April 30, 2010

Ms. Mary Lara
Walker Observatory
DeMiguel Elementary School

Dear Ms. Lara:

In response to your request of last September, the Northern Arizona Mechanical Engineering Capstone team has submitted and implemented a design solution for all three of the mechanical systems at Walker Observatory at DeMiguel Elementary School. The attached design report includes the specifications, design decisions, analyses and the operations and maintenance manual of the improved systems.

As we worked and struggled over the dome's unique systems, we learned a lot about patience and persistence. We greatly appreciated the opportunity to collaborate with you on Walker Observatory.

Please take the time to review the attached design report and submit the final commentary and review to Bryan Cooperrider at bryan.cooperrider@nau.edu. Feel free to contact me with any questions at (928) 301-0264.

Sincerely,

Aaron Echols

Team Lead

NORTHERN ARIZONA UNIVERSITY
Department of Mechanical Engineering

ME 486C

Final Report
Walker Observatory

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(date of the submission)
April 30th, 2010

Refurbishing the Mechanical Systems at Walker Observatory

Abstract

Kenneth Walker, an educator and amateur astronomer of Holbrook, Arizona, designed and created the telescope and wooden dome of Walker Observatory. After sudden illness, Mr. Walker donated his observatory to DeMiguel Elementary School in Flagstaff, Arizona where it is located today.

Since the observatory's reconstruction, the rotation of the dome and shutter system has been problematic. The dome requires multiple people to rotate and the viewing shutter is difficult to control. Since the majority of users are small children, the goal of this project is to have a safe, easy to operate observatory.

The capstone team replaced the existing shutter door and rope pulleys with an aluminum frame and winch system. This lightweight shutter allows for easier, more controlled operation.

The clamps controlling the telescope's drive mounts were adjusted to provide an adequate force around the clamp's body. A stabilizing block was added to the clutch clamp and a spacer to the top clamp.

To improve dome rotation, maintenance and wheel alignment was performed on the existing system. Combined, these changes improved the safety and usability of the observatory.

Table of Contents

Introduction

The Walker Observatory Telescope was transplanted to DeMiguel Elementary School from Holbrook Arizona in 2001. Since the observatory's reconstruction, the rotation of the dome and shutter system had been problematic. The dome required multiple people to rotate and the viewing shutter was difficult to control. The telescope's clamping system was not applying adequate force and was easily moved if bumped by a visitor. Since the majority of users are small children, the goal of this project was to have a safe, easy to operate observatory.

To come to the final decisions of the newly installed systems, the following research was implemented:

- Resources from educational papers, official observatory websites, you tube videos and "do-it" yourself construction tips were implemented to creating the final design.
- Manufacturer and vendor websites were consulted to ensure that proposed designs were feasible. Some of the vendors include: Caster Concepts, Service Caster Concepts, Dutton-Lainson, McMaster Carr and Northern + Tool.
- The local NAU observatory was visited and astronomers were interviewed in hopes to determine what the optimum performance of an observatory might be.
- Ralph Nye from Lowell Observatory visited the dome to assess the existing systems and provide feedback on appropriate modifications.
- Mingus Electric provided loading capabilities of the dome's electrical systems.
- Dr. Constantin Ciocanel was consulted for loading and deformation responses in wooden structures and caster axles.

Refer to the reference section for a complete reference list.

Requirements

The mechanical systems must be able to function properly while being safe enough to operate around small children. The total costs for this project must have been kept to a minimum.

Clamping System

The telescope has two clamps that lock the telescope in a desired position. When the telescope was bumped by a star party participant, the telescope would move “out of line” from the star it was tracking. Both clamps had to be modified to prevent the telescope from moving when touched or bumped.

Dome Rotation

The dome required at least four people to rotate. The goal of this phase was to modify the original system to allow only one person to rotate the dome.

Shutter System

The original shutter system was over 40 years old. Weather and use had deteriorated the wooden structure to the point where it was difficult to open easily. The shutter used two separate ropes and pulleys that made the door a challenge to control with one person. The goal of this phase was to alter the original system into a safe controlled configuration.

Specifications

Clamping System

The telescope uses an equatorial mount with two clamps that secure the telescope from rotating. The lower clutch clamp secures the telescopes right ascension and the upper clamp secures the declination adjustment. Figure 1 below shows the locations of both clamps. Each clamp must be capable of supporting 2,000lbs in both directions. The clutch clamp bolt diameter is 3/8” with course threads (16 threads per inch). The body of the clamp is 22” in diameter.
The upper clamp has two locations that can tighten to engage the clamp. Both bolts are 10” long with 3/8” diameter steel rods and fine threads (24 threads per inch).

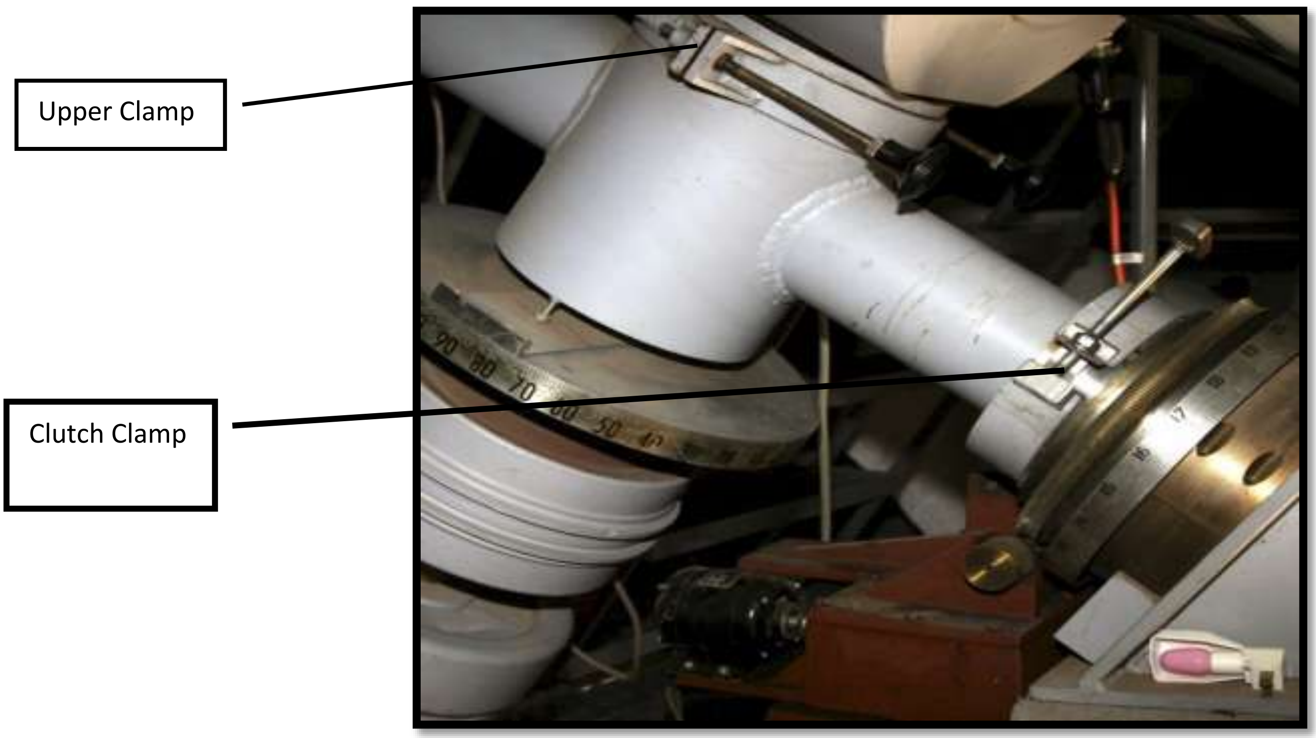

Figure 1- Locations of Top and Clutch Clamp

Dome Rotation

The roof structure of the observatory is constructed of Douglas fir, has an 18 foot diameter and weighs approximately 2,000 pounds. This weight includes the main dome structure, the shutter, shutter components and the sheet metal covering. The dome is supported by 15 support wheels and 15 centering wheels.

The deformation in the wood due to warp and age ranges from 1/8 – 3/8 inch from the centerline of the wood base. All future systems must accommodate for this range of displacement.

The allowable distance between the concrete foundation and the top of the wood structure is approximately 4 inches. Any future modifications to the rotation system must maintain this distance to a tolerance of ± ¼ inch. This will ensure that water, dirt and snow cannot find its way inside the dome.

The current concrete foundation is 9 inches thick and the bottom of the wooden structure is 5 3/8 inches wide. This limits the width of future designs to 5 ¼ inches.
Since the observatory has no insulation from the ambient temperature, all parts and components must be able to withstand a temperature difference of -15˚F to 120°F without compromising the strength or response of a material.

The dome must be capable of rotating a complete 360˚ in both clockwise and counterclockwise directions.

Shutter System

The shutter door weighs approximately 100 pounds, is 54” in width, 169” long and has a radius of 115”. There are four vertical support wheels and four side alignment wheels that help move and center the shutter door as it moves up and over the dome. The existing tracks which support the shutter are 1 1/2” in width.

Analyses

To help aid in the decision of the final design, the following analyses were performed:

Dome Rotation

To assess if the existing wheels were properly rated and installed for the dome's weight, the dome was analyzed as a 56 foot long Douglas fir beam supporting a uniform distributed load by rollers. Figure 2 below shows the cross section used for the beam and the schematic used for the analysis.

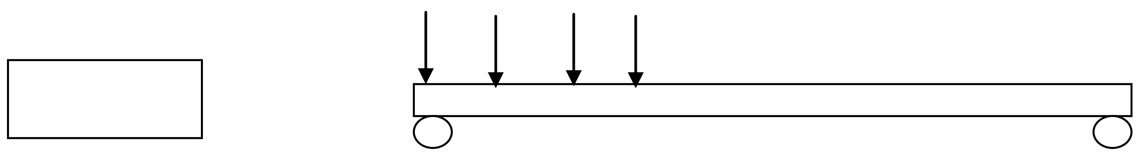

Figure 2 - Distributed Loading Schematic

Since the dome's weight was approximated at 2,000 pounds, a factor of safety of three was used resulting in a 6,000 pound force or a 9.36 pound per inch distributed load across the beam. Using Shigley's Mechanical Engineering Design, Case 7 – Simple Supports, Uniform Load, the following equations were used to find the loading on each wheel:

$$R1 = R2 = \frac{wl}{2} \quad (1)$$

R1=*R2*= the load applied to an individual wheel, lbs
w =the distributed load across the beam, lb/in
l = the distance between the vertical support wheels, in

Equation (2) below shows the maximum deflection of the beam based upon the original wheel spacing of 3.5 feet:

$$y_{max} = \frac{wx}{24EI}(2lx^2 - 3x - l^3) \quad (2)$$

ymax = maximum deflection in the beam, in
E= the modulus of elasticity, psi
I = moment of Inertia, in^4
x= any location along the beam (a point of interest), in

In conclusion, it was found that the current wheels were rated for the appropriate 200 pound load requirement. The wheels were also spaced appropriately apart to create a deformation less than a one hundredth of an inch.

To determine how much force would need to be applied to rotate the dome a full revolution in 4 minutes, the Principle of Impulse and Momentum was applied to the vertical support wheels. In this analysis, it was assumed that one or three vertical support wheels would rotate the dome via a motor. See Figure 3 below for a force diagram of the system. Varying friction factors were used to accommodate for the rolling resistance between the wheel rubber and the dome's bottom surface. The results concluded that the dome required 40-120 pounds to rotate the dome or one 3.5 HP motor.

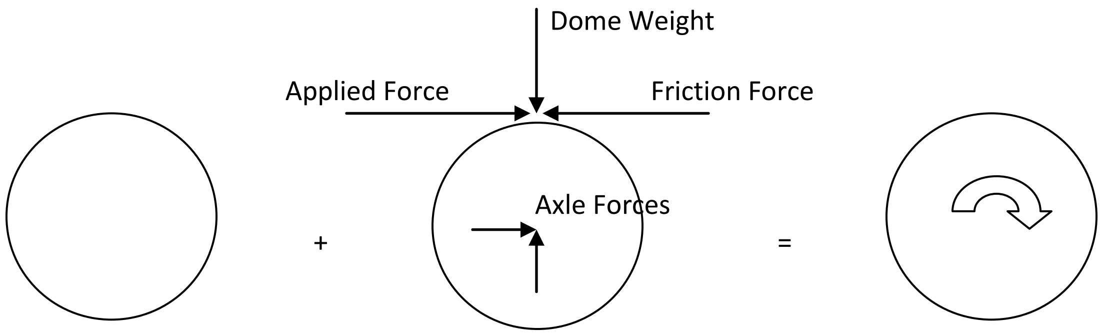

Figure 3 – Force Diagrams

Shutter System

To ensure that the future wire rope could handle the loading and fatigue of the shutter's up and down movement, Shigley's Mechanical Engineering Design was consulted. To choose the appropriate cable, the team first checked the local Home Depot to determine what was available in stock. Next, the existing pulley's were sized and determined to hold a maximum of ¼" rope.

Shigley's recommends a factory of safety of five for lifting applications with wire rope. With the door applying a 200 pound force on the future cabling it was determined from equation (3) below that a wire rope capable of holding at least 1,000 pounds was acceptable.

$$F_u = nF_t \tag{3}$$

Fu=ultimate wire load, lbs
n=factor of safety
Ft= largest working tension load, lbs

The wire rope that could meet the loading and size criteria at the Home Depot was a 3/16" diameter 6 x 19 cable with a 1050 pound ultimate load capacity. To ensure that the wires could bend around the existing pulley without reducing the relative service life, Table 17-27 in Shigley's Mechanical Engineering Design was used. This table tells the designer the appropriate pulley diameter with respect to the wire rope's diameter. Table 1 below gives the desired formulas and results for a 6 x 19, 3/16" diameter wire rope.

Wire Rope 6 x 19	Minimum Pulley Diameter, in	Better Pulley Diameter, in
Equation:	**30d***	**45d***
Results:	**5.63**	**8.44**
		*d is the wire rope diameter

Table 1- Pulley sizes for 3 x 19 wire rope with a 3/16" diameter

Design Decisions

Clamping System:

The upper clamp was limited to modifying the handle arrangement or changing the handle type. This restriction was due to the fact that the body of the clamp also acts as a support for the fine adjustment components indicated by the arrow in Figure 4.

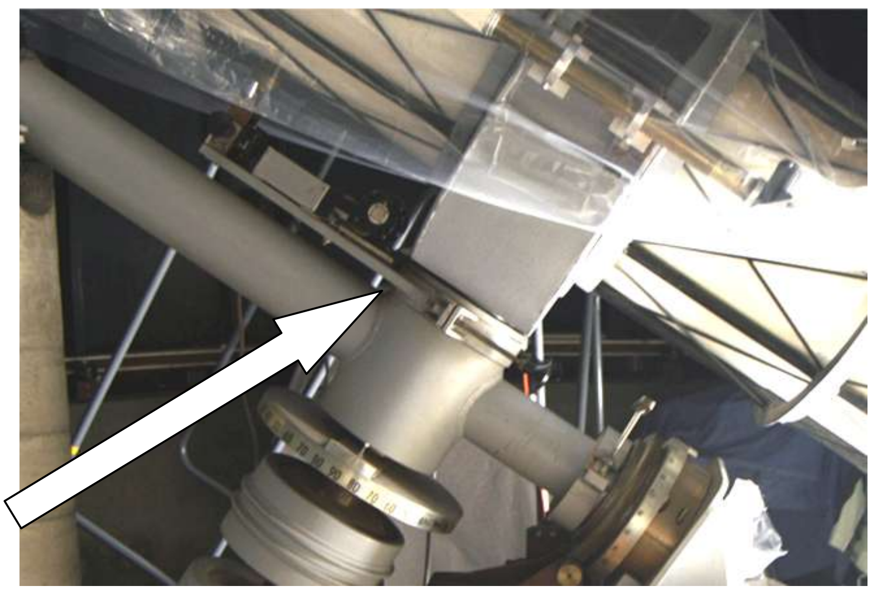

Figure 4 - Upper Clamp with attachment

Cam levers would have been a user friendly, inexpensive option that would apply adequate force to the clamp body. A picture of a cam lever is shown in Appendix A. Due to the restrictions of the existing system, there were no cam levers "off the shelf" that had a long enough fine threaded stud to engage the clamp. This option was not selected.

The best solution for the lower clamp was to fabricate a larger metal block which could apply clamping force without bending. This block can be seen in Figure 5. The upper clamp was fixed by inserting shims into one side of the clamp, which reduces the uneven loading experienced before. This can be seen in Figure 6. Both solutions reduced cost and used parts easily available for repair and replacement.

Figure 5 – Lower Clamp Solution

Figure 6 – Upper Clamp Solution

Shutter System

Concept One:

This design concept changes the movement of the shutter from sliding up and down the dome to a left to right movement. Straight iron track will extend tangentially off the dome structure approximately five feet in two locations. The iron track locations will support the bottom and top ends of the shutter via steel trolleys. Figure 7 shows a similar use of this system on the NAU Observatory.

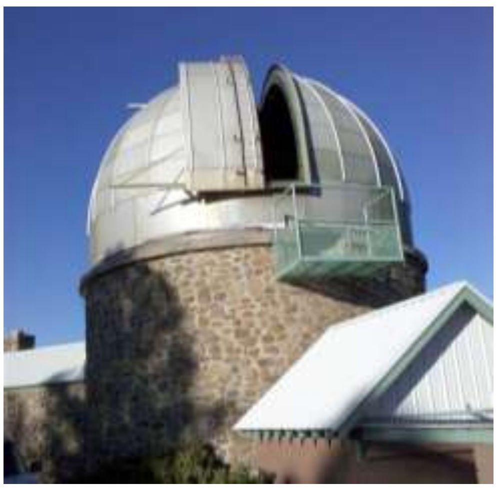

Figure 7 – NAU Observatory

Although this design concept would have prevented free fall and constant monitoring of the shutter door, the disadvantages proved this design impractical. Modifications to the existing structure would have been extensive and costly. There was a very high risk of damaging the structural integrity of the dome by extending angle iron off of its supports. This door motion would also cause an uneven distribution of weight, making dome rotation more difficult.

Concept Two:

This concept changes the movement of the shutter from sliding up and down the dome to opening outward like a draw bridge. The bottom end of the shutter would be attached to the dome by means of high strength door hinges. The shutter and cabling would be controlled by a hand winch secured to the inside bottom frame of the wooden structure. Figure 8 gives a visual representation of this design.

Figure 8 – Draw Bridge Shutter Design

Like concept one, the shutter door completely open would cause an offset of weight on the dome structure. Due to its age and deterioration, it was determined that there was a high possibility that the shutter door opening in this position could cause critical damage to the wooden structure. There was also a large risk of kids jumping on the door and star party participants being hit while the dome was rotating. Overall, the risks of this design were far greater than its advantages.

Concept Three:

Concept three was the preferred and implemented design. In this design, a wire cable is anchored to a worm gear winch, which forms a continuous loop controlled by the worm gear. As one spool of the worm gear pulls the rope in, the other spool releases the wire rope.

The cable continues up and over three pulley blocks then loops around a 12” pulley anchored near the top opening of the door. The cable rides back down the pulley blocks and attaches to the inner spool of the worm gear winch. A schematic of the pulley and wire layout of this system can be found in Appendix A.

This system was proven advantageous for this project because not only were there limited modifications to the dome structure but the loadings remain the same as the existing system. The worm gear winch acts as a clutch controlling the lifting and dropping of the shutter. This gives the user the capability of stopping the shutter at any location. Parts are easy to replace and easy on the budget.

Dome Rotation

Concept one:

This design replaces the existing wheels with an angle iron track along the concrete foundation and v-grooved wheels installed on the wooden base of the dome structure. 20 V-grooved wheels will have a rigid, galvanized, steel frame, capable of holding 300-800lbs.

Advantages: angle iron will produce a level track resulting in constant contact between dome wheels and foundation.

Disadvantages: Added costs due to bending angle iron into exact curvature of the dome. This design does not compensate for future wood deformation due to warp.

Concept 2:

This design creates a raised track out of steel piping and attaches a set of 30 rollers to the wooden base of the structure. The rollers will hug the pipe track and keep the dome from shifting vertically or horizontally. Figure 9 gives the general concept of this design.

Figure 9 – Rolled Pipe Concept

Advantages: Can incorporate existing rollers and frames into design. The pipe track will create a constant contact between dome wheels and foundation.

Disadvantages: Added costs due to bending pipe into exact curvature of the dome. This design does not compensate for future wood deformation due to warp.

Concept 3:

Replace existing wheels with 20 spring loaded casters. Figure A.6 gives an example of a spring loaded caster.

Advantages: These wheels can compensate for the un-axial forces exhibited by the dome and warp deformation in the wood. Bearings are constructed for virtually no maintenance, can withstand extreme temperatures and come with galvanized coating.

Disadvantages: very costly.

Mechanical Advantage Concepts

First was a simple push bar that allowed a more ergonomic position when rotating the dome. With children around, we did not want to have a hanging steel bar be a safety hazard of be seen as a toy.

Figure 10 – Push Bar Prototype

The other idea tested was to have a wheel attached to a crank that rotated the dome. This issue with this system is it requires three sets of wheels, so for our goal of only one operator required to rotate the dome, a hand cranked system would not work. The wheels would have to be motorized and the budget and current electrical service to the observatory didn't allow for such a solution.

Figure 11 – Hand Crank Prototype

The operations and maintenance manual for all three systems can be found in Appendix B.

Conclusion

The capstone team managed to refurbish all three mechanical systems on time and under budget.

To improve dome rotation, the existing system was refurbished by cleaning and lubricating the wheel bearings. The vertical mount wheels were adjusted vertically to make sure all wheels were in contact with the dome.

The two rope system was replaced with a dual wire cable system with a worm gear winch. The cabling connects from the door to the winch in a continuous fashion. The original shutter's wooden frame was replaced with a new aluminum frame, making the door weather resistant, lightweight, and easier to operate.

The lower clutch clamp now uses two stabilizing blocks to provide enough force to secure the clamp body around the drive mount. Grease was applied to the original tightening bolt for ease of use.

The upper clamp had used two adjustment bolts, one on each side, to tighten the clamp. To balance the force applied on the clamp, one side was anchored with a spacer and the adjustment bolt removed. This allows the user to tighten the clamp using only one bolt to secure the telescope.

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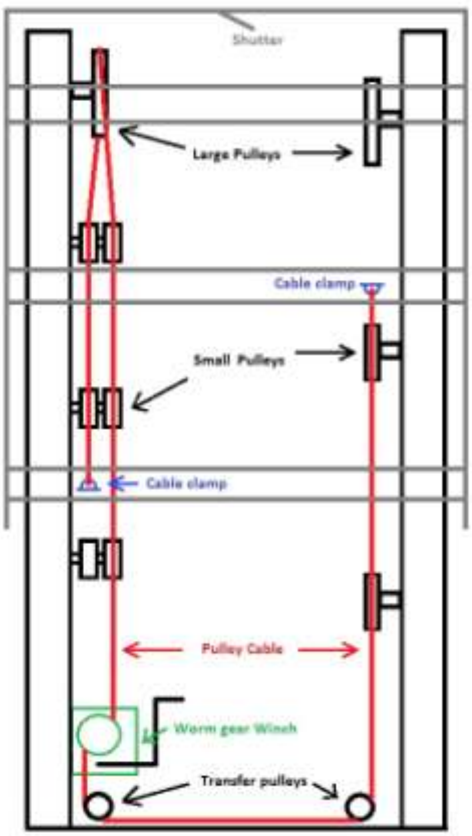
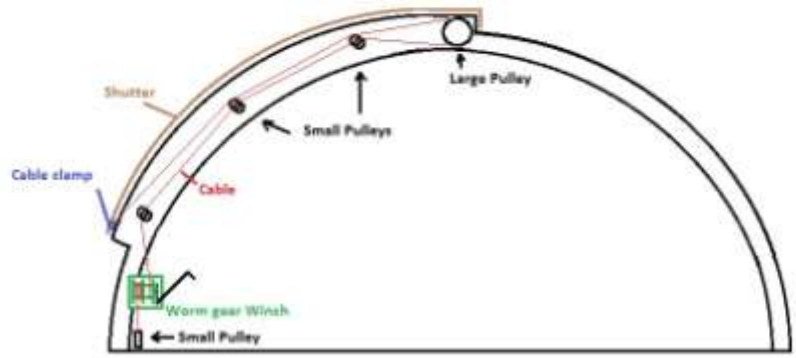
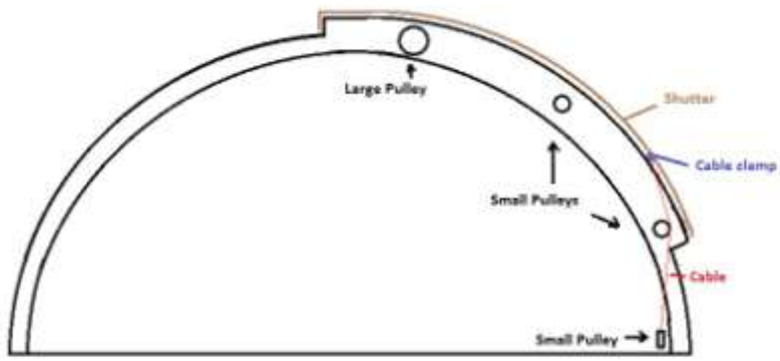
Appendix A – Drawings

Clamping Levers with Eccentrical Cam - Tapped and Stud Types





Right hand side of shutter door opening.



Looking from the outside into the shutter door.

Left hand side of shutter door opening.

Appendix B – Operations & Maintenance Manual