Automated Mirror Cover for Telescope Application

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Concept Generation and Selection

Document

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Introduction

The NPOI (Navy Precision Optical Interferometer) located at the top of Anderson Mesa in Flagstaff, Arizona, is a United States Naval Observatory (USNO). 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; in fact the NPOI gets such high resolution pictures, its main priority is discovering double stars or stars that rotate around each other.

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 covered with a Lexan glass cylinder with a nitrogen purge. The Lexan glass 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 telescope, remove the mirror cap, and crawl out at 4 a.m. with no lights, this process can be very dangerous particularly in winter and is a major safety concern with the addition of 2 new taller telescopes.

Problem Statement

Goal Statement

A solution for removing and replacing essential mirror dust covers must be found while maintaining functionality of existing equipment, adding a minimum amount of mass to the system while incorporating autonomous/ 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.

Test Environment

Testing new designs at NPOI might jeopardize the equipment which is expensive and precise therefore a scale model of the housing will be constructed to provide a more appropriate test environment. The model will need to replicate the -10° to 60° range of motion of the siderostat to assure that our design does not hinder the movement of the mirror. The scale model will also assure that the mirror cover does not interfere with light collection while in the open position. The design is also required to operate between a temperature range of -20°F to 100°F. Critical components will be tested in an environment cooled by dry ice in order to replicate operational requirements. Large components will be tested during sufficiently cold nights. A comprehensive thermal analysis will supplement findings if negative 20 degrees is not reached. The design will be tested with the nitrogen purge operating to assure the design does not restrict the flow of the inert gas protecting the siderostat. NPOI will provide the compressed nitrogen for this test.

Recapitulation of Problem Statement

An automatic mirror cover is needed at NPOI and must operate without interfering with current equipment while maintaining a nitrogen purge.

Concept Generation

Brainstorming

While brainstorming identifying the main objective of the cover was the primary focus, the mirror cover must keep all debris and moisture off of the mirror. The nitrogen purge is currently required to keep moister off of the mirror but whether or not this method is the only way to remove moister is questionable because theoretically if the mirror cover can make a tight enough seal unto the mirror the nitrogen might not be necessary. Ultimately, the design concepts continue using the nitrogen purge but the idea that the nitrogen purge requirement might be completely mitigated if the seal was tight enough was considered.

In addition, while brainstorming it was established that if any idea for a mirror cover blocked starlight in any way the idea was disregarded. Any concepts that risked equipment or would fail if in low temperatures were also disregarded. These criteria are absolute because if a mirror cover failed any of these requirements the mirror cover would be completely useless.

Concept Generation - Continued

Generation

During the concept generation meetings, concept formation was not the only subject that was discussed. Having already brainstormed many ideas, our main task for generating viable concepts was determining the core design solution for each idea. Clear explanation and understanding of our brainstormed ideas was a critical first step for further discussion. Once a basic understanding of the root concept was established, our team was able to more accurately voice concerns about any of the designs being discussed. Cataloguing each design concepts potential concerns helped bring to light what aspects a good design should incorporate. This information will be critical to future evaluation of mirror cover designs. Another benefit of clearly identifying all of our conceptual ideas at a foundational level was that we realized some of our original brainstormed ideas were actually iterations of the same root concept. Lumping together similar root concept designs reduced wasted time during our weighting and selection process as well. The final design concepts that our group evaluated were all unique, functional legitimate design possibilities that have potential to solve our problem statement.

Designs

Worm Gear Design

This design incorporates a worm and gear assembly as the means by which the cover is raised from the closed to open position. As depicted in the following idealized cad drawing the entire drive mechanism would be mounted to the top side of the siderostat. Ideally, the whole assembly would be self-supporting and would require a simple bolt on installation. The drive system would operate with the use of a standard electric motor that would drive a shaft. The shaft would have a worm gear on its end which would drive a gear. The gear would rotate with its shaft, on the shaft there would also be a fixed armature. The mirror cover would be attached to the armature which would complete the assembly. Other considerations are that due to the high torque characteristics of a worm a gear set up, a set of sensors would be used to determine when fully open and close positions were acquired. As a fail-safe, the key securing the gear to its shaft would be designed to fail before any harm would befall the siderostat and mirror. Lastly, the worm and gear assembly would need to enclosed in a gear housing which if designed correctly would replace the current mount securing the gear and armature assembly.

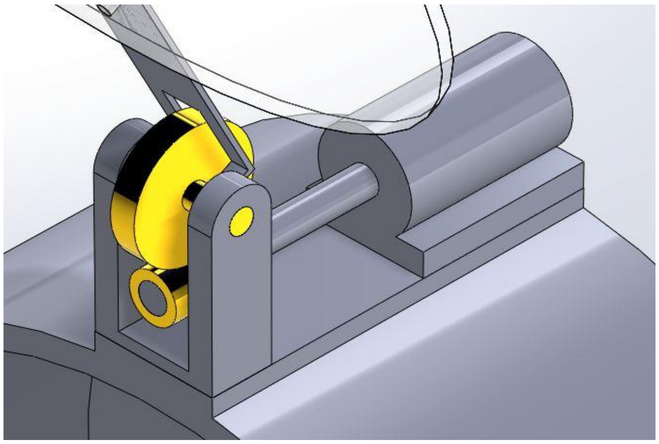


Figure 1-idealized worm and gear drive mechanism.

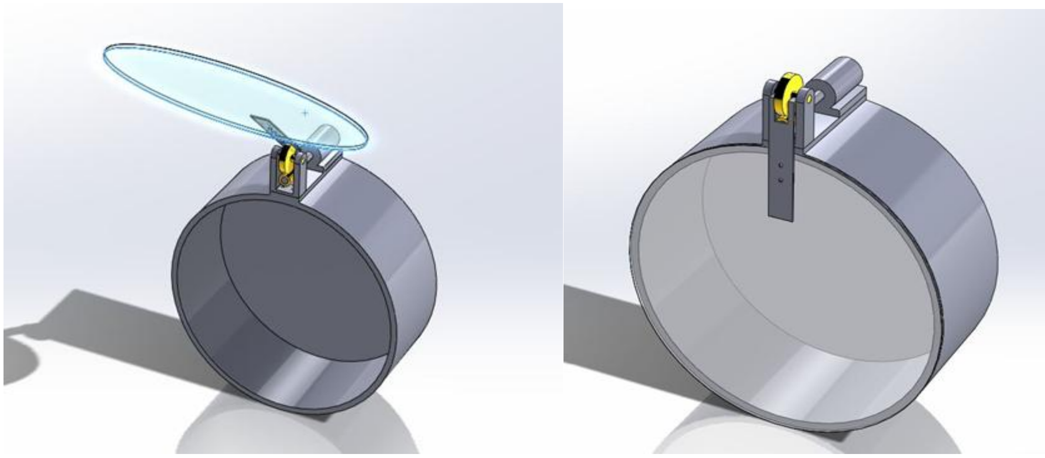
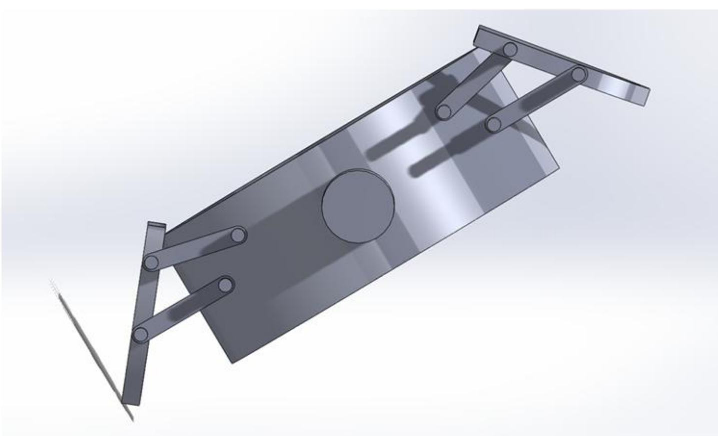


Figure 2- idealized representation of worm and gear design in it open and it closed positions.

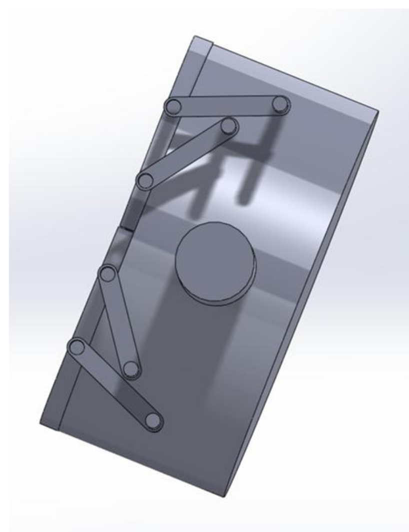
Four Link Design

This design was chosen for further analysis because it is a possibility for an easy solution to protect the mirror of the siderostat. The four link system can be designed with a geometry that does not interfere with the movement of the siderostat and the light of the stars. By choosing the right materials and making the right analysis it is possible to make it light weight, so the increase in mass of the whole system is minimal and the end results does not have a negative effect in the siderostat motors. The nitrogen purge can easily be installed on the mechanism and when the system is in the closed position should provide a good seal using rubber between the siderostat and the mechanism. The mechanism would need basic maintenance such as lubricating the pivot points and checking that the bearings of the links are in good condition. The cost should not be high because of the simple design. The siderostat would need to be adapted to accept the links of the mechanism.

The four bar design presented previously in the **figure XX** is not the final design. Movement of the links would need to be engaged by either linear actuators or a motor. Actuators or motors could both be viable options for this design.



Cover Open



Cover Closed

Concept Selection

Weighted Criteria Tree (Figure 1)

In order to assess the viability of each concept, the objectives and constraints for the project were evaluated thoroughly. Each criterion was broken down into specific descriptors that are applied to each concept.

The six main categories are:

- Geometry/Dimensions
- Mechanism
- Nitrogen
- Maintenance
- Operating Conditions
- Cost

The geometry of the mirror cover is the most important category for this project. The cover must fit into each siderostat housing without obstructing the dome or movement of the siderostat. Also, the cover must not block any star light from being collected by the mirror. The third consideration for the geometry is balance. The Siderostat is a precision instrument that is balanced in order to be able to make minute angle adjustments. Our cover must not disrupt the overall balance of the mirror. In order to accomplish this, there are adjustable tungsten counterweights that will be moved to counteract the mass of the cover.

The mechanism is broken down into three categories. The most important consideration is the impact that the mechanism will have on the siderostat during opening and closing. In order to maintain the alignment of the siderostat, little to no shock or abrupt force should be applied to the housing during opening or closing. Simplicity and Reliability are also considered for the mechanism.

The nitrogen system is a vital component for the life span of each mirror. During storage, moisture contained in the atmospheric air condenses on the mirror causing corrosion. To counteract this, a steady stream of nitrogen is injected into the mirror cover, displacing atmospheric air and vapor. The current system does not employ a shut off valve for the nitrogen when the cover is open. In order to conserve nitrogen and reduce operating costs for the facility, we will investigate the possibility of having an automated valve to turn off the nitrogen flow while the cover is open.

The maintenance was a small portion of the overall design considerations. The life and ease of installation are directly related. If a solution allows for increased life but difficult installation, the benefit of the long life will outweigh the inconvenience of an extended installation time. The opposite is also true, a concept with a relatively short life could still be considered if replacement is simple.

The cost of each concept was also considered. Due to the expense of the components the cover will be protecting, a higher cost is permitted granted the design achieves higher levels of protection. This is also a government funded project, allowing further lenience over the budget.

Decision Matrix (Figure 2)

Using the weighted values in the criteria tree, a decision matrix is created for each of the concepts. A rating from one to nine is given based on competency for each category. The values are then multiplied by their respective weights and summed to give a weighted score to each concept. In the matrix shown, the top four concepts are compared.

Conclusion

After evaluation different design concepts some of the top ranked designs will be prototyped and tested.

Weighting Factors

Figure 1 is a tree diagram of the weighting factors

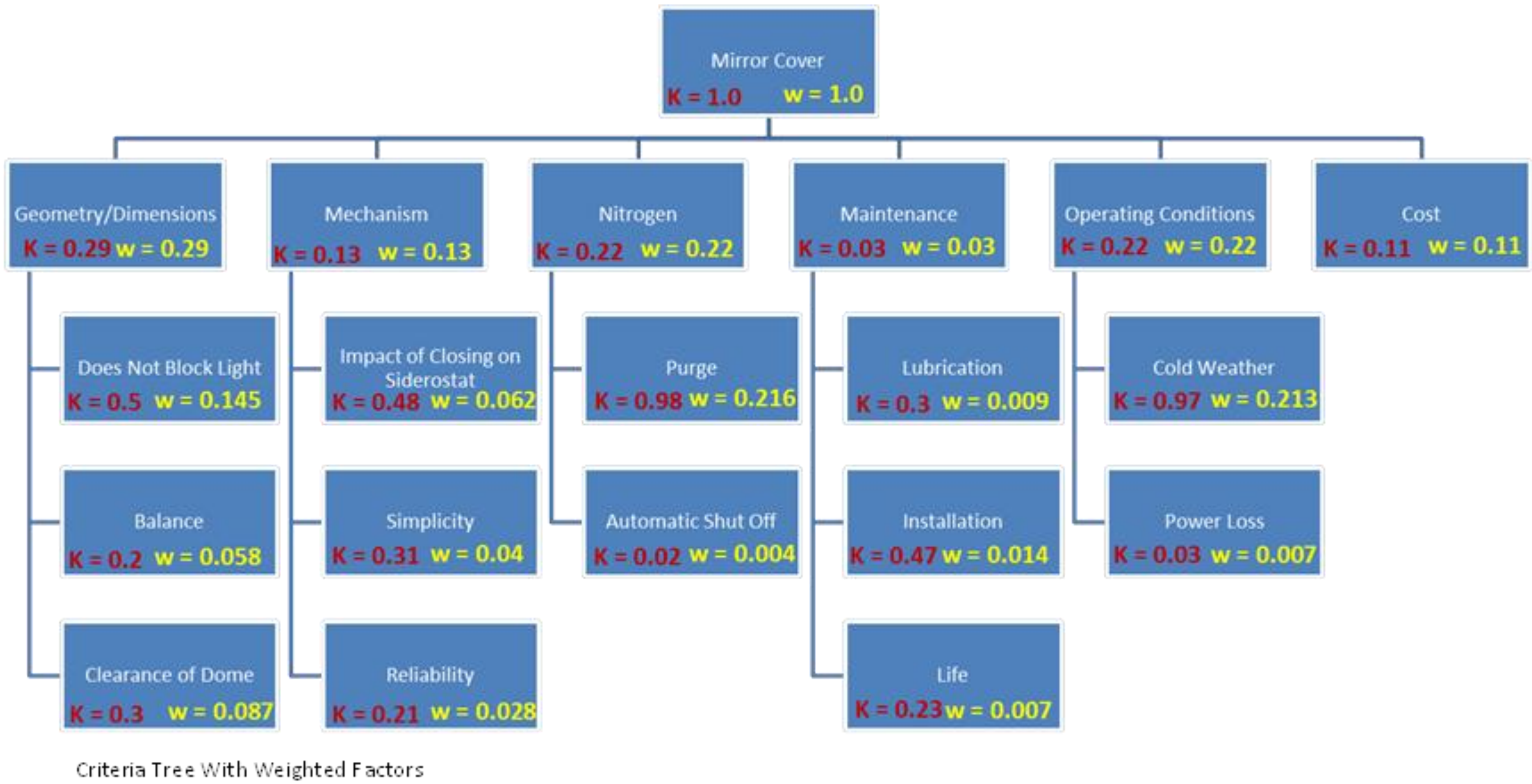


Figure 1- Weighting Factors

Figure 2 is the design matrix

Criteria	Design Options			
	Pneumatic Roller	Two Piece Four Link	Inflatable	Worm Gear
Doesn't Block Light	6	9	9	8
Balance	8	8	7	6
Clearance	5	4	9	2
Impact	6	8	9	8
Simplicity	4	8	4	8
Reliability	5	5	6	7
Purge	3	7	3	7
Auto Shut Off	7	7	9	7
Lubrication	3	3	7	2
Installation	2	5	7	8
Life	8	6	2	7
Cold Weather	5	5	3	5
Power Loss	6	6	9	4
Cost	5	8	5	8
Total	73	89	89	87
Weighted Total	4.885	6.739	5.491	6.386

Top Four Concepts Shown in Weighted Matrix

Figure 2-Design Matrix

Project Plan Gantt Chart

The project Gantt chart had to be modified in the last revision. The concept selection has increased in length of time because the team wants to do more analysis of the previous concepts selected before choosing the final one. Material selection was postponed until finite analysis has been done, because the team wants to know the maximum stresses of the system before choosing the material. The creation of a siderostat model has moved because the team has to take the exact measurements of the siderostat and the team has not been able to go and visit NPOI again to take the exact measurements.

Task Name	Duration	Start	Finish	Predecessors	Resource Names
Project Assesment and Identification	**8 days?**	**Thu 9/27/12**	**Tue 10/9/12**		
Design and Testing	**24 days**	**Sat 10/13/12**	**Thu 11/15/1**		
Concept Generation	1 day	Sat 10/13/12	Mon 10/15/1	1	
Concept Selection	3 days	Fri 10/19/12	Tue 10/23/12	10	
Presentation: Concept Generation	0 days	Tue 10/23/12	Tue 10/23/12		
Report: Concept Generation	0 days	Fri 10/26/12	Fri 10/26/12		
Visit NPOI/Jim Clark - Accurate measurements for Siderostat Model	1 day	Tue 10/30/12	Tue 10/30/12	1FS+3 days	
Test Proposed Concepts	14 days	Mon 10/29/12	Thu 11/15/12	14FS-2 days	
Prototype Analysis	**23 days**	**Tue 10/30/1**	**Fri 11/30/12**		
Solid Works model	3 days	Wed 10/31/1	Fri 11/2/12	14	
Finite element analysis	2 days	Fri 11/2/12	Mon 11/5/12	17FS-1 day,11	
Materials Selection	3 days	Tue 10/30/1	Wed 11/7/12	18	
Presentation: Engineering Analysis	0 days	Tue 11/6/12	Tue 11/6/12		
Report: Engineering Analysis	0 days	Fri 11/9/12	Fri 11/9/12		
Redesign of Analyzed	5 days	Tue 11/6/12	Mon 11/12/12	18	
Concept Finalization	8 days	Tue 11/13/1	Thu 11/22/12	22	
Presentation: Final Design	0 days	Tue 11/27/12	Tue 11/27/12		
Report: Final Design	0 days	Fri 11/30/12	Fri 11/30/12