Filter Mounting and Mechanism Design for the Pan-STARRS PS1 Prototype Telescope System

Alan J. Ryan
Institute for Astronomy
Jeffrey Morgan
Institute for Astronomy
Walter Siegmund
Institute for Astronomy
Carole Hude
Institute for Astronomy
The Pan-STARRS Team

ABSTRACT

The Pan-STARRS PS1 telescope is a 1.8m Cassegrain telescope with a 7 square degree field of view and a 1.4 billion pixel CCD camera. The required clear aperture at the filters is 496mm in diameter, and therefore the filters needed are quite large. The Pan-STARRS filter complement consists of six octagonal shaped filters that have a distance between the flats of 514mm and a thickness of 10mm.

The automated mechanism that will move the filters needs to fit into a small area. A filter wheel would be prohibitively large, so the mechanism will consist of three layers with two athermally mounted filters that slide on each layer. Each layer will be identical to the other two to provide interchangeability and commonality in manufacturing. The layers will be stacked and held together with top and bottom cover plates to form a rigid structure. The shutter will be mounted to the bottom of the mechanism and they will be installed as one unit. A separate structure will be utilized to clamp the mechanism to the telescope cassegrain core registration points. This installation system will allow the mechanism to be isolated from other structural loads and be easily removed without affecting the camera.

1. INTRODUCTION

A sliding mechanism was chosen over the classical filter wheel and cassette type mechanism for a couple of reasons. In a filter wheel design, the size of the filters would create a large footprint that would be difficult to mount on a four-telescope system that is proposed for PS4. It would also create a large unbalance resulting in more counterweights and larger telescope bearings. The cassette type mechanism has a smaller footprint, but it is a more complicated mechanism and susceptible to numerous problems. This system also has an unbalance since the filters will be located in a cassette on one side. The layered design is similar to the cassette system since the filters will slide into the aperture, but there will be no cassette nor vertical movement of the filters. There is enough clearance lengthwise to have two filters on each layer so the overall thickness can be kept to a minimum. Three layers will be able to satisfy the six filter requirement. Each layer will be identical and will provide commonality in manufacturing and maintenance support.

The filters do not need to be precisely positioned in the aperture since they are far from the focus of the camera. Also, the flexure of the filters under their own weight does not cause any appreciable degradation to the Point Spread Function (PSF). The filters are very costly so protecting them from harm is a priority. They will be potted using an elastomer that will help reduce any stresses from thermal expansion and shock loads. Collisions between filters will be controlled through software and bumpers have been added to the filter frames as an extra safety measure. Motion control measures have been added to create a smooth and slow filter movement. Humidity will degrade the coatings on the filter so a nitrogen purge is incorporated with a slight positive pressure. Pneumatic cylinders were chosen over equipment with electrical motors because excessive internal heat would be detrimental to the optical quality and negate the gains from the future Atmospheric Dispersion Corrector (ADC).

It would be very useful to have the mechanism removable without affecting the camera. The reasons are two fold. Maintenance can be performed quickly since only one component needs to be removed and the mechanism will not have to carry the load of the camera. A separate structure called the Lower Cassegrain Core (LCC) will be used to mount the filter mechanism, shutter and camera. The design will minimize flexures from the weight of each component and will mount directly to the telescope rotator. Some of the controls and cables for the filter mechanism will also be mounted to this structure.

2. OPTICAL CONSTRAINTS ON FILTERS

The telescope Point Spread Function (PSF) is not extremely sensitive to the location of the filters. Fig. 1 shows the optical layout of PS1 with baffles. Filters are labeled F1, F2, and F3. The three layer design implies that there are essentially no despace or decenter requirements on the filters. The tilt requirements on the filters are only ± 50 arcminutes and only changes the PSF by less than 0.3 percent.

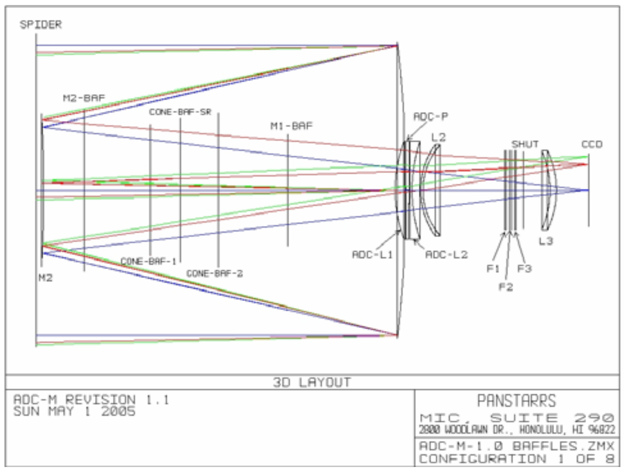

Fig. 1. PS1 optical layout with baffles

A 10 mm (0.39 inches) thick fused silica filter has less than 5 microns distortion under self-gravity when pointing towards zenith (Fig. 2) [1]. The red arrow indicates the direction of gravity. None of these distortions from gravity are sufficient to have any impact on the telescope PSF. The largest increases are only six percent. At some fields of view, the distortions actually improve the telescope PSF.

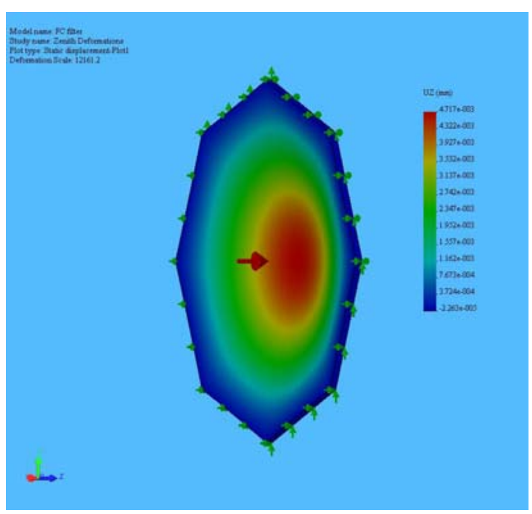
Fig. 2. FEA analysis of a 10 mm thick filter pointing at zenith [1]

The contrast of dust motes decrease rapidly as the distance from the focal plane increases. A theoretical dust mote of 1 mm in diameter at 20 mm from the focal plane has a shadow diameter of 8 mm (0.3 inches) and contrast of 8 percent (Fig. 3). The minimum distance that a dust mote can be from the focal plane is at the top surface of the dewar window which is 240 mm (9.4 inches). The closest filter is 448 mm (17.6 inches) from the focal plane and by scaling an f/4.4 beam for a 1 mm diameter sphere, the predicted mote shadow diameter is 202 mm (7.95 inches) and contrasts less than 0.01 percent. Therefore, dust motes on any optical surface will only decrease the general throughput by a very small amount and will not put structure in the flat fields and images.

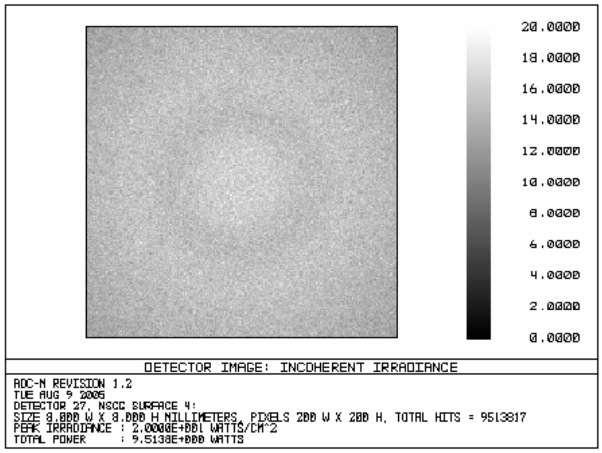

Fig. 3. Dust mote from a 1mm sphere at 20mm above the focal plane

3. FILTER POTTING

To create an athermally mounted filter, the fused silica filters are potted into aluminum filter frames using Dow Corning 3112 RTV silicone rubber. This is two part elastomer provides a firm and flexible mechanical joint that cures at room temperature. The proper procedure for potting requires the filter frame and filter surfaces to be clean, dry and oil free before the Dow Corning 1201 primer is applied. The primer increases adhesion in bonding surfaces made of metal, glass and ceramic. After the primer is cured, there is a window of an hour for the potting of the RTV joint before the primer needs to be reapplied.

The potting joint size has been adjusted to compensate for the Coefficient of Thermal Expansion (CTE) differences between the glass and the aluminum frames. The stress on the filter from the RTV joint was analyzed using Finite Element Analysis (FEA). Using a 34 degree Celsius change in temperature, the 5mm thick RTV joint applied a stress of 0.8 MPa (120 psi) on the filter in the clear aperture (Fig. 4)[2]. This is eight times less than the safe maximum stress on the glass, 6.9 MPa (1000 psi).

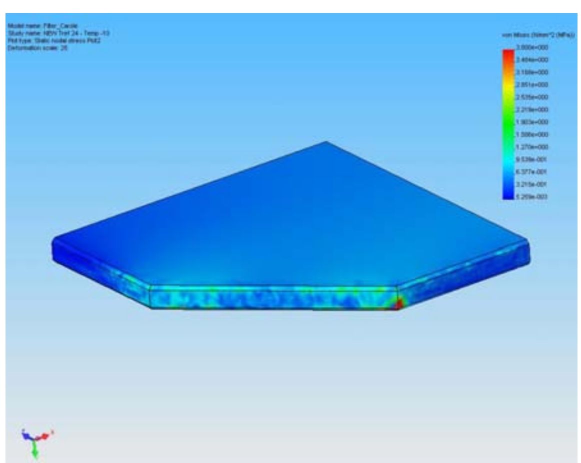

Fig. 4. Local peak stresses in filter glass [2]

The potting of the filter will require fixtures to keep the potting material in the correct area (Fig. 5). The entire outer perimeter of the filter will be lined on the upper and lower surfaces with a seal made of latex. Preliminary tests have shown that latex is the best material since the potting material does not adhere to it after curing. Silicone compounds have been found to be unfavorable because of sticking. It is undesirable to use a mold release because of the possibility of migration and contamination on the filter surface. The upper and lower seals will first be cast in a molding fixture and one half of each of these molds will be used as supports during the potting of the filter. A slight vacuum between the seal supports and the filter will ensure that a seal is maintained. The filter frame will be positioned upside down during the potting to utilize a flat reference surface. Alignment holes in the seal supports will correctly align the upper and lower seals to each other. A reference edge on the upper seal support will register both seals to the filter frame. By using jacking screws and temporary alignment blocks, the filter can be correctly positioned in the filter frame. The potting material will be injected from the upper seal location into the joint cavity. A mechanical lock between the filter frame and the potting material is achieved by machining in a groove on the inside surface of the filter frame. Additionally, the filter is mechanically locked to the potting material by potting the complete filter section including the bevel on the top and bottom surfaces.

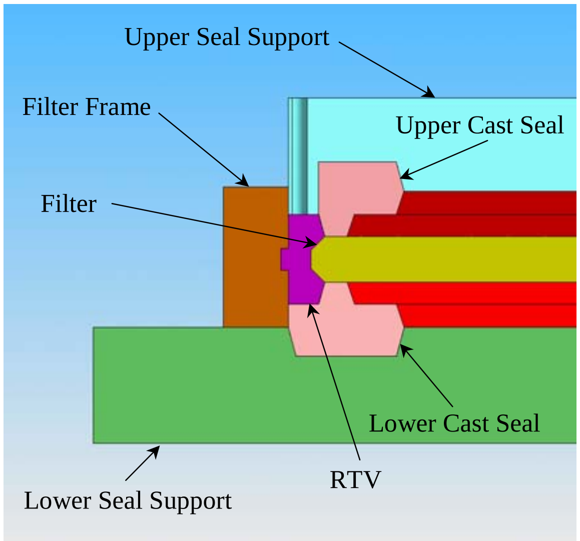

Fig. 5. Cross-section of potting fixture

4. FILTER MECHANISM DESIGN

All of the major components of the filter mechanism were made out of MIC-6 cast aluminum. These included the layer frames, top and bottom covers and the six filter frames. Each piece was rough cut using a water jet to reduce machining time. Fig. 6 shows the complete filter mechanism with the shutter attached to the bottom. The top cover plate is basically a cover plate, but also has the pads for the registration of the top feet on the LCC. The bottom plate is an adapter to mount the shutter that was fabricated by the University of Bonn in Germany. The filter mechanism and shutter will be removed from the telescope as one unit. All sections are fitted with an o-ring groove to make a sealed unit. Each section is also fitted with an alignment pin and mating half to aid in stacking. Around the perimeter of the layer frames, there are thirty-four standoffs that attach to the top and bottom cover plates. The layer frames are clamped together to form a rigid assembly. The total weight of the filter mechanism alone is 170 kg (375 lbs) and with the shutter attached it weighs 202 kg (445 lbs).

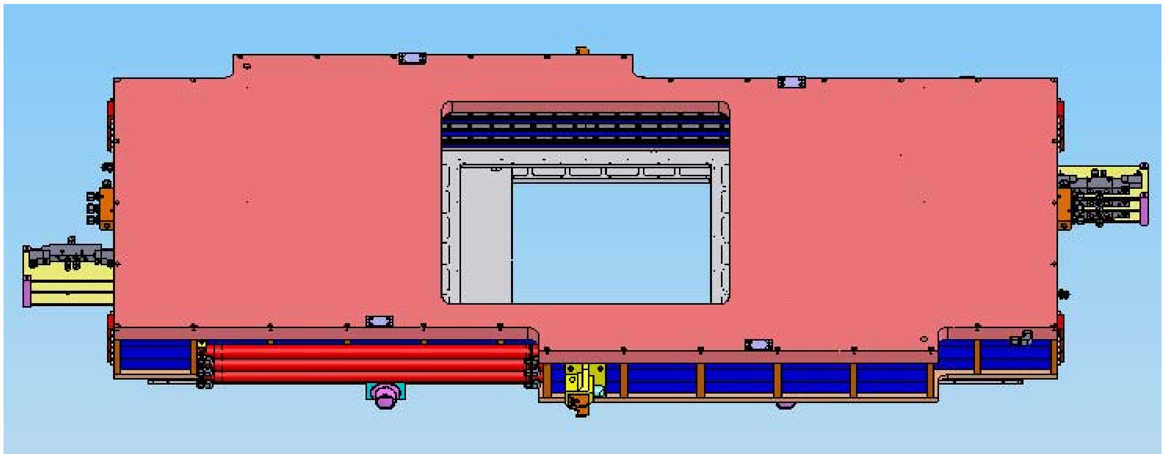

Fig. 6. Filter mechanism with shutter

The overall height of each layer, 31.8mm (1.25 inches), is driven by the cross-section size of the pneumatic cylinder. The overall diameter of the Bimba C-09 model cylinder is 28.4mm (1.12 inches) and has a power factor of 0.9. At 100 psig air pressure, this cylinder can produce 90 pounds of force in both extending and retracting motions. The nose mounting of the cylinder makes assembly easy and an alignment coupler on the rod reduces the required mounting precision (Fig. 7). A bracket at the other end of the cylinder supports the cylinder in case of incidental contact. The cylinder is located in a separate compartment to reduce the possibility of contamination of the filters. A feature to protect the cylinder also helps protect the filters. An adjustable internal cushion starts to slow the rod speed at 19 mm (0.75 inches) from both ends. Lubrication of the cylinder is not needed for the entire life of the cylinder given the low number of cycles required for filter changing.

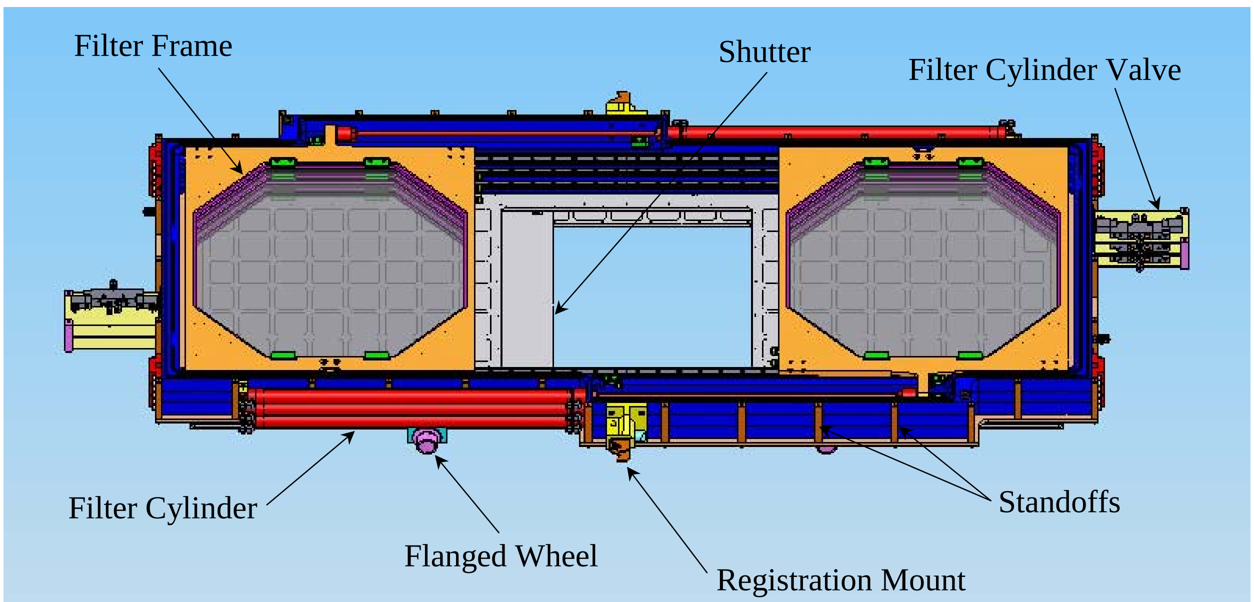

Fig. 7. Filter Mechanism with top cover plate removed

The linear motion of the filter frames is accomplished using profile guide rails and recirculating ball carriages (Fig. 8). The THK model SHW12HRM guide rails have an overall height of 12 mm (0.47 inches) and produce a high-precision and smooth linear motion. The tolerance over the entire travel of the filter, 565 mm (22.25 inches) is less than 15 microns (0.0006 inches). Three carriages will be used in a triangle pattern to support the filter frame. Two of the carriages are mounted on one rail and will hold the filter frame in all degrees of freedom except three, linear motion for the filter frame, rotation around that direction (rail) and rotation perpendicular to the surface of the filter (yaw). The third carriage is located on the opposite end of the filter frame on a second rail and will control rotation around the rail. It will be loosely mounted with belleville washers so that it will float along the rail. A rubber bumper is attached to the filter frame and will absorb any shock that may occur from a collision with the other filter frame on that layer. The filter frame also has eight clips attached to the top and bottom surfaces as a safety measure to keep the filter from falling in the unlikely event that the RTV bond fails. The total weight of the moving filter assembly is 10 kg (22 lbs) and will be over four times less than the capacity of the cylinder at 100 psig air pressure.

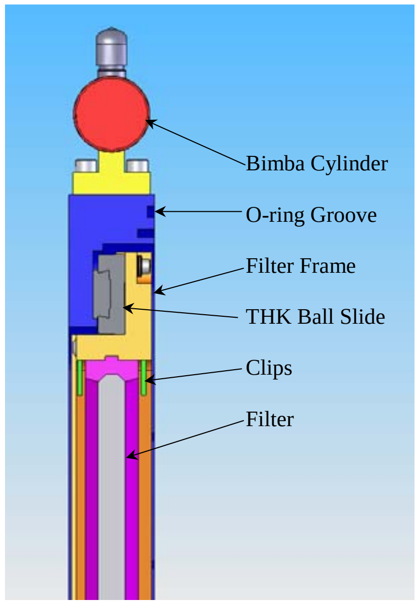

Fig. 8. Cross-section of filter layer

The flexure of the carriage on the rail will dominate the repeatability of the system. The worst case scenario is when the telescope is pointing at the horizon. The third carriage is designed to float and the other two carriages must carry that cantilevered load (Fig.9). Each carriage has a deflection of 7E-4 radians with this load. The load of a 20 mm thick filter and frame, 15 kg (33 lbs) was analyzed with a distance of 476 mm (18.7 inches) between carriages. The movement of each carriage translated into a movement of 39 microns (0.002 inches) at the edge of the clear aperture near the third carriage. This value is well within the requirement of less than 500 microns (0.020 inches).

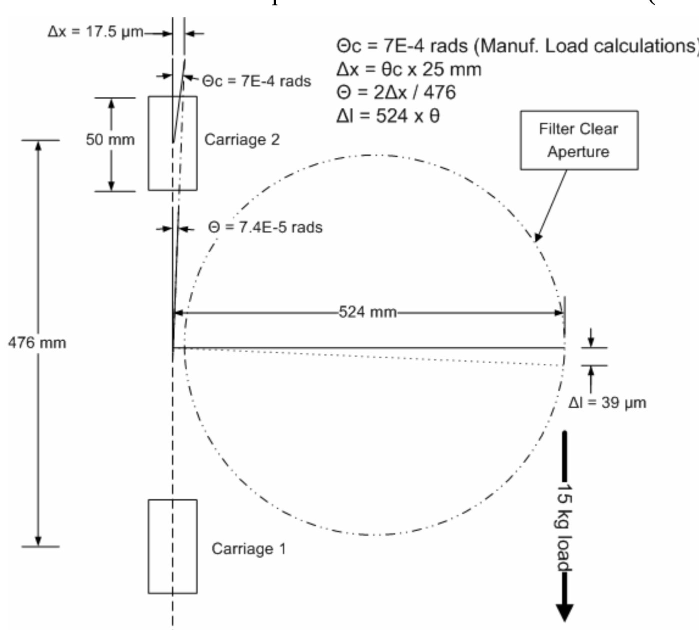

Fig. 9. Repeatability of a 20 mm thick filter and frame. Telescope is pointing at the horizon.

There are two limit switches for each filter and one is attached to each hard stop (Fig. 10). These hard stops are located at the retracted and extended positions of the cylinder. The hard stop and limit switch at the retracted position is to locate the filter when it is in the aperture. The extended position is for the home location. At each position, the filter will be held in place by the force of the cylinder. Air pressure will be in the cylinder at all times.

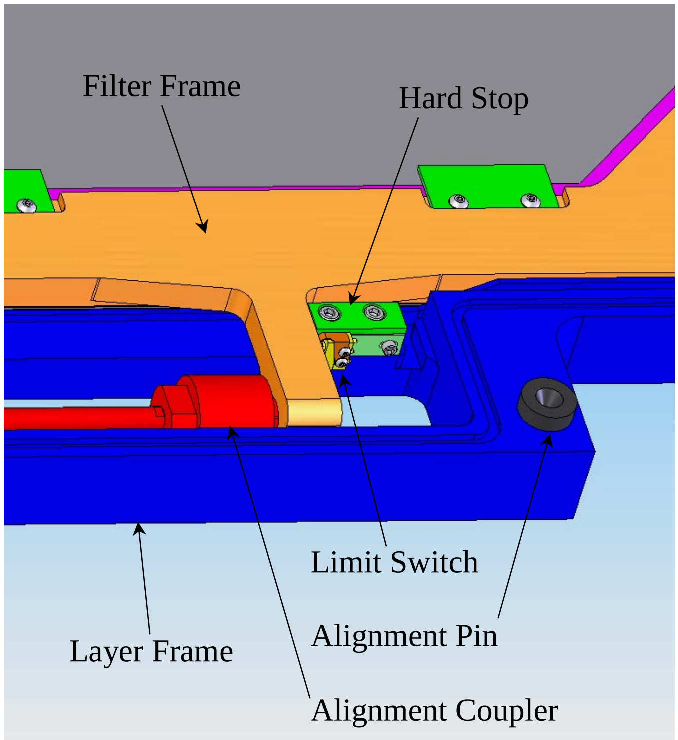

Fig. 10. Hard stop and limit switch

5. INSTALLATION

The most useful feature of the filter mechanism is its removability. The camera will not be affected when it is time to perform maintenance or to correct a problem on the filter mechanism or shutter. The balcony crane is capable of lifting the filter mechanism and shutter along with its lift support structure in and out of the dome. For installation, the filter mechanism is placed on a modified lift cart made by Econo Lift (Fig. 11). The lift cart had been fitted with vee-type wheels that allow it to run on the angle bars on the observatory floor. The lift cart can also be used to install and remove the Upper Cassegrain Core (corrector lens L1 and L2) and the LCC.

The flanged wheels under the filter mechanism allow it to roll into the LCC. The lift support structure has some compliance built into the design that allows it to move independently from the lift cart. This allows the rails from the cart to align with the rails on the installation lift. Just before the filter mechanism comes into contact with the registration columns on the LCC, two spring loaded pawls are automatically activated under the wheels. The pawls are located on the installation lift rails and are a safety measure that keeps the filter mechanism from rolling out of the LCC at any time. During removal, these pawls will have to be manually released. Over center clamps on the registration columns hold the filter mechanism in place.

The registration columns locate the filter mechanism back to the same position every time. On one column there is a vee shape feature and on the other there is a flat. A third locating position is at the top feet on the LCC that contacts the top cover plate when the installation lift is raised using pneumatic cylinders from Bimba. Flow restrictors are used to provide a slow and smooth movement over the 2 mm (0.08 inches) distance. Over center clamps are also used on the installation lift as a secondary attachment method in the event that air pressure is lost. With these three hardened features the filter mechanism is constrained in all directions.

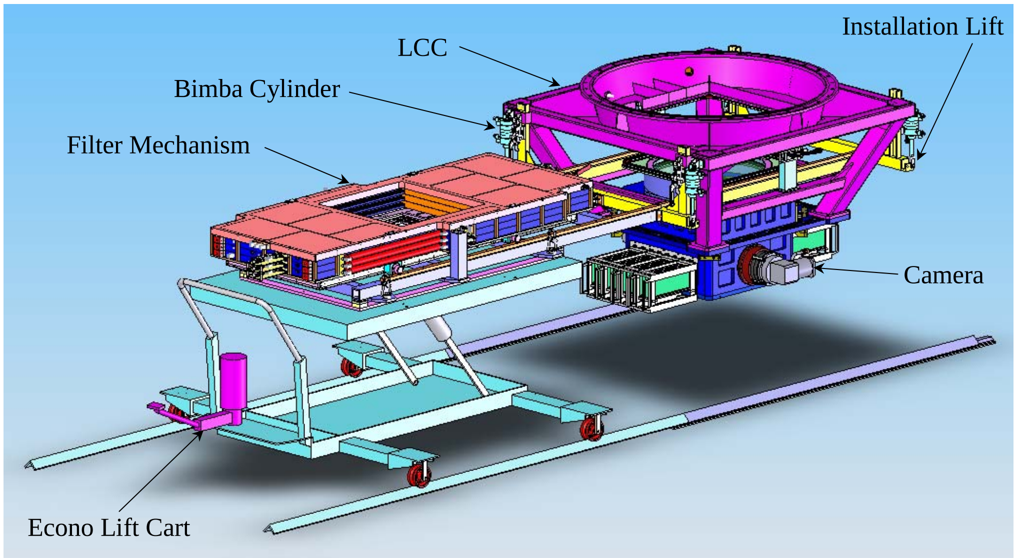

Fig. 11. Filter mechanism installation using lift cart

Dry nitrogen will be used to purge the interior of the filter mechanism and the shutter. Problems can occur if the humidity is too high. The coatings on the filter are adversely affected and frost can occur on the dewar window, L3. All sections of the filter mechanism are sealed with an o-ring including the shutter, but when the filter mechanism is installed there are gaps that allow for rolling clearance. Two rubber inflatable seals made by Pawling Corporation are used to seal these gaps. One is located next to L3 and will inflate to seal against the shutter surface. The other is located on the LCC above the top cover plate. This will seal the filter mechanism surface. The area that is purged with dry nitrogen is from the L3 dewar window to the corrector lense, L2 which is located above the rotator. A slight positive pressure of less than 0.1 psig helps keep the environment inside the filter mechanism controlled. A specially made pressure relief valve is attached on the LCC and opens at the set pressure of less than 0.1 psig to ensure that there is only a slight extra load on the dewar window.

6. PNEUMATIC SYSTEM

A double solenoid valve made be Parker Hannifin controls the filter cylinders (Fig. 12). It is a four-port and two-position valve that either extends or retracts the cylinder. By adding flow restrictors to the inlet and outlet ports of the cylinder, the velocity of the filters can be controlled in a smooth motion. The flow restrictors are made by Mott Corporation and are made of a porous metal that is inserted into a standard Swagelok fitting. The parameters of the flow restrictors are a flow rate of 15 lpm and a supply pressure of 100 psig. At this rate, the cylinders will travel the complete stroke length in 14.5 seconds up and 8.5 seconds down. The orientation is taken in the vertical position, as this will be the largest and smallest load on the cylinder. Average velocities would be 1.5 inches per second and 2.6 inches per second, respectively. A two-port and two position valve will control the master air supply to the filter mechanism. This solenoid valve is a normally closed type and will stop all cylinder movement during a power failure or if other unsafe conditions occur.

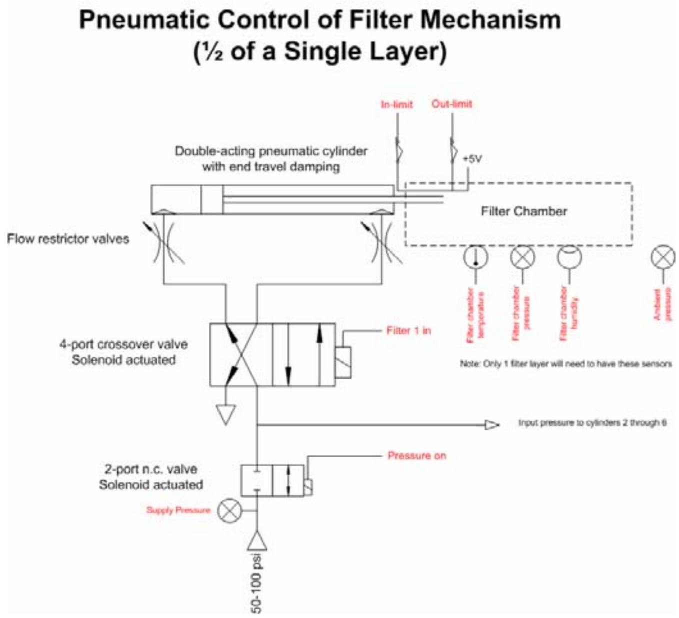

Fig. 12 Pneumatic diagram for the filter cylinder

7. CONTROL SYSTEM

A programmable controller is used to control and monitor the filter mechanism functions. The Z World BL2100 Smartcat is a high-performance single-board computer in a compact package. The program is written in Dynamic C and will monitor eighteen digital inputs, five analog inputs and control thirteen digital outputs. The digital inputs include the twelve limit switches in addition to six identification bits for the three layers. The filter layer identity bits are simply pins that are shorted to ground or left open. The analog inputs include the ambient internal temperature, ambient internal humidity, air supply pressure, inflatable seal pressure and dry nitrogen purge pressure. The digital outputs include the solenoids for each filter cylinder valve and the master air supply valve.

Only one filter from each layer can be in the aperture at the same time. In order to avoid collisions, partner filters are always checked and moved out (clearing move) before the desired filter is moved into the aperture (final move). If the clearing move times out, the system re-commands the clearing move. If the final move times out, the system reports an error, but does not take any corrective action because there is no danger of collision. The user will have to determine the appropriate course of action.

When the controller powers on, it assumes the worst as far as the interlocks are concerned. This state persists until the controller has taken enough measurements to determine that the interlock conditions are acceptable. As soon as that happens, the controller turns on the master air supply valve and sends all filters out of the aperture. It does this in case any solenoids have been replaced and are in a state that could drive filters into collision. There are two interlocks in the system. The humidity threshold will be set around 3 percent relative humidity. When the humidity rises above this threshold, the filters will move out to the home position and are diabled until the humidity returns to and acceptable level. The second interlock is the air supply pressure. When the air supply pressure drops below 50 psig, the main air supply valve will close and all filter movements will cease until the pressure becomes acceptable.

8. CURRENT STATUS

The fabrication of the filter mechanism, LCC and installation lift system has been completed by the University of Washington -Physics machine shop. The LCC and installation lift system are currently at the PS1 facility atop Haleakala in Maui. The filter mechanism is currently still at the machine shop in Seattle and is being tested with the controller and software. The plumbing and wiring for one layer is complete and a successful test of the controller hardware and software was performed. The next step is to perform a test on multiple layers. The filter potting procedure is being currently tested. The potting of filters will commence after successful performance of the procedure. The installation cart and removal system has been designed and is awaiting fabrication.

9. REFERENCES

1. J. Morgan, *PS1 Filter Thickness Specification*, University of Hawaii, Honolulu, Hawaii, 2004.
2. C. Hude, *The PS1 Filter Mount Design;PSDC-300-021-00,* University of Hawaii, Honolulu, Hawaii, 2005