Automated Mirror Cover for Telescope Application

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Progress 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, 2, and 3 show the iris in different modes of operation.

Figure 1 - Fully Open

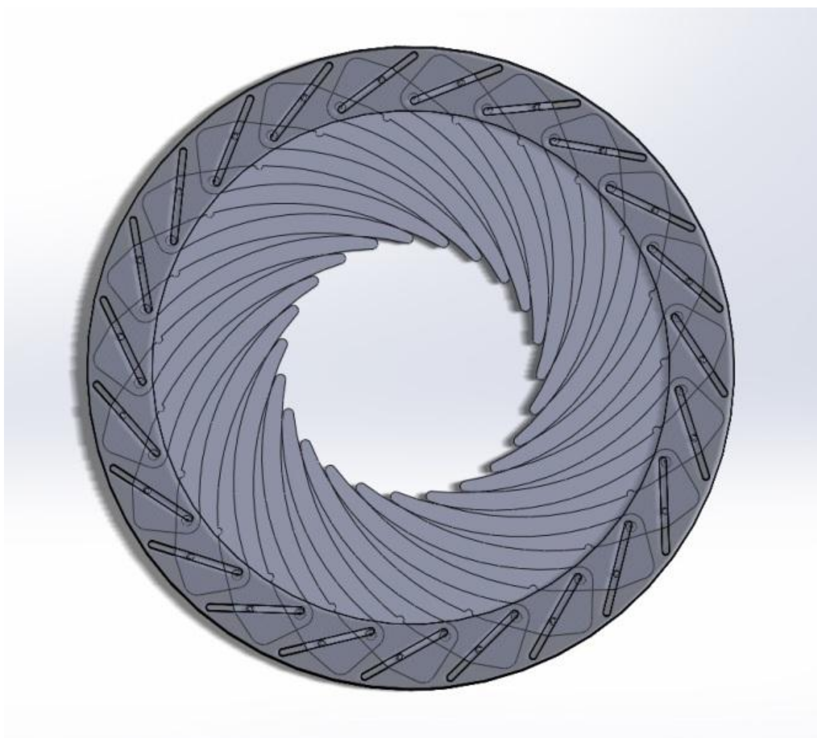


Figure 2 - Partially Closed

Figure 3 - Fully Closed

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, post 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.

Mounting Rings

The iris will be mounted to the cast aluminum mirror cell using six existing quarter inch threaded holes. The mounting ring will be made of two individual rings that will be machined out of 1/4" Lexan and adhered together with an epoxy. These individual rings can be seen color-coded below as the yellow and red rings. The mounting ring works by setting the ring over the bolts and twisting it counter clockwise. The bolts are then tightened down to secure the mounting ring. The mounting ring is adhered to the iris assembly before the mounting the finished assembly to the mirror cell. The mounting ring also provides us with the location for mounting the nitrogen purge indicated by the blue circle. The channel will be drilled through the side of the mounting ring to fit the orifice, which will purge nitrogen onto the surface of the mirror.

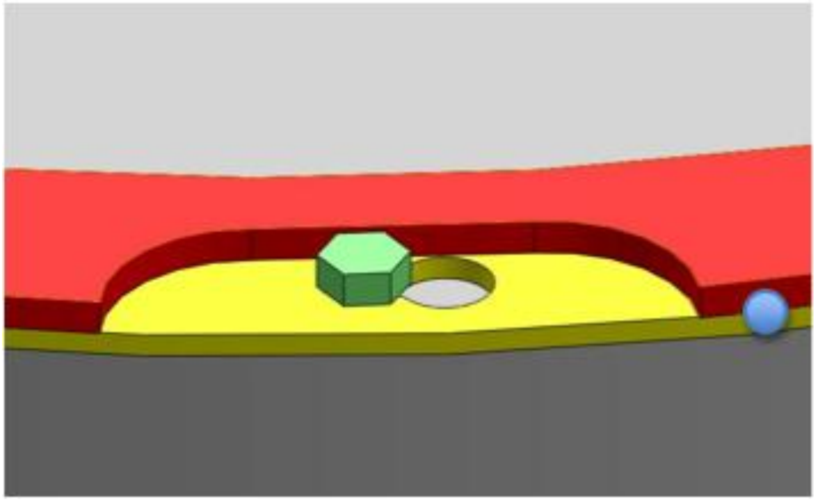


Figure 4- Hole and slot mounting

In order to allow for the free movement of the mirror cell the orifice for the nitrogen will be located at the point indicated by the blue arrow. The location was chosen since it is close to the point at which the mirror rotates so the tube supplying nitrogen to the mirror cell will not have to extend it self.

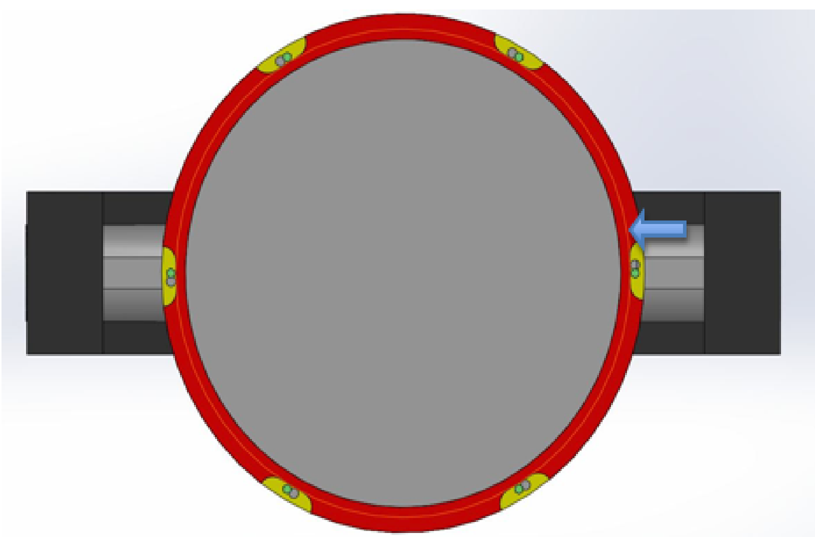


Figure 5- Mounting ring on mirror cell & nitrogen purge location

Scaled Prototype

In order to test and refine the production design, a scale prototype will be built. The prototype will be approximately 1/3 scale and will provide valuable design insight without the cost of building the full size design. The team will seek insight into two primary areas of the project: the manufacturing processes and the mounting scheme of the iris.

The manufacturing process, discussed in detail below, must be completely defined and tested prior to construction of the full scale model. The minimal cost and repeatability of a scaled design allows for several different methods of production methods to be tested with little to no impact on the project budget of $500. The base ring, top ring, and mounting ring can be constructed out of scrap Plexiglas available to the team from local hardware stores at a fraction of the cost of purchasing new sheets. In addition, the Plexiglas can be the much more common and inexpensive 1/8 inch thick material as opposed to the ¼ inch required for the full size design. The iris leaves will be constructed of a thinner sheet of non-UV stabilized Delrin, further reducing the materials cost of the prototype.

The project sponsor has made an 8 inch prototype mirror cell available to the team for testing purposes. This will allow a mounting scheme to be tested and implemented in its entirety for the scale prototype. The mirror cell does not have tapped holes around its perimeter like the large siderostat, and as a result they will be added in the same configuration. The diameter will be altered to use a #4-40 thread pattern as the stainless steel mounting hardware is readily available.

Manufacturing Process

The scaled prototype will be produced at the machine shop in building 98C on NAU's campus. The process of manufacturing begins with developing G-codes through 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. The team has successfully developed G-codes for the Iris blades, the top plate, and the base plate for the scaled prototype. The team has found that there are minor bugs within the code as the incorrect diameters are not being machined as desired. The diameter of the top plate and the base plate are not aligning correctly. It seems that the diameter of either the top plate or base plate is off by about a 1/16 inch. Also the Iris blades are being cut incorrectly as well. We found that the problem may lie in the cutter compensation code where the machine should be cutting on the outside and not the inside of the line. The code will be re-modified so that we get the correct dimensions machined.

Once the scaled prototype is complete and proven to work, the process for manufacturing the full scale prototype begins. The process is similar to the scaled prototype in which we develop a G-code and transfer it over to the Mach 3 program and prove simulations. Since the outer diameter of the full scale model will be 28 ¾ inches, the machining process will have to be conducted in parts as the range of the Supermax is less than 16 inches. The team must find a reliable way to generate separate codes to completely machine the rings of the prototype. To ensure this reference points must be created in order to machine the correct dimensions of the rings. Also a proper set up must be established to ensure that the large material will not move while machining.

Motor

Opening and closing the iris requires that the outer ring be rotated approximately 10 degrees. The drive mechanism consists of a 12 Volt DC electric motor supplied by Jim Clark, a friction wheel which is going to be made of rubber and two limit switches. The Motor is going to be powered by an uninterruptible power supply. The friction wheel is going to be powered directly by the electric motor which already has a reduction gear box to provide high torque. To make sure the motor stops when the iris is open or close there is going to be two limit switches which is going to prevent any damage that can be caused by the motor applying the force when the iris is completely open or close. If the friction wheel does not have enough friction to open the iris, it is going to be replaced by a gear with teeth, and the top plate of the iris mechanism is going to have the matching teeth to ensure a flawless operation.

Material Selection

The leaves will be made out of Polyoxymethylene, commonly referred to as Delrin. This is a high quality thermoplastic with a very low coefficient of friction and it is non-hydroscopic. A non-hydroscopic material will not absorb moisture that could evaporate and condense on the mirror's surface, the wide temperature range of the plastic is suitable for the temperatures experienced in the region, and the low friction will allow for smooth operation of the iris with minimal power from the drive mechanism. Polyoxymethylene is available in a black homopolymer that is resistant to ultra-violent degradation.

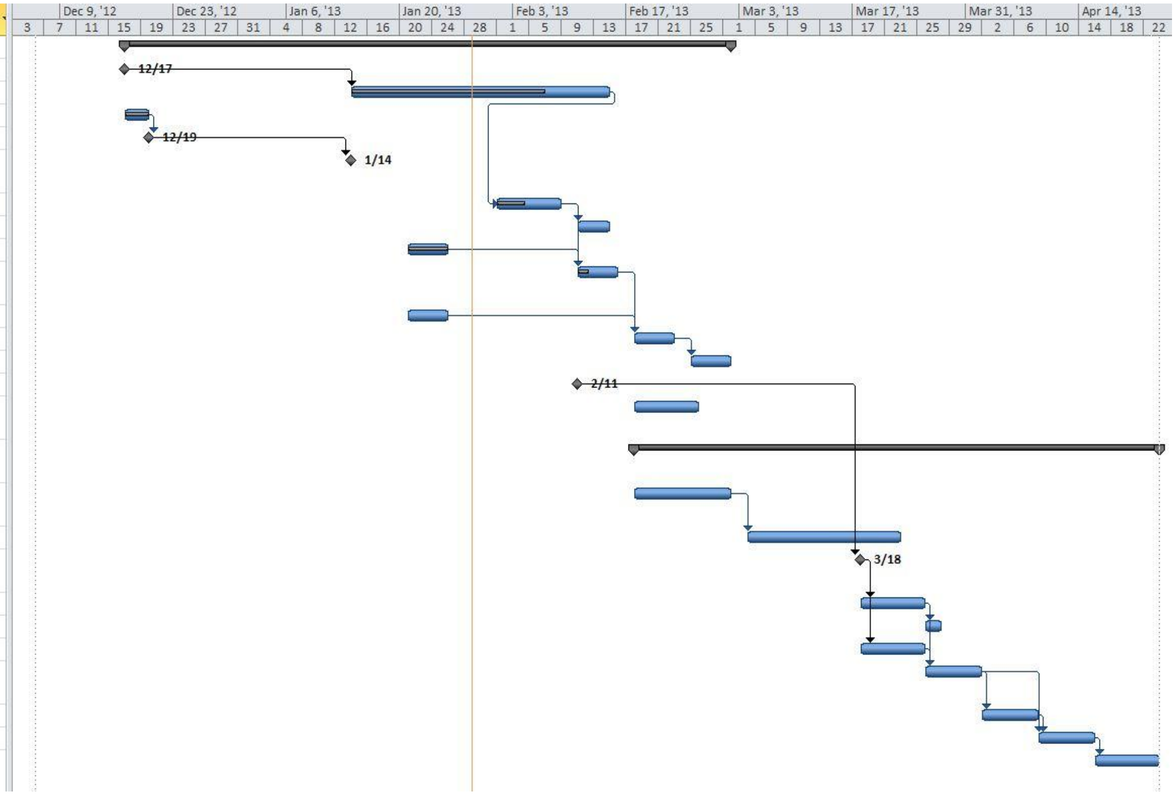
The cover's rings were originally going to be made of a caste or plated aluminum to ensure a similar thermal conductivity as the mirror cell. The mirror cell is made of caste aluminum and there was concern that a cover made of a polymer would add stress when the cell naturally expands and contracts due to a change in temperature. For ease of installation a cover that slide and locked onto the cover was developed. Not only did this mounting scheme provide for easy installation but the rings mounting points now have slots allowing room for the mirror to expand and contract. This circumnavigated the need for a similar coefficient of thermal expansion such that the mirror's rings could now be made of a wider variety of available material. The team's sponsor provided the team with Lexan and Plexiglas.

Conclusion

In the weeks following this update, the team will produce a scale model in order to work out any unforeseen manufacturing difficulties. This prototype will be the first proof of concept for the team. Once the scale model operates correctly, any design modifications will be applied to the full scale prototype. A working, installable unit will be constructed by the end of April, 2013.

Gantt Chart

Task Name	Duration	Start	Finish	Predecessors
Working With Prototype	**55 days**	**Mon 12/17/12**	**Fri 3/1/13**	
Finalize Model	0 days	Mon 12/17/12	Mon 12/17/12	
G-Code	24 days	Mon 1/14/13	Thu 2/14/13	2
Find the Best Supplier	3 days	Mon 12/17/12	Wed 12/19/12	
Order Materials	0 days	Wed 12/19/12	Wed 12/19/12	4
Have Materials at the latest for	0 days	Mon 1/14/13	Mon 1/14/13	5
Cut Blades	6 days	Fri 2/1/13	Fri 2/8/13	3FS-10 days
Blade Testing	4 days	Mon 2/11/13	Thu 2/14/13	7
Cut Plexiglass	5 days	Mon 1/21/13	Fri 1/25/13	
Assembly and Trouble Shoot	5 days	Mon 2/11/13	Fri 2/15/13	9,7
Create Gasket	5 days	Mon 1/21/13	Fri 1/25/13	
Full Assembly	5 days	Mon 2/18/13	Fri 2/22/13	10,11
Trouble Shooting	5 days	Mon 2/25/13	Fri 3/1/13	12
Order Materials	0 days	Mon 2/11/13	Mon 2/11/13	
Testing of the Whole System	6 days	Mon 2/18/13	Mon 2/25/13	
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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