Automated Mirror Cover for Telescope Application

By
Rogelio Blanco, Miles Dehlin, Leland Doyle, Salazar Grey,
Katherine Hewey, and Paul Owen
Team 8

Final Report

Document

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design – Spring 2013

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

Table of Contents

Table of Contents 2

Problem Statement 3

- Introduction 3
- Background Research 3
- Project Goal and Scope of Project 5
- Objectives 5
- Constraints 5

The Iris Design 6

- Issues with the First Iris Prototype 8
- Improved Prototype 8

Final Iris Design 9

Fabrication Process 10

Deliverables 11

Conclusion 12

References 13

Problem Statement

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

Introduction

The Naval Precision Optical Interferometer (NPOI) located at the top of Anderson Mesa in Flagstaff, Arizona, is a United States Naval Research Laboratory (NRL) facility. This facility uses expensive aluminum coated mirrors to reflect starlight down vacuum tubes, where the starlight is then captured by sensors. To negate the need for a significantly larger mirror NPOI uses an array of small mirrors to capture star light. The light waves are then translated to create a composite image of a star; by doing this the facility creates a high resolution image.

Background Research

The mirror's 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. When not in use the mirrors must be covered and currently this requires the manual removal and placement of a Lexan cover for each mirror, as seen in Figure 1. This requires NPOI employees to crawl into each siderostat housing, remove the mirror cover, and crawl out either late at night or before dawn with little to no light. This process can be very dangerous particularly in winter and is a major safety concern with the addition of two new taller siderostat housings, as seen in Figure 2.

Figure 1- Manual mirror cover removal demonstrated by the project sponsor, James Clark.

Figure 2-Employees of NPOI must climb into the dome housings in order to manually remove the mirror cover.

Although the aluminum mirrors are re-coated once every three years the mirrors are cleaned three to four times in between to lengthen the time in between coatings. Aside from cleaning the mirrors, to prevent damage little to no unnecessary contact with mirror is made. A protective dome closes to protect the siderostat and is climate controlled to protect the mirror from harsh weather and debris. While the dome is closed, moisture can condense on the mirrors surface forming frost, significantly reducing the useable life of the mirror. In order to counteract this process, the 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 the essential mirror covers has been found while maintaining the functionality of existing equipment. The replacement cover has a low profile and added a minimum amount of mass to the system. The new system is autonomous but can be operated manually during power loss situations or for maintenance purposes.

Objectives

The new cover can be operated remotely, which will keep observers out of potential danger and protect the equipment from accidental impacts. The mirror must be kept in a nitrogen environment in order to displace moisture laden air. Currently in order to do this, an orifice, four thousands of an inch in diameter must allow 10 psi flow of nitrogen to be injected into the mirror cell, purging atmospheric air. 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 primary objective of the facility is to view stars therefore the new cover must not block any light from the mirror's surface. The full range of motion of the siderostat including a vertical tilt from -10 to 60 degrees and a horizontal pan of -60 to 60 degrees must be maintained. The cover is capable of opening and closing in the dome when it is closed, to allow maintenance to be performed at any time. The critical clearances that are accommodated include 10 inches between the bottom of the mirror cell and the base as well as 4 inches between the top of the mirror cell and the closed dome.

The cover can be closed and opened manually in the event of a power failure. This is important due to the high cost of running the facility each night. If the automated cover fails the facility can manually open the cover quickly in order to minimize the down time. It is also important that the cover be can closed manually should the automated system fail, ensuring that the mirror is still protected.

The siderostats are precision instruments that use small movements to track celestial objects while the Earth is rotating. Anything that is mounted on the equipment 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 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 thermal expansion of the mirror cell. In order to account for this a polymer which will induce negligible stress on the cell due to thermal expansion can be used. Another option is to use aluminum which will have nearly identical coefficients of thermal expansion of the mirror cell.

Readily available lubricants cannot be used since they evaporate and deposit a film on the mirror affecting the resolution of the images. The only grease that is allowed near the mirror is a lubricant comprised of high molecular weight oil with suspended Teflon micro particles. This option is out of the project budget because this lubricant cost approximately $600 per ounce therefore any cover cannot use a lubricant.

If a polymer is used, it must be able to withstand small to moderate amounts of ultraviolet radiation without ceasing to function. The cover will be exposed to moisture and if it is constructed of a non-hydrophobic material it may swell and could cease to function properly therefore the material must be hydrophobic.

The Iris Design

The low clearances around the mirror cell require that the automated cover have a small footprint and be a self-contained unit. The use of a solid moving cover was investigated and dismissed because of the large space required to clear the cover during movement. The team began designing covers which operated with multiple pieces to cover the mirror. The final conceptual design that met all of the criteria and was feasible to build with the given budget was the Iris Diaphragm. This design incorporates multiple "blades" which are actuated by a rotating ring. The rotation of the ring moves the blades in an arc until they are concentric with the retaining rings. This is referred to as the open position. When the blades are actuated in the opposite direction, they will meet in the center of the exposed mirror. This is referred to as the closed position and will be the position in which the Iris is protecting the mirror surface.

The Iris offers several other advantages to other designs. The small footprint of the cover will reduce observation interruptions due to high wind conditions. The blades are comprised of a solid material which will be resistant to environmental hazards and degradation.

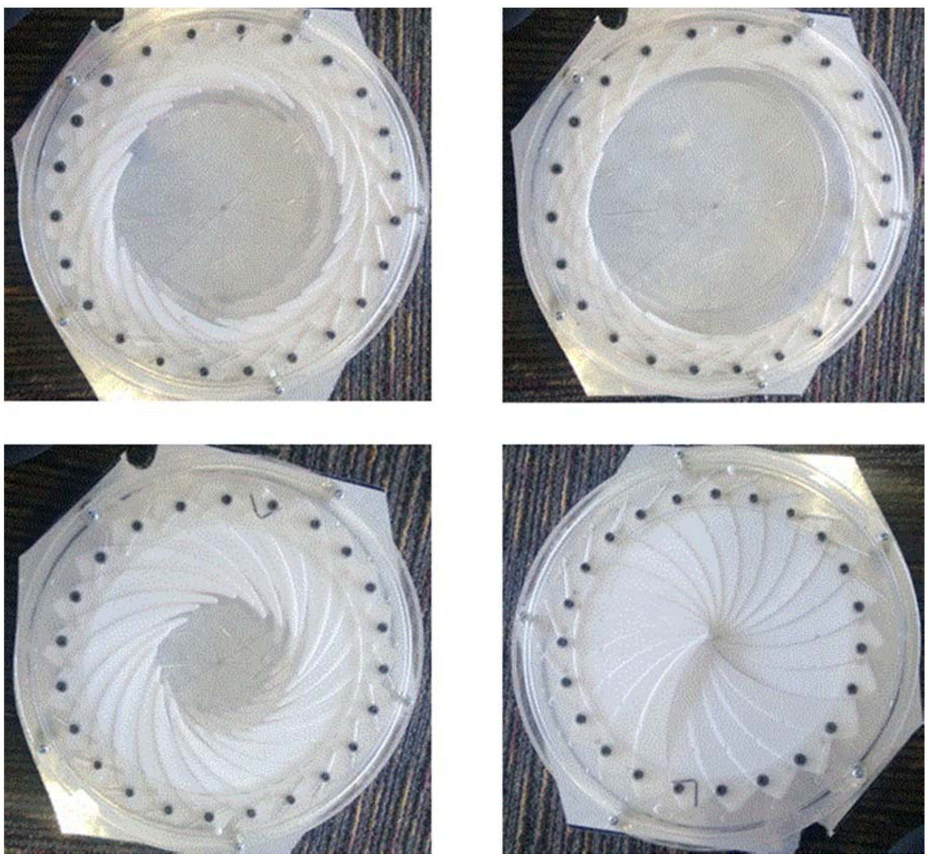

Figure 3 – The Iris Mechanism, first prototype

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 consists 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 closes the iris. A video of this process is available online at the capstone project website.

Issues with the First Iris Prototype

Once the bottom plate, top plate, and Iris blades were manufactured, the first iris prototype was assembled. The three components of the Iris prototype were held together by the pins composed of a simply a nut and screw. 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.

Improved Prototype

After some research, the second prototype was designed to mimic commercial irises currently in use at steal dowel manufacturing facilities. The second design utilizes a long curved blade design that greatly reduced the friction between the blades and the rings. The second iteration also utilized ball bearings to reduce friction between the rings. This design was used as a proof of concept that was fast to manufacture.

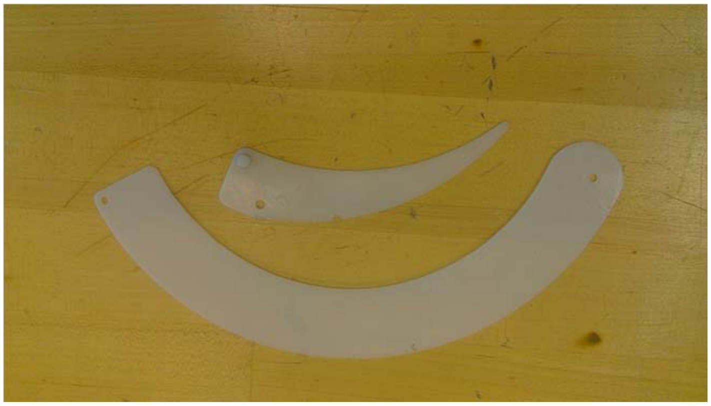

Figure 4 – The initial Iris blade compared to the second iteration.

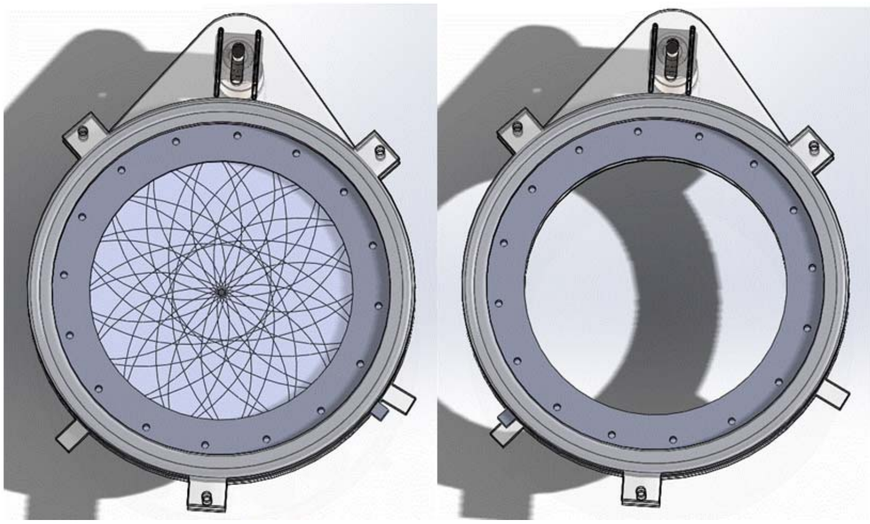

Figure 5 – The final iris design shown in both open and closed position.

Final Iris Design

Our final design includes multiple features and details developed during our iterative prototyping process. With each prototype that was built, potential improvements were identified and additional functionality features were documented. Meeting all constraints was the principle measure of success for our final design. However, many other factors and considerations for daily operation and smooth functionality were integrated into our model. Creating a fully constrained actuation ring was critical to this designs success. Integrating a top bearing-track along with a lower bearing-track allowed motion to be predetermined and tolerances to be tightened. Fully assembled single unit construction is a built feature of this design, allowing easy installation into its working application. Combined with an improved blade design, our deliverable addresses every shortfall of our previous prototypes while still meeting or exceeding minimum constraint requirements.

Fabrication 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 and Kevin Montoya.

The process of manufacturing started with developing a G-code through the WLPM1000. The code produced was then transferred over to the Mach 3 program that the shops Supermax CNC machine operated on. The transfer over from one program to another caused many issues as some code did not properly translate over from WLPM1000. The Code was then visually checked by doing a dry run on the CNC machine in order to identify any unwanted cutting paths. Once the G-code was modified, the components were machined out of the proper material using the Supermax. This was iterated for the different prototypes up to the final design. The final design itself required code for four separate parts including; the base ring, actuation ring, retaining rings, and the iris blades.

The next step was to secure the pivot pins to the iris blades. The pins themselves were standard 3/16th inch pop rivets that had their head sanded flat to increase glue contact area. To finish the assembly brackets and spacers where fabricated to attach the finished iris to the scale mirror cell provided by our client. To demonstrate the automated capability of the final design the motor was wired to a power source and limit switches.

Figure 5 –Iris Rings Being Machined

Deliverables

A fully automated 8 inch scaled prototype has been provided to the sponsor for a long term testing before he produces a full scale model. The prototype uses a servo provided by the sponsor to close and open the iris, the same model of servo is going to be use in the bigger prototypes. The servo is controlled by a three way and kill switches to ensure the blades would not bind against each other. The prototype rings include a three point mounding system such that the scaled model can be mounted upon a small siderostat where the sponsor is going to do a long term testing before producing a full scale model.

The full scale and prototype drawings are going to be summited to the sponsor so he can fabricate as many mirrors are required by facility. The drawings contain the appropriate tolerances and materials certifications to ensure the right fabrication and for a flawless function of the mirrors covers.

Conclusion

The team was able to develop and fabricate a small scale prototype for the NPOI facility which is in need of an automatic mirror cover that operates without interfering with the current equipment while maintaining a nitrogen purge. All constrains were resolved but it took multiple iterations of the main design to come up with a full working prototype. The first prototype did not worked because it had excessive friction between the rotating rings and the blades, unacceptable gaps because of the staking of the rings. After identifying the problems from the first prototypes, a final prototype was fully manufactured that meet all of the projects requirements.

References

Navy Precision Optical Interferometer. "Automated Mirror Cover for Telescope Application." Navy Precision Optical Interferometer. PowerPoint. 5 Oct. 2012. <https://bblearn.nau.edu/>.

Navy Precision Optical Interferometer. Navy Precision Optical Interferometer, n.d. Web. 5 Oct. 2012. <http://www.lowell.edu/npoi/index.php>.

"Teflon, Teflon Coatings, Coating Services, Powder Coatings, Nonstick, Non-stick, Ptfe, Etfe, Kephos, Plasma Coatings, Rotomolding, Mold Release, Heat Resistant Coatings, Chemical Resistance, Anilox Ro." *Teflon, Teflon Coatings, Coating Services, Powder Coatings, Nonstick, Non-stick, Ptfe, Etfe, Kephos, Plasma Coatings, Rotomolding, Mold Release, Heat Resistant Coatings, Chemical Resistance, Anilox Ro*. N.p., n.d. Web. 01 Mar. 2013.