the female half of the punch had not been mirror imaged in the machining process and the male end could not mate with it. To solve the problem the back of the female half was milled out to allow the halves to mate together. With the back of the female half machined out there was no way to secure any pins to punch the required holes. In order to get the desired holes in our blades, alignment holes were drilled in the male half of the stamp to facilitate hand drilling the holes. Below the finished male half of the stamp can be seen on the right and the female end can be seen in the process of having its profile machined.

Figure 2 –Stamp Being Machined

The stamp was used in conjunction with a cordless drill and an arbor press to make the blades for the iris. To use the stamp the Delrin was cut to width to fit in between the alignment post on the female half of the stamp. The male half was then set on top of the Delrin and the holes were drilled. With the holes drilled the blade was stamped out using the arbor press. With the blade complete the edges were filed down to remove any rough edges or burs. Lastly, the pivot pin was aligned using one of the drilled holes and glued into place. This process was complete for approximately 50 blades in order to provide excess blades for testing and back up replacements.

Figure 3 –Iris Blades Being Stamp

Iris Rings

The rings were manufactured using the Supermax, a CNC mill from Lexan glass. The CNC mill runs through a serious of instructions given by a program in G-Code. The G-Code was written by Leland Doyle, it took about five modifications to the code to get the right cut of the rings for each ring. The test trials of the cuts were run using a piece of plywood, because it was inexpensive and available. After debugging the program the rings were fabricated using Lexan glass which took approximately 30 minutes per ring. When the cuts were being performed by the CNC mill the Lexan glass had to be heavily lubricate to prevent post welding because of the heat created by the friction between the Lexan Glass and the end mill. This process required two people lubricating the Lexan Glass, one person vacuuming the debris created by the cut, and one more person supervising the CNC control module. Once the rings were cut from the CNC machine the rings had to be filed to break all sharp edges and remove burrs.

Figure 4 –Iris Rings Being Machined

Issues with the First Iris Prototype

Once the bottom plate, top plate, and Iris blades were manufactured, the Iris Prototype Version 1.0 was assembled. The three components of the Iris prototype were held together by the pins which were simply a nut and screw as seen in Figure 5. The first prototype had quite a bit of unexpected friction at the pivot points and between the blades and the rings. There were binding issues with the retaining rings because the angle of attack was too high. The rings were not concentric and the pins need to be manufactured with tighter tolerances for the scaled down version. These issues with functionality of the scale model were unacceptable. The performance shortfalls had a number of causes including improper pin selection, an under emphasis of the designs' concentric constraint, improper mounting resulting in a non-ridged system. Although these issues were problematic, uncovering design pitfalls was the express purpose of the scale prototype. Considering the prototype was fabricated solely to identify potential improvements, it could be said that the scale model has accomplished its intended goal: to evaluate the final designs feasibility.

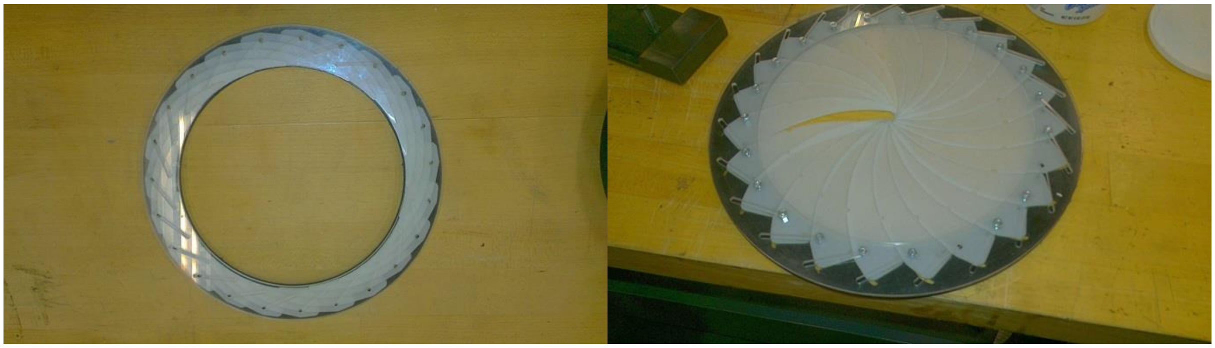


Figure 5 – The Iris prototype version 1.0 in the open position on the left and in the closed position on the right.

Plans for the Next Prototype

Many additional features have been incorporated for the next iteration of the scale prototype. The principle design modification will be the addition of a ball bearing support system for the upper ring. Specifying a distance between the upper and lower ring will create a space for the blades to form an infinite staircase without adding friction to the system. Limiting the degrees of free motion to only rotation will allow for tighter absolute position tolerancing for the actuation pins and their related slots. Having the top and bottom rings located and connected independently of the blade actuation pins eliminates the need to multi-purpose one of the most critical components of the design. In the new design, the actuation pins have only one purpose; to actuate the motion. Allowing the pins to preform only one task will make fabrication and assembly of this iteration much simpler.

Low Coefficient of Friction Coatings

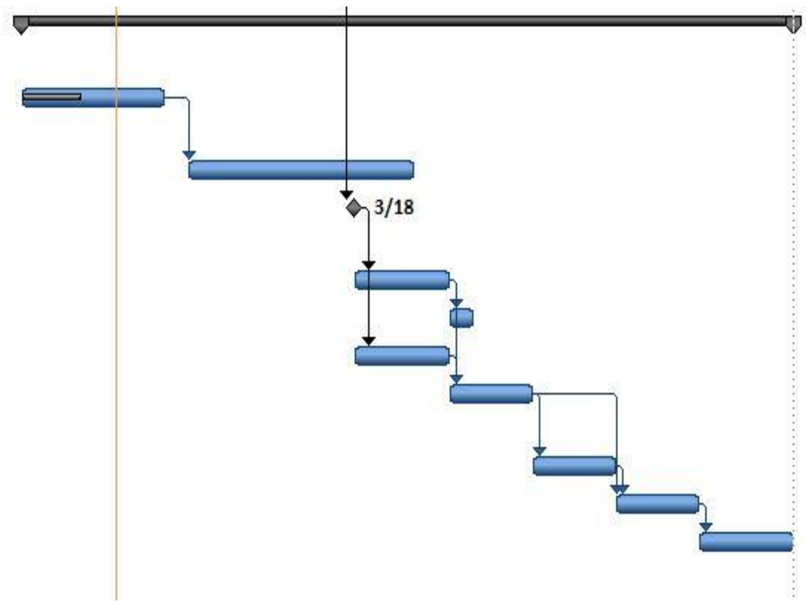
Low coefficient of friction coatings (COF) are another option for reducing the friction between the pins, blades and rings. This option will increase the cost of the iris because the rings would need to be shipped to a surface enhancement facility that offers low COF coatings for polymers. Keco Engineered Coating, Inc. is the primary surface enhancement supplier being considered. This option may be deemed necessary because they advertise specifically that "In some applications our low-friction coatings eliminate liquid lubrication altogether." Free samples have been ordered from the company, and should arrive before completion of the second prototype.

Conclusion

Over the course of the next month the second prototype will be manufactured with the previously mentioned design modifications. The current prototype did prove the concept of the iris mechanism but had a few issues and required excessive torque to function. To improve the design a second prototype will be manufactured incorporating several design modifications that will reduce the overall torque required to drive the iris. If the iris continues to have issues a low coefficient of friction coating will be considered. The second prototype will be completed by the end of March, and will provide plenty of time for further trouble shooting. Upon completion of the second iris the drive mechanism will manufactured and implemented.

Gantt Chart

Finished Product Production	**47 days**	**Mon 2/18/13**	**Tue 4/23/13**	
Revise Model and Design Improvement	10 days	Mon 2/18/13	Fri 3/1/13	
G-Code	15 days	Mon 3/4/13	Fri 3/22/13	17
Have Materials at the latest for	0 days	Mon 3/18/13	Mon 3/18/13	14
Cut Blades	6 days	Mon 3/18/13	Mon 3/25/13	19
Blade Testing	2 days	Tue 3/26/13	Wed 3/27/13	20
Cut 1/4 inch polymers	6 days	Mon 3/18/13	Mon 3/25/13	19
Assembly and Trouble Shoot	5 days	Tue 3/26/13	Mon 4/1/13	20,22
Create Gasket	5 days	Tue 4/2/13	Mon 4/8/13	23
Full Assembly	5 days	Tue 4/9/13	Mon 4/15/13	23,24
Testing of the Whole System	6 days	Tue 4/16/13	Tue 4/23/13	25



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