DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

April 26, 2010 to August 13, 2010

Development of Remote Tools for Characterizing and Inspecting the Inside Walls of Off-gas Stacks

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ABSTRACT

During the summer 2010 internship at the Oak Ridge National Laboratory (ORNL), work was completed on the in progress stack characterization system (SCS). The SCS is a remote system that will be deployed into stacks located at ORNL to assist in the characterization of the stacks. The SCS is currently being designed by the ORNL Robotics and Energetic Systems Group. During the internship, work was performed on a deployment mechanism for a radiation detector and a core drill design capable of retrieving six core samples from within the stacks was completed.

Before the start of the internship, experiments consisting of comparisons between smear pads and adhesive pads were conducted at FIU. The experiments were performed to determine if the adhesive pads could substitute for smear pads inside the stacks. The experiments were continued at ORNL and it was concluded that the cloth smear pads would be damaged on concrete surfaces. The adhesive pads were added and tested on a smear sampler design created by the group at ORNL. The Robotics and Energetic Systems group developed the smear sampler before the start of the summer 2010 internship. The sampler consists of a carousel that is capable of storing 20 individual samples. The design has one linear actuator that pushes out the pads, the outer ring which is referred to as the “carousel” is made up of five arced segments that when bolted together create the circular carousel. The linear actuator can only engage the sample pad that is front of it while the others are not. Design changes were made to the carousel after initial testing of the carousel and collection material took place.

The SCS has two instrument bays that will carry all the characterization surveying equipment needed for the stack campaigns. One of the bays will carry radiation detectors that will be used to survey the radiation levels on the walls. The instrument bays will be pushed up to two inches from the inside of the stack walls. However, the radiation detector needs to be located ¼ inch from the wall in order to work properly. A deployment mechanism needed to be designed that would advance the detector forward from inside of the instrument bay.

Core samples from the inside of the stacks may be needed. The SCS will have several cameras and a radiation detector located inside its instrument bays. The detectors and cameras will provide real time data back to the operators; if a location is found to have a high level of radiation, a core sample will be taken from the wall. Also, if the onsite Health Physicist’s, HP’s, decide that a particular location needs to be cored, a sample will be taken.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

As part of the Oak Ridge National Laboratory (ORNL) Central Campus Closure Project, the Department of Energy (DOE) Environmental Management (EM) Program must demolish the central gaseous waste system and associated facilities including the off-gas stacks and systems. These stacks range from 75 feet to 250 feet tall. Stacks are made of steel reinforced concrete with brick liners or unreinforced radial brick masonry with varying brick sizes and an acid-proof lining. Since being built in the 1950s, the central gaseous waste collection system has received no upgrades and minimal repair with some stacks now unsafe to access even for routine inspection. Some stacks, along with their associated filter banks, are contaminated with transuranic material and other radionuclides while being located adjacent to active operating facilities in a densely populated section of ORNL.

The stack characterization system (SCS) is a remote system which can characterize the quantitative and qualitative levels of contamination inside off-gas stacks, protecting workers from the physical, radiological and chemical hazards of deteriorating contaminated stacks. Data collection targets the pre-demolition survey needs for structural, health physics and waste management analysis. The system under development by the ORNL Robotics and Energetic Systems Group will deploy into the top of the stacks via an external overhead crane.

The SCS consists of two stages of tripod sections connected in line by a rotating positional joint. The upper tripod is used for stabilization against the stack walls. The lower bipod section, controlled independently from the upper section, is used to position survey instruments against the inside stack walls. Survey instruments include alpha/beta/gamma radiological detectors, smear sampling, and core sampling. Position information, depth in the stack and rotation within the stack, is recorded and identified for each survey position. An array of real-time video cameras provides guidance for remote systems operators for entrance and egress in the stack and for targeting areas of interest inside the stack for inspection and survey. Video is recorded to provide data for further analysis.

During the 2010 summer internship at ORNL, work on the sub-assemblies and components was performed. Three main mechanisms of the SCS were designed and re-designed. A radiation detector deployment mechanism and a core drill were designed and the smear sampler was re-designed after the original rapid prototype carousel created by the Robotics and Energetic Systems group was tested. Different materials that could potentially be used as the collection medium for the smear sampler were tested on different concrete surfaces. After the experiments were completed, one collection medium was recommended for use with the smear sampler.

2. EXECUTIVE SUMMARY

The research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2010, a DOE Fellow intern (Mr. Mario Vargas) spent 16 weeks doing a summer internship at ORNL's Measurement Science & System Engineering Division under the supervision and guidance of Mr. Mark Noakes and Mr. Randall Lind. This internship was organized and directed by the Higher Education Research Experience (HERE) and the Oak Ridge Institute for Science and Education (ORISE). The intern's project was initiated in April 26, 2010, and continued through August 13, 2010.

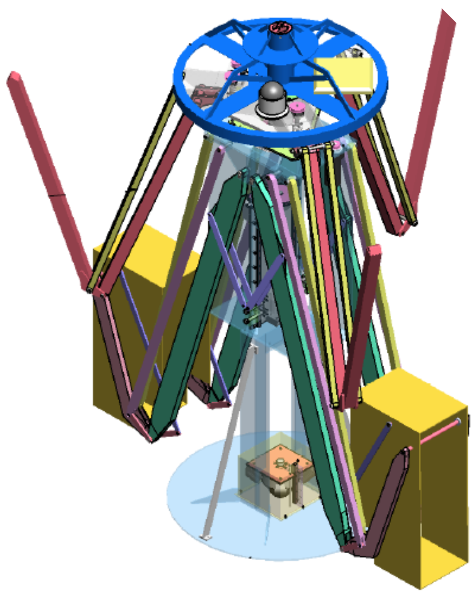

Figure 1: Stack characterization system.

The stack characterization system (SCS) is a remote system which can characterize the quantitative and qualitative levels of contamination inside off-gas stacks, protecting workers from the physical, radiological and chemical hazards of deteriorating contaminated stacks. Data collection targets the pre-demolition survey needs for structural, health physics and waste management analysis. The system under development by the ORNL Robotics and Energetic Systems Group will deploy into the top of stacks via an external overhead crane. The SCS consists of two stages of tripod sections connected in line by a rotating positional joint. The upper tripod is used for stabilization against the stack walls. The lower bipod section, controlled independently from the upper section, is used to position survey instruments against the inside stack walls. Survey instruments include alpha/beta/gamma radiological detectors, smear sampling, and core sampling. Position information, depth in the stack and rotation within the stack, is recorded and identified for each survey position. An array of real-time video cameras provides guidance for remote systems operators for entrance and egress in the stack and for targeting areas of interest inside the stack for inspection and survey.

The first stage of work at ORNL involved experiments to determine the appropriate material to use as the collection medium for the smear sampler. The smear sampler is a sub-system that will be deployed to take samples for loose contamination inside the stack. The traditional smear sampling method of wiping an “S” shape through a 100 cm^2 area will not be used in the stack due to the rough surface of the concrete. The concrete surfaces inside the stacks can be so rough that cloth smear pads can be torn when used. Adhesives pad surfaces were tested to determine the best material. The experiments concluded that the best material is a double-sided stick foam tape that is able to collect loose material on the surface of the stack walls. The foam is rigid enough to collect the material but also flexible enough to mold around small cracks and surface extrusions.

The SCS has two instrument bays that will carry all the characterization surveying equipment needed for the stack campaigns. One of the bays will carry radiation detectors that will be used to survey the radiation levels on the walls. The instrument bays will be pushed up to two inches from the inside of the stack walls. However, the radiation detector needs to be located ¼ inch from the wall in order to work properly. A deployment mechanism needed to be designed that would advance the detector forward from inside of the instrument bay. One of two radiological detectors will be used to survey the radiation levels in the stacks. The first detector is the model 44-88 pancake G-M detector used for sample counting of alpha beta gamma (combined count) and the second is the model 43-1-1 dual phosphor alpha/beta scintillator which can discriminate alpha from beta. Product sheets for the radiation detectors can be found in Appendix A. A design of the mechanism was created that is capable of being used with either of the two radiation detectors.

The Robotics and Energetic Systems group developed the smear sampler before the start of the summer 2010 internship. The sampler consists of a carousel that is capable of storing 20 individual samples. The design has one linear actuator that pushes out the pads; the outer ring (which is referred to as the “carousel”) is made up of five arced segments that when bolted together create the circular carousel. The linear actuator can only engage the sample pad that is front of it while the others are not. Design changes were made to the carousel after initial testing of the carousel and collection material was completed.

3. RESEARCH DESCRIPTIONS

3.1 Collection Medium Experimental Testing

The first stage of work at ORNL involved experiments to determine the appropriate material to use as the collection medium for the smear sampler. The smear sampler is a sub-system that will be deployed to take samples for loose contamination inside the stack. The traditional smear sampling method of wiping an "S" shape through a 100 cm^2 area will not be used in the stack due to the rough surface of the concrete. The concrete surfaces inside the stacks can be so rough that cloth smear pads can be torn when used. Adhesives pad surfaces were tested to determine the best material.

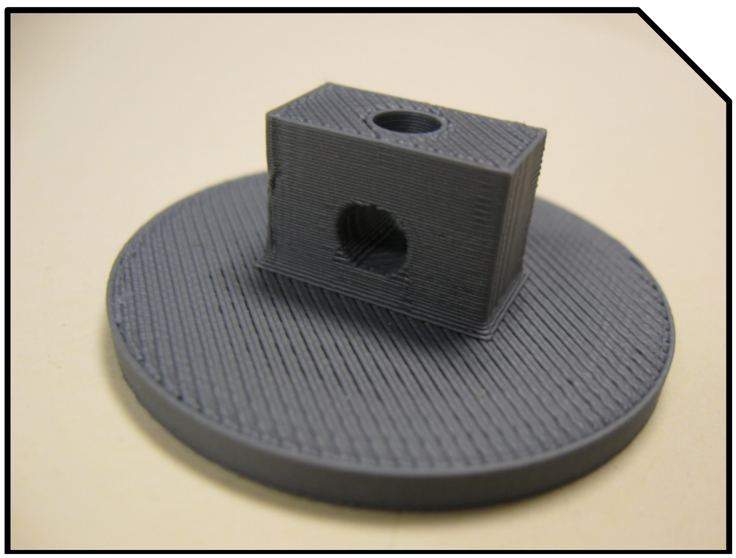

Figure 2: ABS smear sampler pad.

Figure 2 illustrates the test ABS pads used with the collection mediums. The test material has two adhesives sides. One of the sides adheres to the bottom of the test ABS pad and the other side is the one that will collect the loose contamination from the surface. Figure 3 illustrates the spring scale used to measure the amount of force needed to remove the test mediums from the surface. The ABS test pad has two apertures, the one on top is for pushing the test pad onto the surface with the spring scale and the one on the side is used to remove the test pad with the spring scale. The left end of the spring scale, the hooked end, is used to measure the removal force and the right end is used to measure the application force. The spring scale can be calibrated before each use and measures forces in lb_f.

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Figure 3: Chatillon 719-10 spring scale.

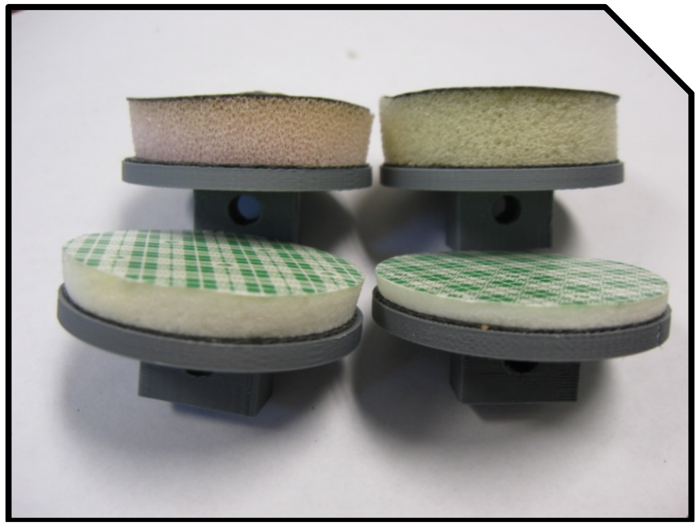


Figure 4: Pad material, foams and double-sided tape.

There is a possibility that non-uniform sections of the wall will be encountered. To ensure that every sample taken is able to collect loose contamination with obstructions on the wall, foam is needed to allow for the collection medium to flex around the obstruction. Figure 4 illustrates the collection materials tested. Four different configurations were used. Two had two different types of foam used with stick ribbon and the other two were double-sided adhesive foam pads that differed in foam thickness. Figure 5 shows the qualitative test results for the collection medium and Figure 6 shows the different surfaces tested and how the spring scale was used during the testing. Near the 7601 building at ORNL, there are concrete blocks that were originally meant for use with the gas cooled reactor that never became operational. The concrete blocks are exposed to the environment and have been weathered for many years. The concrete blocks (shown in Figure 6) were evaluated to determine if it was suitable for testing.

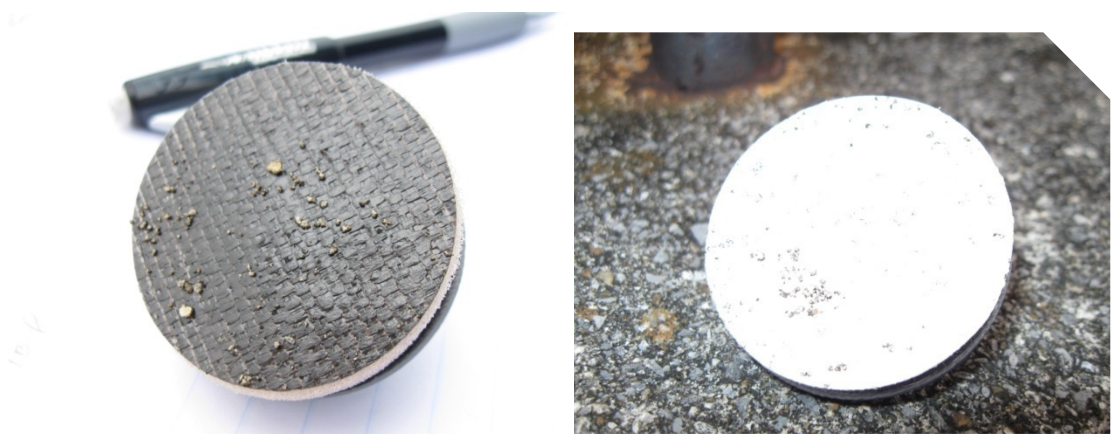


Figure 5: Collection medium qualitative test results.

During testing, it was concluded that some of the adhesive material needed more than 12 lb of force to remove the test pad from the wall. Also, it was determined that the ribbon material was not suitable for use with ABS plastic because it has trouble adhering to the material. Two other surfaces were tested, including an indoor clean smooth concrete wall and a dusty smooth outdoor concrete wall (Figure 6). After all the surfaces and materials were tested, it was concluded that the thicker of the two double-sided adhesive pads was the best selection to use with the smear sampler.

Figure 6: Test surfaces.

The tested surfaces were selected to simulate the type of surfaces that can be encountered during an actual campaign of the system. The concrete block contained a lot of loose material on its surface which was ideal for the initial testing of the collection material. The smear sampler is meant to be deployed only when a survey of loose material is needed. As previously mentioned, the double-sided foam pads had the best results. Figure 5 illustrated the end results of testing between the ribbon, image on the left, and the double-sided adhesive foam pads. Even though the black ribbon pad has much more adhesive on it than the double-sided adhesive pad, the combination of foam and black ribbon is not ideal because the foam selected is not rigid enough.

Because the smear sampler will utilize a three pound actuator, the three pounds of force used to push the pad against the wall would be absorbed by the foam, not allowing the full force to transfer to the black ribbon. On the other hand, the double-sided foam tape is made up of a rigid foam material with a layer of adhesive glue added to either end. On the off chance that a clean surface is encountered during a campaign, two smooth concrete walls were tested. The first wall was located inside the building and the second was an exterior wall. Both walls were constructed with the same concrete blocks; the only difference being one wall was exposed to the outside elements but was not as weathered as the first concrete block tested.

After testing the exterior wall, it was concluded that if a surface with minimal dust was encountered, more force was needed to remove it from the surface. In other words, because there is not much loose contamination to collect, the adhesive material would adhere to the concrete material itself. Again, due to the linear actuators capacity of three pounds of force, it might not be able to retrieve the sample, resulting in the loss of the entire smear sampling device. A solution to this problem will be presented later in this report.

3.2 Radiation Deployment Mechanism

The SCS has two instrument bays that will carry all the characterization surveying equipment needed for the stack campaigns. One of the bays will carry radiation detectors that will be used to survey the radiation levels on the walls. The instrument bays will be pushed up to two inches from the inside of the stack walls. However, the radiation detector needs to be located ¼ inch from the wall in order to work properly. A deployment mechanism needed to be designed that would advance the detector forward from inside of the instrument bay. One of two radiological detectors will be used to survey the radiation levels in the stacks. The first detector is the model 44-88 pancake G-M detector used for sample counting of alpha beta gamma (combined count) and the second is the model 43-1-1 dual phosphor alpha/beta scintillator which can discriminate alpha from beta. Product sheets for the radiation detectors can be found in Appendix A. 3D computer aided drawings (CAD) were created to aid in the design of the mechanism. The larger of the two detectors, the dual phosphor alpha/beta scintillator has a smaller diameter than the G-M detector. The final design has not been made on which of the two detectors will be used. One detector is able to differentiate between alpha and beta levels but the other cannot. The HP's will determine which will be used after cold testing of the system is complete. For purposes of design work, both will be used in the CAD drawings. Figure 7 shows the overall dimensions of the detectors in inches. The deployment mechanism needs to be able to advance the detector forward. Three designs were created for the detectors. The first design is meant to hold the larger detector only and the second is meant to hold the smaller detector. The final design was developed with interchangeable parts, meaning that the base for the mechanism is able to hold either of the two detectors. Either detector can be adapted to the base with the changing of screws and clasps.

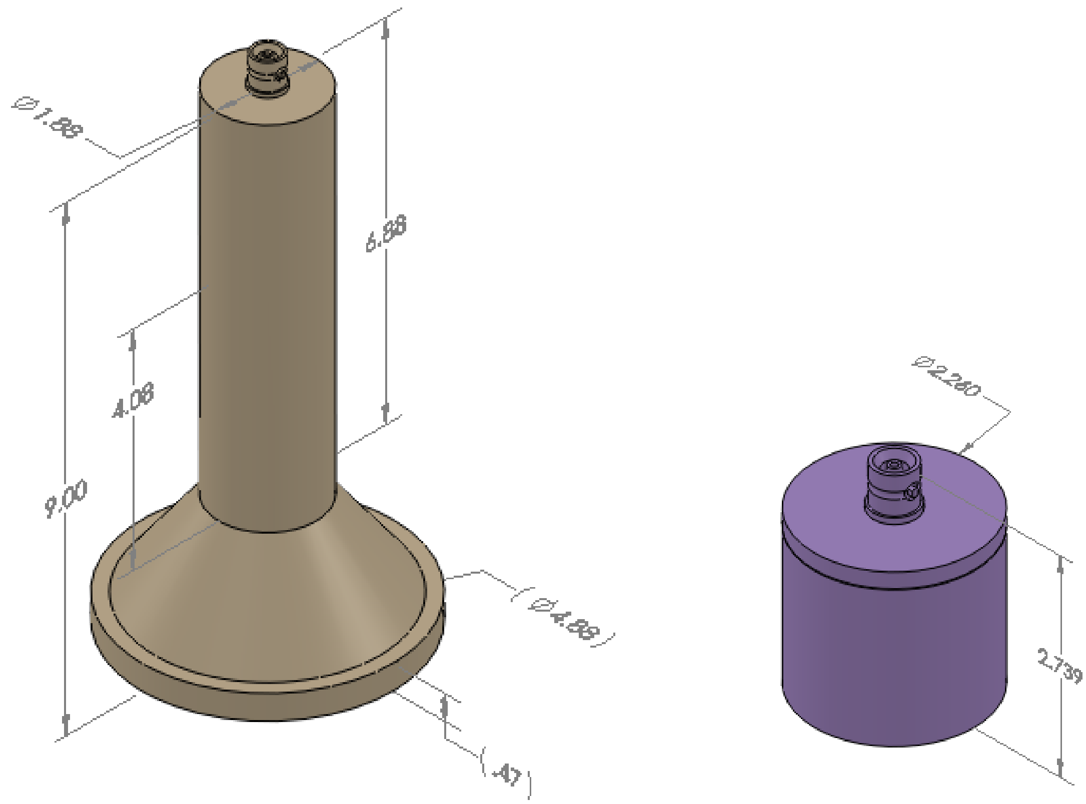


Figure 7: Radiation detectors – SolidWorks models (dimensions are in inches).

Figure 8 shows the design of the mechanism tailored around the dimensions of the larger detector. The detector is held in place by a bracket that is mounted onto an actuated base that is able to slide in and out of the instrument bay. A limit switch along with a self adjusting rod will inform the actuator when the detector is the correct distance away from the wall for surveying. The slide rails are rated at 100 lbs and the linear actuator is capable of providing 8 lb of force over a distance of 4 inches. The Robotics and Energetic Systems group has access to a 3D rapid prototyper that is capable of creating plastic components. The prototyper is capable of creating any parts or components within an 8 by 8 inch area. Most of the components for the deployment mechanism will be plastic parts printed on the prototyper.

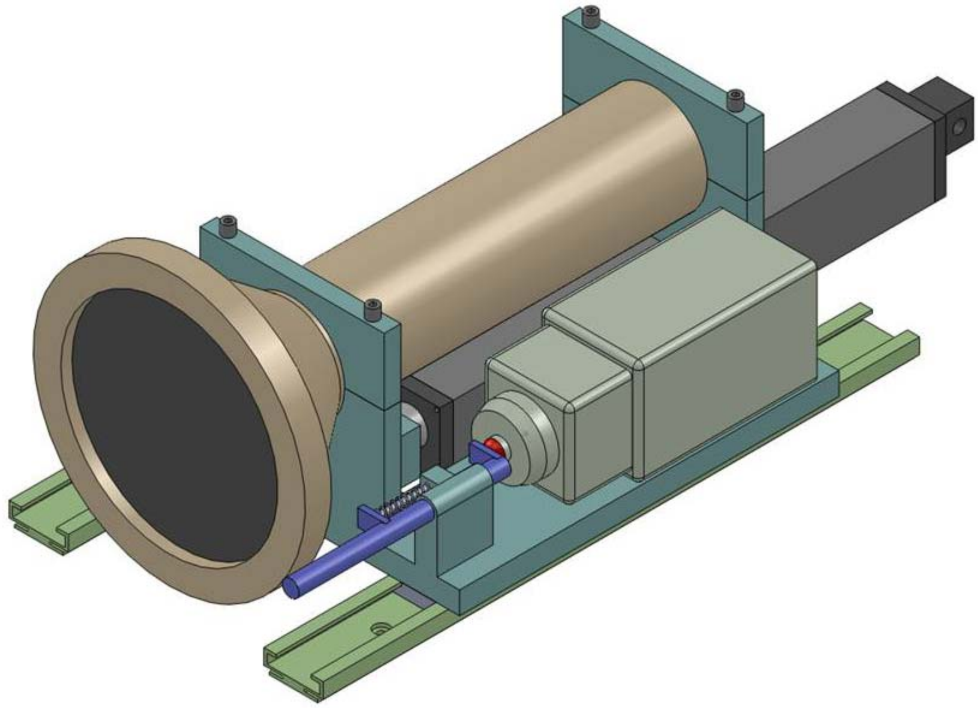


Figure 8: Deployment mechanism with dual phosphor alpha/beta scintillator.

The overall design of the mechanism has an actuator for advancing the unit forward and a limit switch. The linear actuator used for the current design is an industrial switch. The function of the limit switch is to stop the advancement of the actuator. The actuator has a 4 inch stroke but less than 3 inches are needed. The limit switch also alerts the technician when the actuator has been stopped, allowing them to reverse the actuator back to its original position. All three designs for the mechanism use the same limit switch. The switch itself is not the ideal unit for the mechanism because it is quite big and bulky. The switch is used in the design because it is currently available in the Robotics and Energetic Systems group's lab. The switch can be changed for a smaller one but for now it serves its purpose. In front of the switch, there is a rod that extends out further than the detector does. The rod is spring loaded; as the actuator pushes the entire base forward, the rod will make contact with the wall first and it will push on the plunger bottom on the limit switch that will in turn stop the actuator from advancing the case any further. The rod is spring loaded in order to keep it off the bottom when the working distance is met. Figure 9 shows the deployment mechanism without the radiation detector and the limit switch. The base that holds the detector and the limit switch is one part and the clasp for the radiation detector is screwed into the base with four screws. The base is mounted on four rail slides that are able to slide on the rails when the base is pushed forward by the actuator. Both slide rails will be mounted onto either the instrument bay or a metal plate that will mounted to the instrument bay.

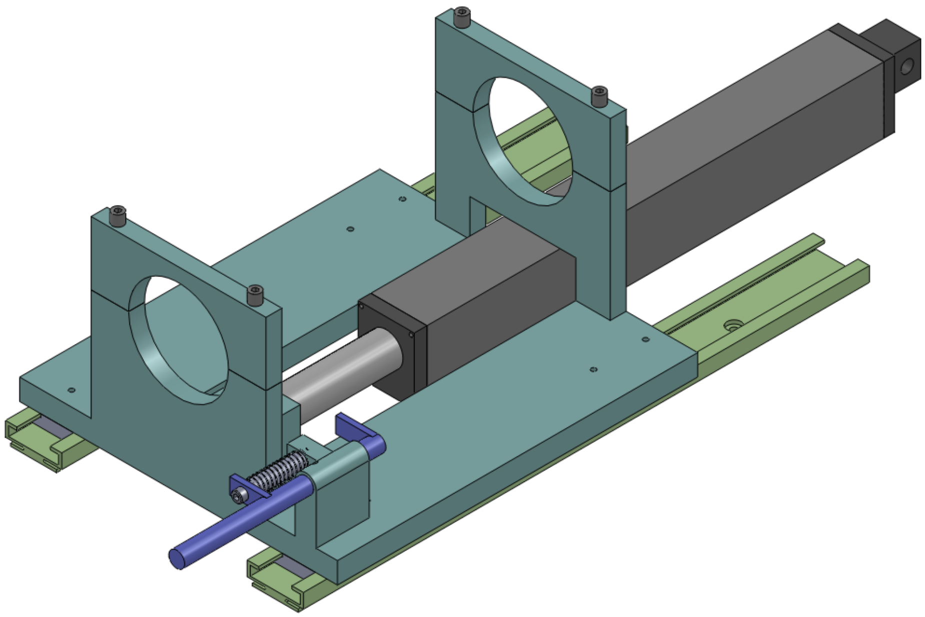


Figure 9: Deployment mechanism.

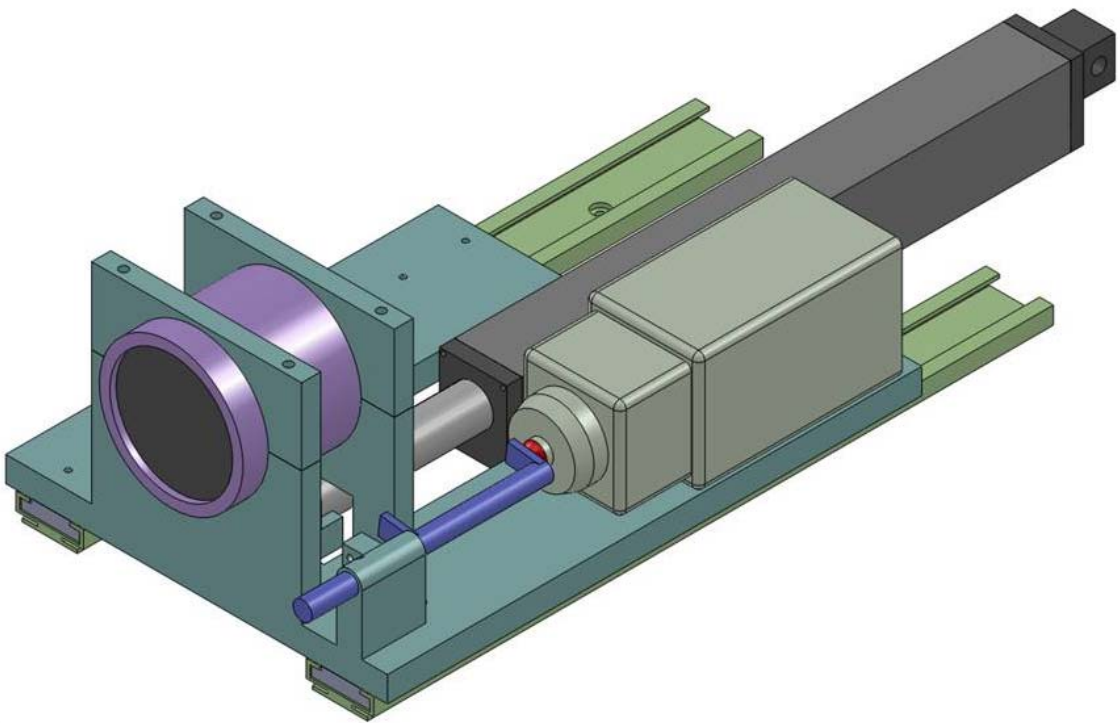


Figure 10: Deployment mechanism with G-M detector.

The G-M detector is the smaller of the two detectors but has a larger diameter. Due to the difference in diameter, a separate deployment mechanism was created for it. Also because it is smaller, the clasps have to be closer together. Because the weight is less than 2 lbs, the parts can be created on the rapid prototype; the base, clasps and rod would all be prototyped on the printer. As previously mentioned, a deployment mechanism would be developed for each of the detectors. Even though prototyping the parts out of plastic would be less expensive than metal, it would be better to have one deployment mechanism capable of being used by either of the detectors.

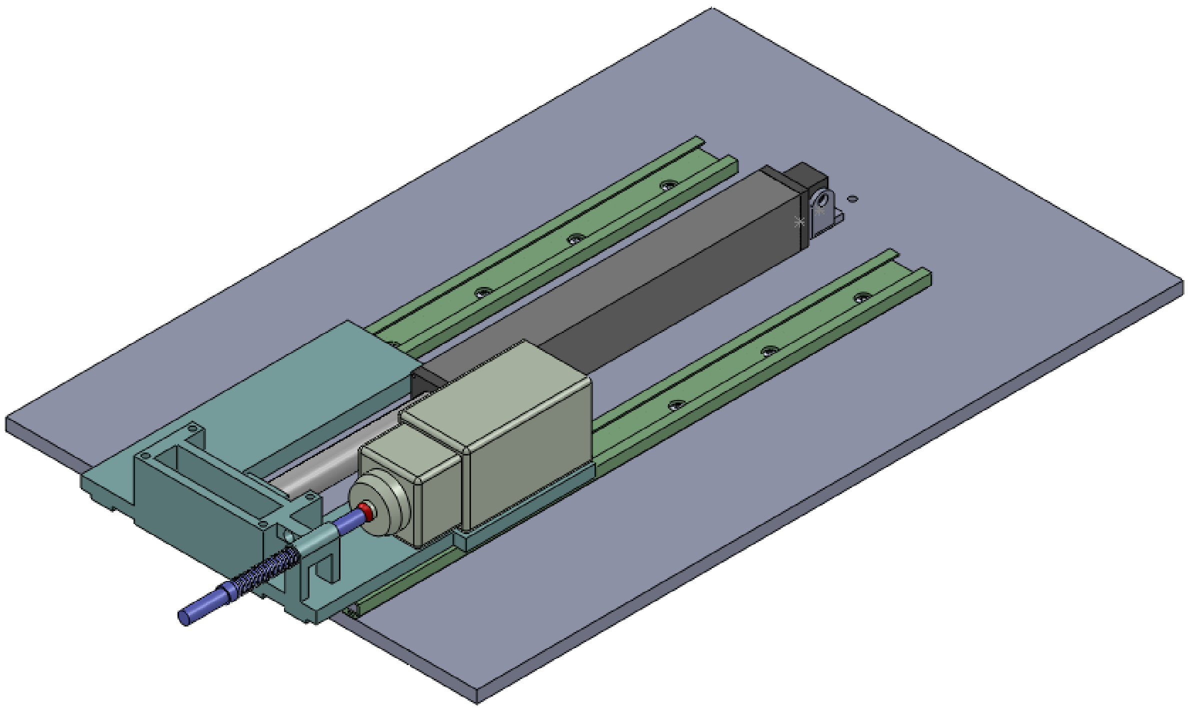


Figure 11: Deployment mechanism with interchangeable parts.

An updated design of the mechanism was created as shown in Figure 11. The base carries the limit switch and the push rod for the switch along with the spring that holds the rod away from the limit switch. Either of the detectors can be added to the base with a series of screws. Figures 12 and 13 show how the detectors can be added to the base with the addition of a clasp for each detector. Each detector has a clasp fitted for its diameter and the screws that hold the clasp to the base are the same ones. Rather than printing a base for each detector, one base will be printed and each detector will have its own clasp. Also, the figures show that the entire mechanism is mounted to a ½ inch metal plate. The plate will be mounted to the inside of the instrument bay. The coaxial cables for the detectors are easily accessible in the current design.

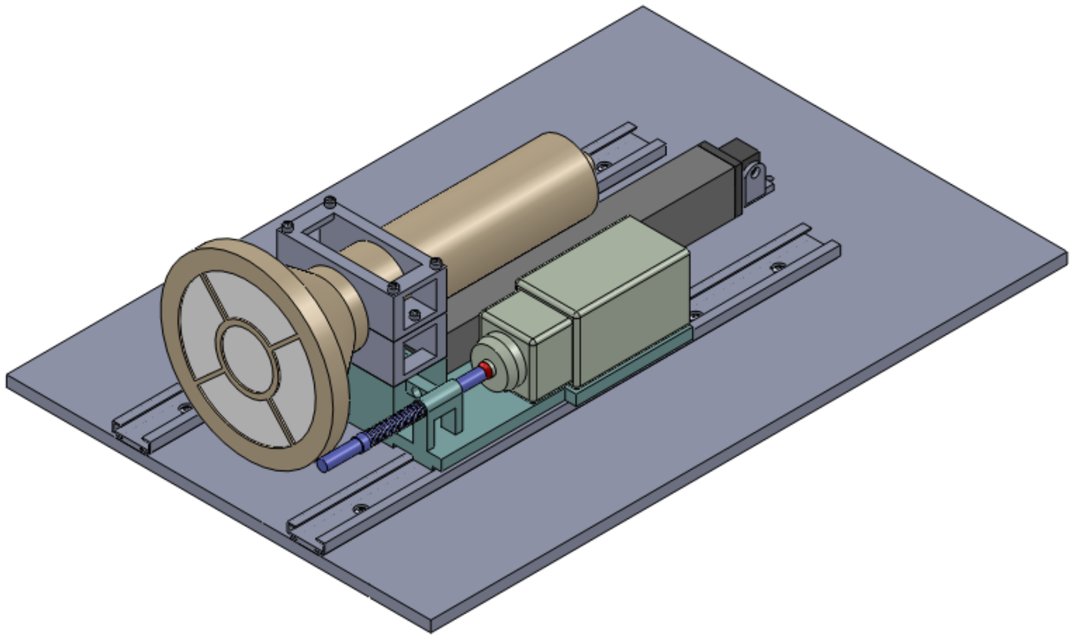


Figure 12: Updated deployment mechanism designs with scintillater.

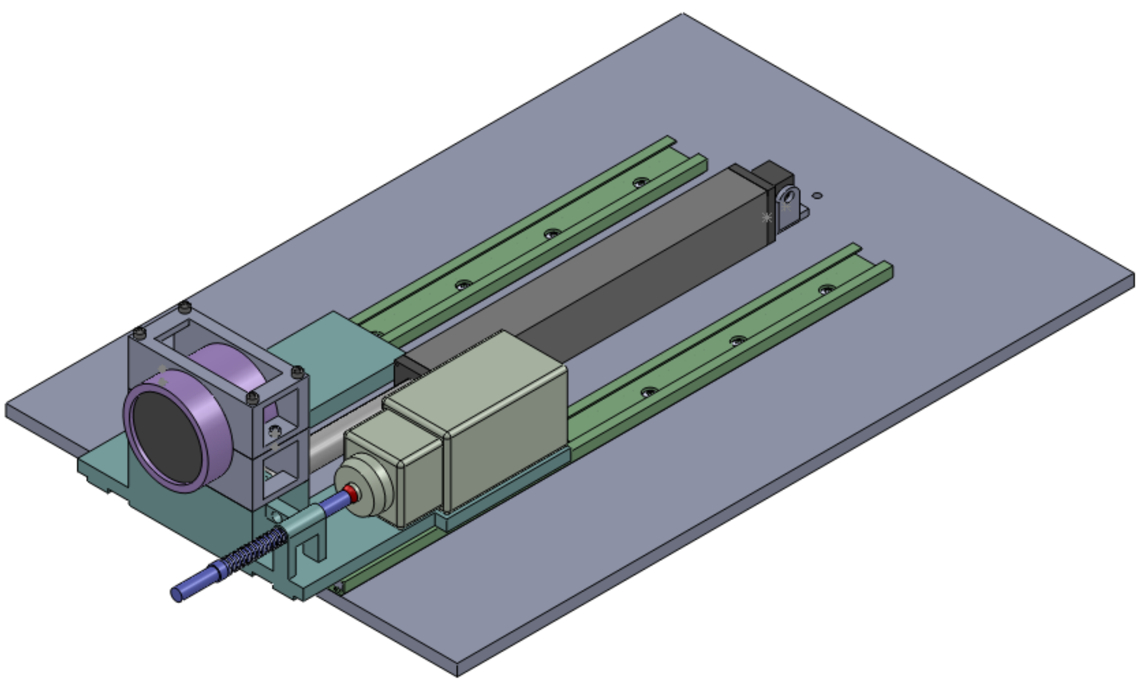


Figure 13: Updated deployment mechanism designs with G-M detector.

3.3 Smear Sampler

The SCS will carry a number of fixed and remotely operated cameras that will allow the operators to see the inside of the stacks. They will also allow the operators to monitor the surveying equipment in the instrument bays. The combination of visual inspections as well as data gathered by the radiation detectors will determine where loose contamination samples will be taken. The smear sampler's main purpose is to collect any loose contamination on the surface of the concrete walls. The adhesive pads chosen from the collection medium experiments will be one of the tests to determine what contamination is inside the stacks. If there is any loose contamination on the surface, the adhesive pads will collect it.

The Robotics and Energetic Systems group developed the smear sampler before the start of the summer 2010 internship. The sampler consists of a carousel that is capable of storing 20 individual samples. The image shown in Figure 14 is the original CAD design created by the Robotics and Energetic Systems Group at ORNL. The original design has one linear actuator that pushes out the pads and one rotation gear motor that turns the carousel and prepares it for the next sample. The outer ring, which is referred to as the "carousel," is made up of five arced segments that when bolted together create the circular carousel. The linear actuator can only engage the sample pad that is directly in front of it.

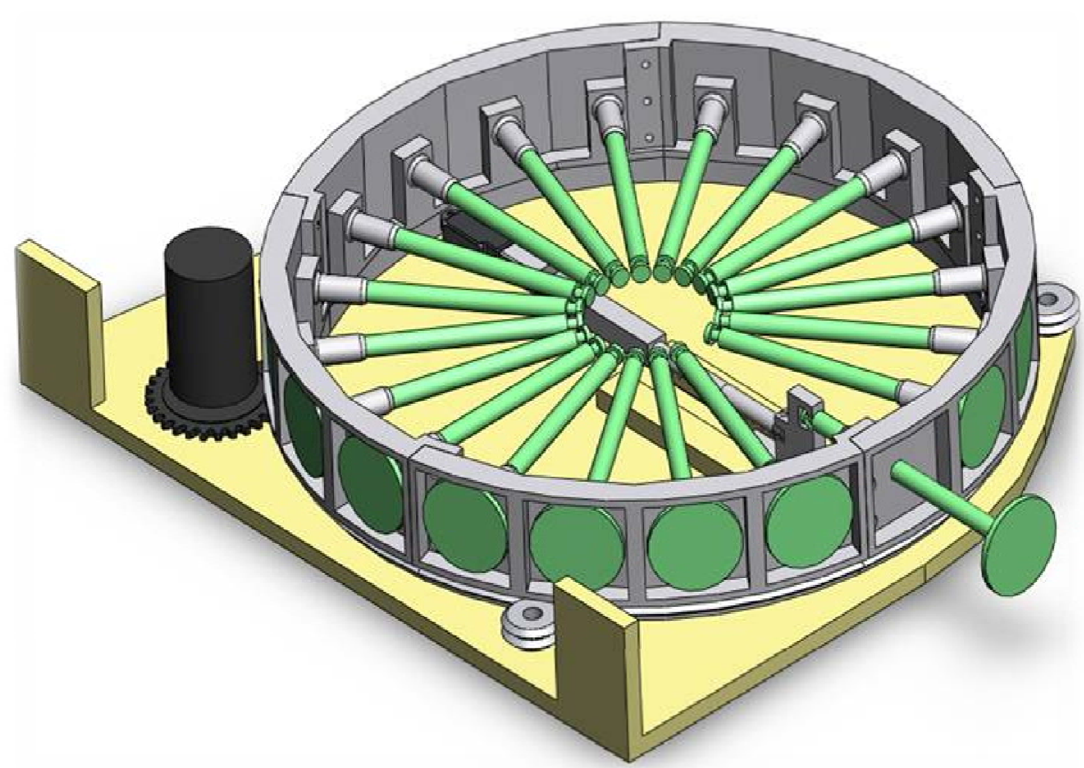


Figure 14: First CAD of smear sampler.

Figure 15: First rapid prototyped smear sampler.

The first physical smear sampler was prototyped by the Robotics and Energetic Systems Group, shown in Figure 15. Changes to the original design were made. Instead of using a rotational geared motor to rotate the carousel, another linear actuator was added instead. The actuator is not shown in the picture; it is located below the aluminum base. The second actuator pushes an access door forward which is attached to the bottom of the carousel which rotates it. A detent was added at the base of the carousel as shown in the lower end of the picture. A detent is a mechanical component that prevents rotation. The detent was added to keep the carousel form rotating in the opposite direction and allows it to rotate forward only when the bottom actuator is energized. In Figure 15, all the plastic elements shown in black were created in the rapid prototyper.

Electrical connections and mechanical components were added to the sampler. The actuators run on 10 V; a limit switch was added to the carousel to prevent the actuator from stalling. Again, because the inside walls of the stacks can be non-uniform, any obstruction encountered by the actuator can become a problem. The actuator is able to extend out 4 inches, if an obstruction is encountered by the actuator while extending, the limit switch will be tripped and the actuator will retract. Figure 14 shows how a push rod extends out when the actuator is engaged.

Testing of the prototype took place after the collection medium was added to it. Figure 16 illustrates how the collection medium, the double-sided adhesive foam tape, was added to the end of the push rods. For the preliminary testing, the adhesive sides of the pads were kept covered until it would be used for collection. The sampler and its base were mounted on a cart along with its voltage supply and the controller hardware (OPTO 22 PAC Controller), for preliminary testing of the design on outdoor surfaces (Figure 17).

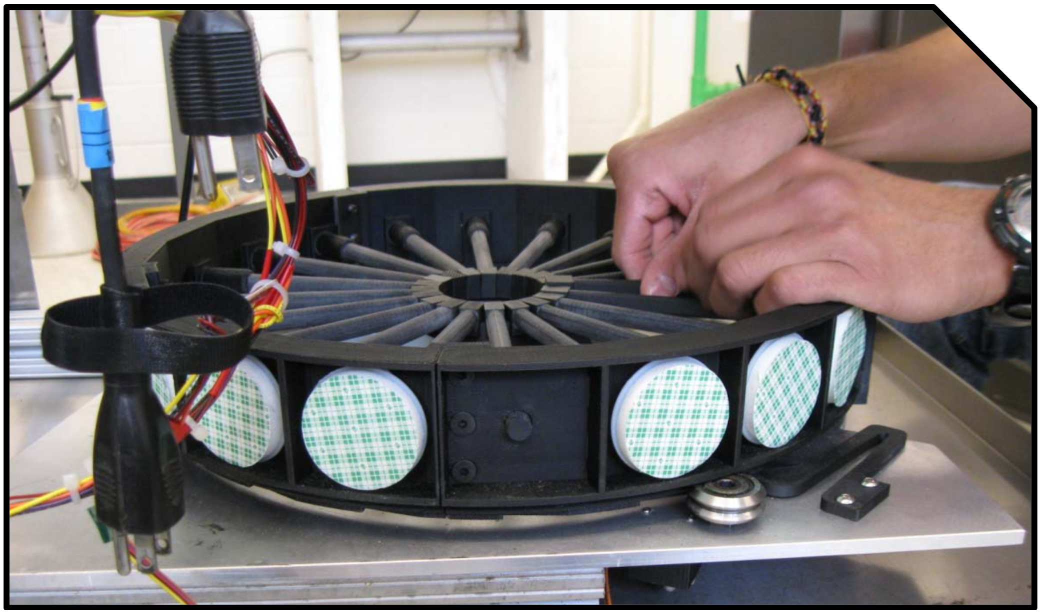


Figure 16: Smear sampler with double-sided adhesive pads.

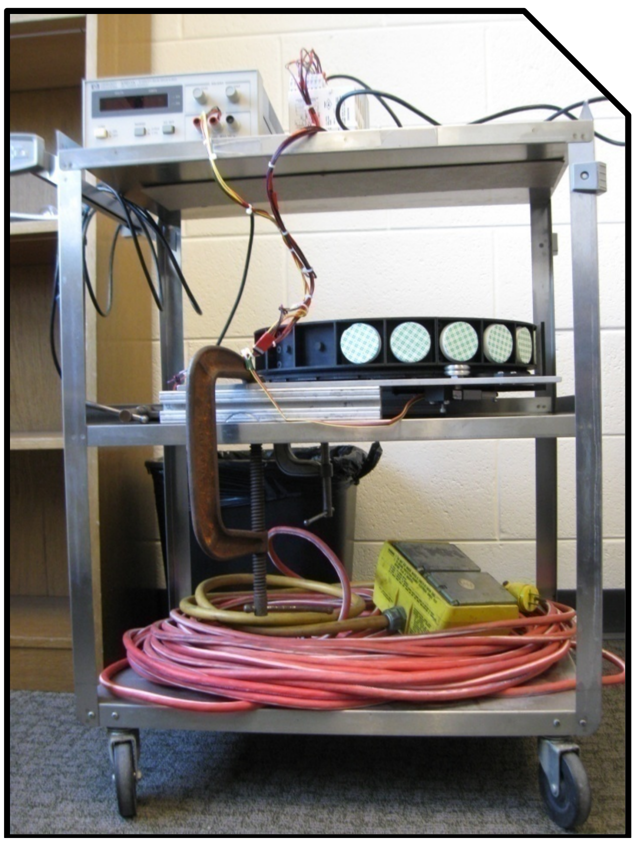


Figure 17: Mobile smear sampler.

The original smear sampler prototype was tested on the same outdoor surfaces that the collection medium materials were tested on. Because the sampler was now mobile and was going to be tested outside, a ground fault circuit interrupter (GFCI) was added to it. The GFCI protects the unit, the surroundings, and the operator from electrical shocks due to water, rain, puddles, etc. A normal 120-volt outlet in the United States has two vertical slots and then a round hole centered below them. The left slot is slightly larger than the right. The left slot is called "neutral," the right slot is called "hot" and the hole below them is called "ground." If an appliance is working properly, all electricity that the appliance uses will flow from hot to neutral. A GFCI monitors the amount of current flowing from hot to neutral. If there is any imbalance, it trips the circuit. It is able to sense a mismatch as small as 4 or 5 milliamps, and it can react as quickly as one-thirtieth of a second.

If the sampler testing was outside and it were to rain, the operator would be standing on the ground and since the voltage supplier for the sampler were wet there would be a path from the hot wire inside the unit through operator to the ground. If electricity flows from hot to ground through the operator, it could be fatal. The GFCI can sense the current flowing through because not all of the current is flowing from hot to neutral as it expects, some of it is flowing through the operator to ground. As soon as the GFCI senses that, it trips the circuit and cuts off the electricity. The GCFI is shown in Figure 17 on the bottom shelf of the cart.

Figure 18 shows one of the experiments with the sampler on a concrete block. The block has a lot of dust and grainy particles on it. The resulting qualitative result is shown in Figure 19.

Figure 18: Smear sampler test on concrete block.

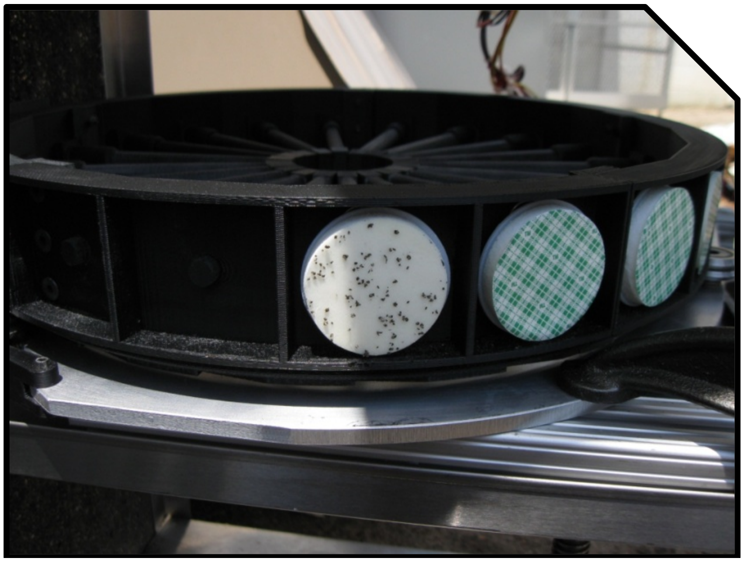


Figure 19: Qualitative result for smear sampler testing of concrete block.

The loose material on the blocks surface can be seen on the pad in Figure 19. Large grain particles were collected during the testing. One of the main objectives of the outdoor testing with the sampler was to observe if the actuator that extends the push rods with the pads would stall. As concluded in the collection medium experimental testing section of the report, the concrete block had enough surface particles to be collected by the sampler. As expected, the sampler did not stall when taking samples on the concrete block. The limit switch was tested during preliminary lab testing but was also tested again with the concrete block. Instead of allowing the push rod to extend out fully, an obstruction was set in front of it and the limit switch tripped the actuator to retract the rod as soon as it touched the obstruction.

Figure 20: Smear sampler test on semi-rough exterior building wall.

A semi-rough outside concrete wall was tested next; the outside wall did not have large particles but had much finer dust particles on it (Figures 20 and 21). The semi-rough surfaces also had enough particles to be collected by the sampler. A picture is not provided to demonstrate the amount of material collected because the particles are too fine to show in detail. Afterwards, the sampler was tested on a smoother concrete wall, the same results were yielded. The qualitative results yielded from the sampler testing proved that if there are any loose particles on the surface selected for sampling that:

- The adhesive pads would be able to collect it.
- The linear actuator would not stall.
- That the limit switch would retract the push rod if the full stoke of the actuator could not be accomplished.

Figure 21: Smear sampler test on smooth exterior building wall.

The carousel on the sampler is meant to be transportable and meant to be an independent component of the sampler (Figure 23). When the carousel is set on the base of the sampler, the actuator is able to control the rotation it makes. In actual field work, the carousel is meant to be added to the base to create the smear sampler. The metal base of the sampler is made up of the linear actuator, the access door, the detent, the limit switch, the bearings that allow the carousel to turn and the aluminum plate the components are mounted to (Figure 22). Individually, the base and the carousel are independent of each other. With that stated, the carousel is meant to be removed from the base when the campaign is over and a new one is meant to be added for the next campaign. The sample pads will be removed from the carousel and analyzed for characterization.

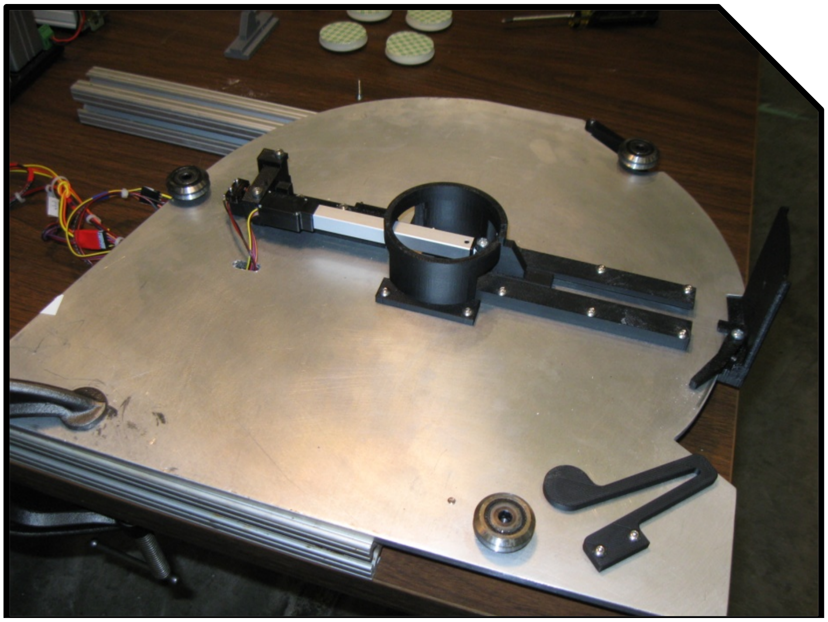


Figure 22: Sampler base.

Because the carousel will be transported around, all the push rod stems need to be in their retracted position before it can be added to the base. The original carousel design was not able to keep the rods in without them sliding out when the carousel was being transported. Also, the rods have a circular cross section that allows the rods to rotate, making it harder for the linear actuator to extend the rod out. It was also noticed that the carousel itself did not have a location for the technician to pick up the carousel. The carousel design was the main objective to be completed during the internship as set by FIU and the Robotics and Energetic Systems group.

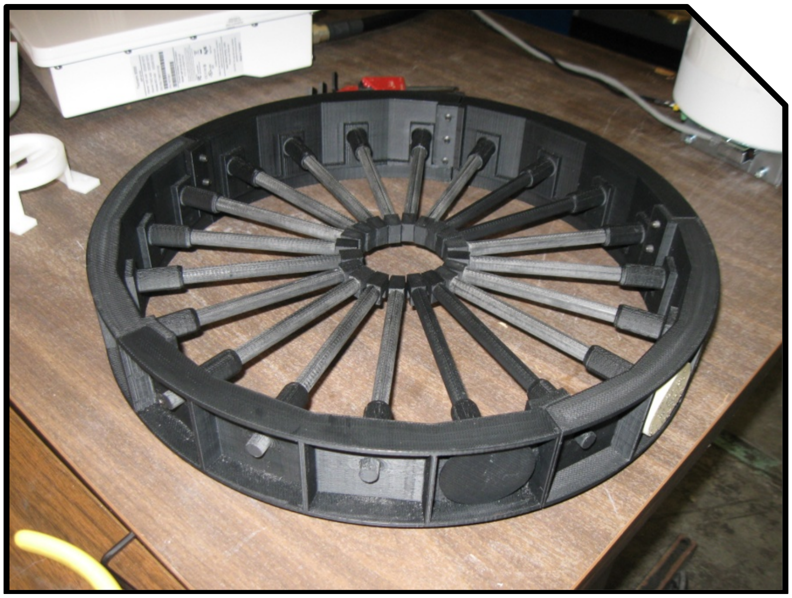


Figure 23: Carousel.

The first change made to the carousel was the cross section of the push rods. The circular rods were prone to rotating in place while the carousel was being moved. The new rods used a rectangular cross section (Figure 24). A support was also added to guide the rod and the rod has a slot on each side so that the support can act as rail for the rod. The rod also has a groove on the top surface; the support has an extruded circular section on it, the detent,that fits into the groove on the rod. The detent prevents the rod from sliding out when the carousel is being moved, as seen in Figure 25.

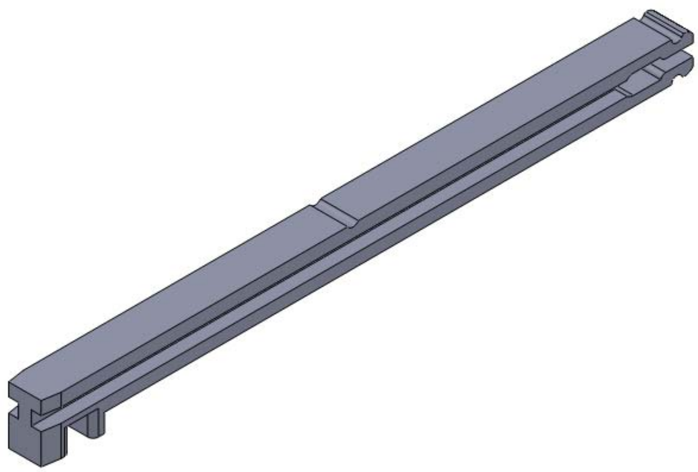


Figure 24: New push rod (stem) design.

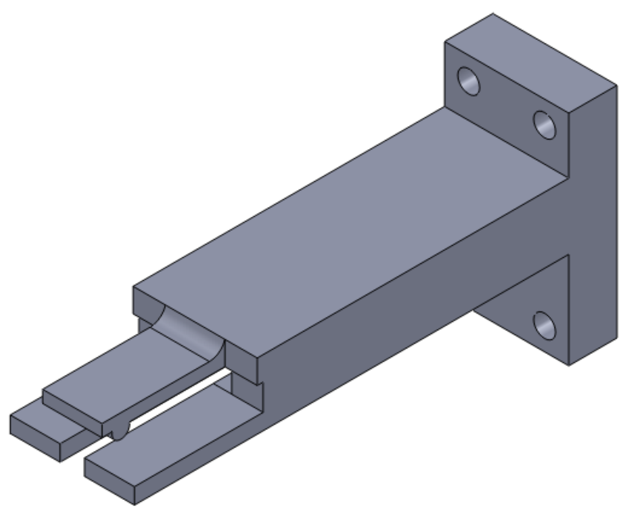


Figure 25: Push rod (stem) support.

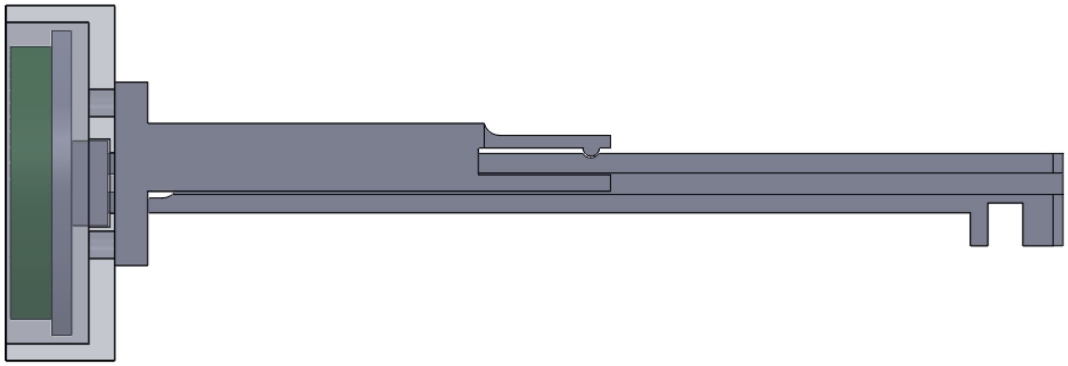


Figure 26: Stem and support with adhesive pad.

The detent is shown in Figure 26; the support has a flexible cantilever end that is able to flex up and down as the groove on the support passed by it. If the detent is in the groove, the rod is not able to slide out until it is pushed forward by the actuator. The detent allows the rods to stay in their retracted position at all times until they are pushed forward by the actuator. The detent facilitates in the transportation of the carousel. At the end of the stem, as seen on the right end of Figure 26, there is a cut out rectangular section. That cut out section allows the actuator to engage the stem when the stem is rotated in front of it and it also allows the actuator to push and pull on the stem. On the opposite end of the stem, there is a disk that the adhesive pad sticks to. The adhesive pad is protected from cross contamination by the arced sections that make up the circle of the carousel (Figure 27). The figure shows the outside of the segment; the original segment was modified to accommodate the new cross section of the stems and support. On the left side of each segment, as seen on the right side of Figure 27, there are three holes that the next segment will be screwed in to.

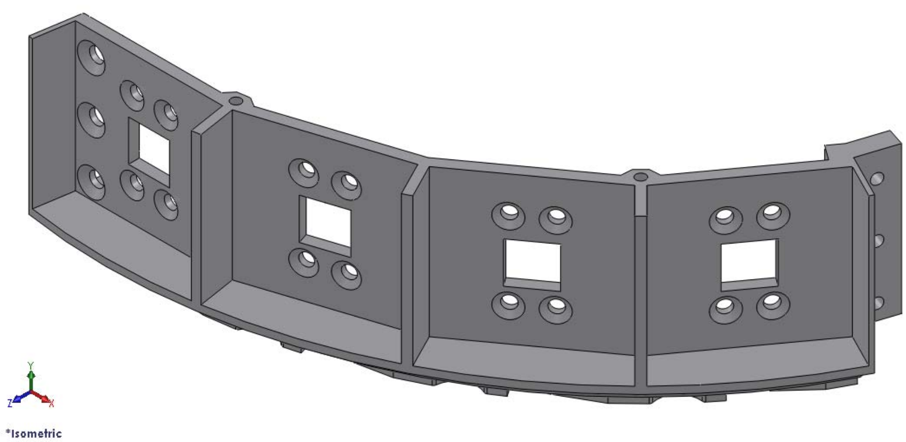


Figure 27: Modified carousel arc segment.

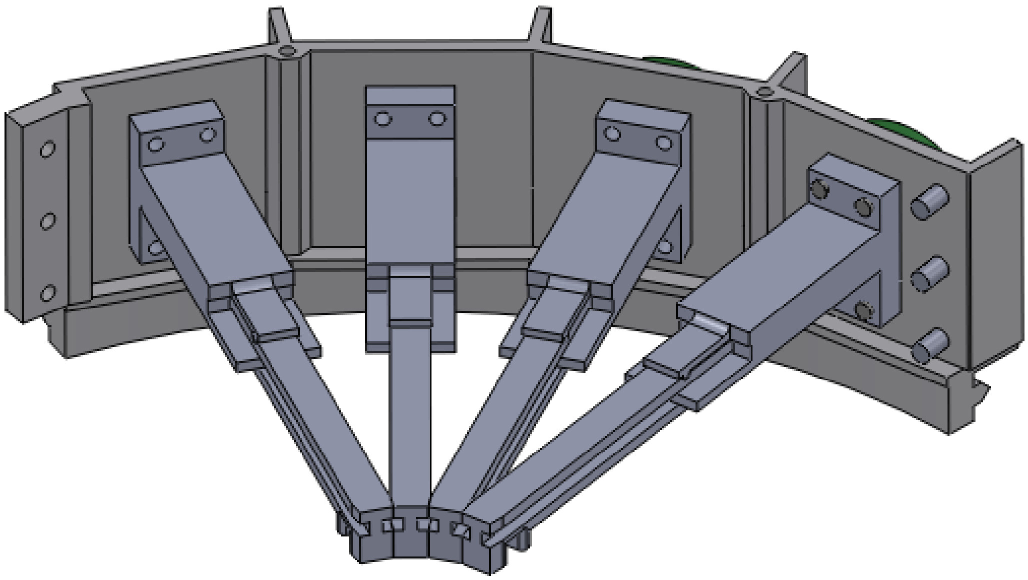


Figure 28: First segment of carousel.

Figure 28 shows how the supports and rods are mounted to the arc segment. Each of the stems is tapered at the end so that it does not interfere with the stem next to it; where they all meet, an arc is formed. The linear actuator will be located in the middle and the arc allows the stems to rotate into place with the actuator. To address the problem brought up in the collection material experiential testing section of the report, if a clean smooth surface were to be encountered during a campaign, a second detent was added to the stem. The detent acts as a snap-on and off feature. The detent was designed to snap off when 2.5 lb of force are exceeded. Because the actuator can only provide up to 3.4 lb force, if a clean surface were encountered and the adhesive pad were to stick to the wall itself then when the actuator pulls back, the disk will snap off, allowing the actuator to retract without stalling. The disk pad would remain adhered to the wall while the carousel was free to move to another location. The original disk pad design is shown in Figure 29 and the updated design is shown in Figure 30.

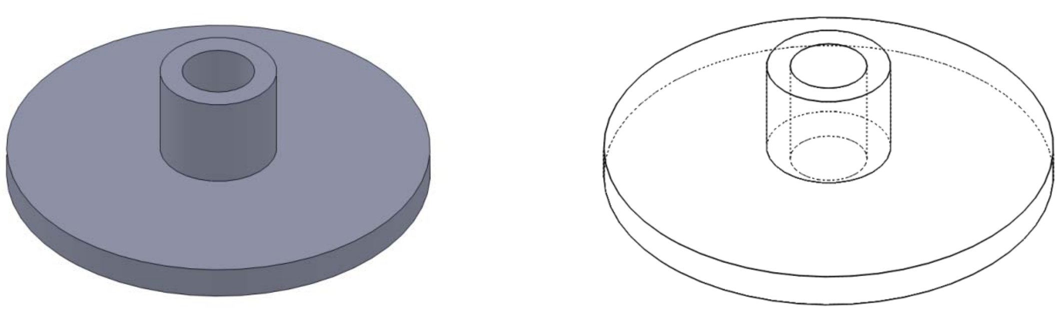


Figure 29: Original disk pad design.

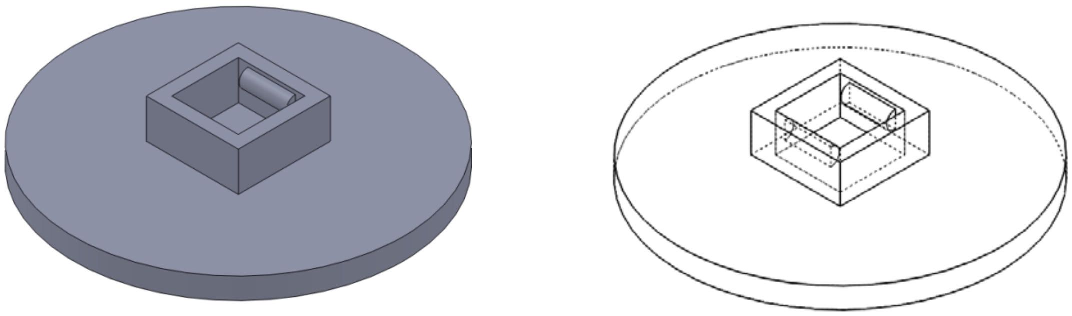


Figure 30: Modified disk pad design.

The changes to the disk pads are minor. The original rod design had a circular cross section; the new design uses a square cross section that reduces any rotation of the pad while a sample is taken. Because there is a change to the rod design, the disk pad design also needed to change. The new design, Figure 30, has a detent built into it. The detents main purpose is to replace the pin that is currently being used to hold the disk to the rod. Previous testing of the adhesive pads with varying concrete surfaces showed that if a smooth clean surface is used, the adhesive pad could not be removed. The current design of the carousel does not prevent the sample pad from remaining adhered to a surface. In other words, the linear actuator provides 3.4 lb of pushing and pulling force and the pads are so adhesive that they will remain adhered to a dust-free surface, requiring more than 3 lb of force to detach. The new rod and disk design does not require a connecting pin and will snap off if more than 2.5 lb of force are required to detach the pad from the surface.

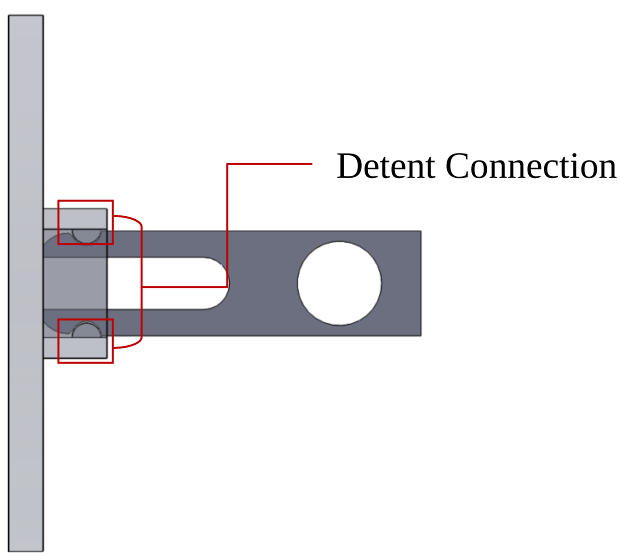


Figure 31: Detent rod and disk assembly, side view.

Figure 31 shows how the detent of the disk fits into the grooves at the end of the stem. The accuracy of the rapid prototyping machine is not very reliable if the dimensions being fabricated are less than .100 inches. The detent of the disk is .100 inches and the groove on the stem is .150. The disk is completely flush against the end of the stem to reduce any looseness between the two parts.

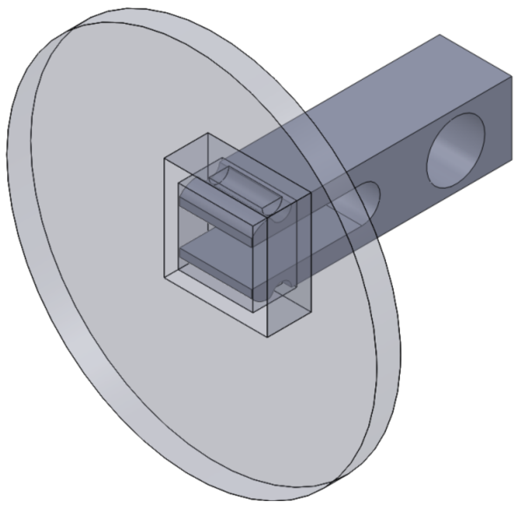


Figure 32: Detent rod and disk assembly.

Figure 32 shows the test model created for the detent. The rod and disk snap together, removing the need for a connecting pin. Also, the new end of the rod is able to flex. If the force needed to remove the disk is greater than 2.5 lb, the ends of the rod will flex in, allowing the disk and sample pad to remain on the surface while the actuator and rod are able to return to their retracted positions.

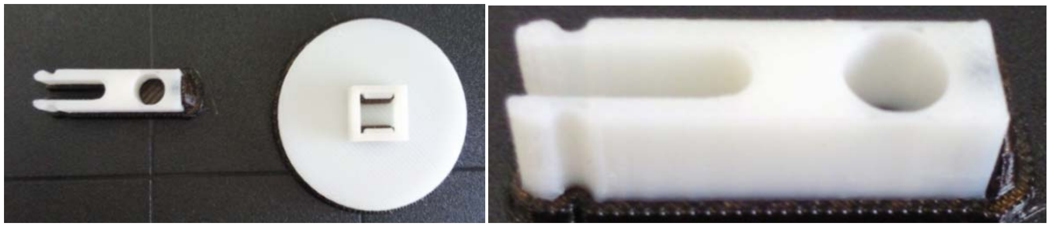


Figure 33: Rapid prototyped parts for detent testing.

Figure 33 shows the first parts printed for the new carousel design. The test detent/snap-on parts were tested with the spring scale shown in Figure 3. The rod was not printed in its entire length, only a small section was printed to test if the end of the stem would flex enough to release the disk when the 2.5 lb force was exceeded. The testing of the test stem concluded that the disk would be released between 2.5 to 3 lb of force.

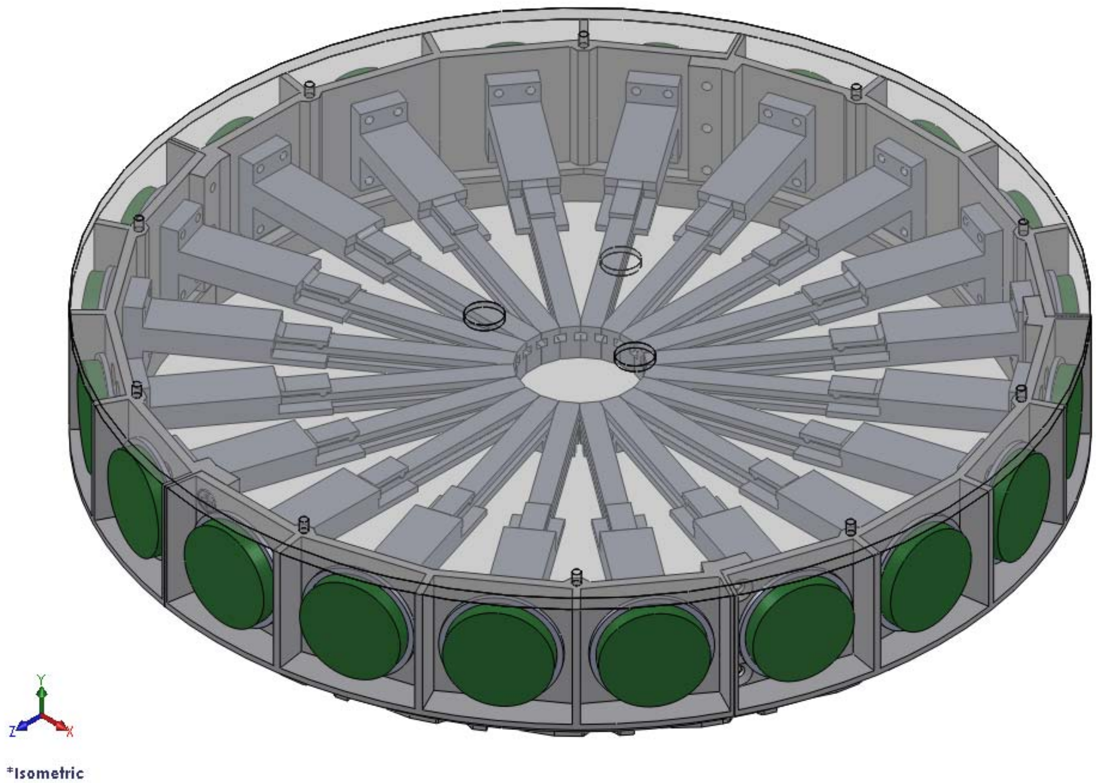


Figure 34: Modified carousel - SolidWorks model.

The carousel consists of 5 side segments, 20 stem supports and 20 stems. At the end of each stem, there is a disk that snaps on to the stem and a collection medium; in this case, double-sided sticky foam tape is adhered to the disk. Figure 34 shows the complete carousel assembly. Because the carousel is removable, there is a 1/8 in plastic cover that screws into the carousel segments that allows the technician to pick up the carousel and remove it from the sampler base and replace it with a new one.

Each collection medium is adhered to a circular disk that snaps onto the front of each stem. The snap-on feature also works in the reverse fashion. If the surface being surveyed is free of loose contamination, the adhesive pad will not be able to be removed by the actuator. If this problem is encountered, the snap feature of the disk will allow the actuator and stem to snap off the disk and adhesive pad, leaving it on the surface, safely letting the actuator return to its retracted position without stalling. Figure 37 shows a sectional view of the sampler with one of the stems extended out. The snap on detent also makes it easier to replace the disk and to remove them from the carousel when they are needed for laboratory testing of the material collected. After the disks have been removed, a new batch of disks can be printed and added to the carousel.

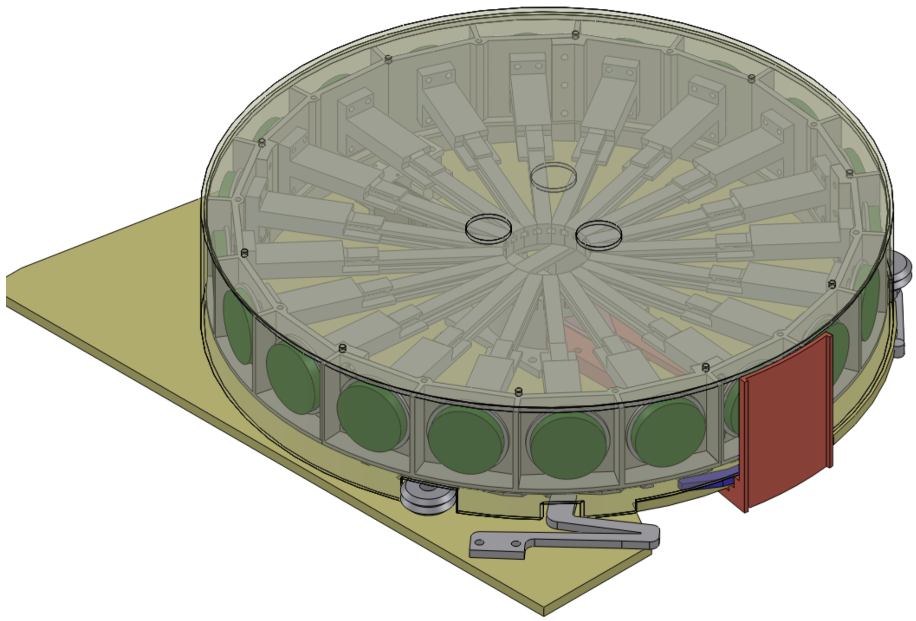


Figure 35: Modified smear sampler with transparent cover.

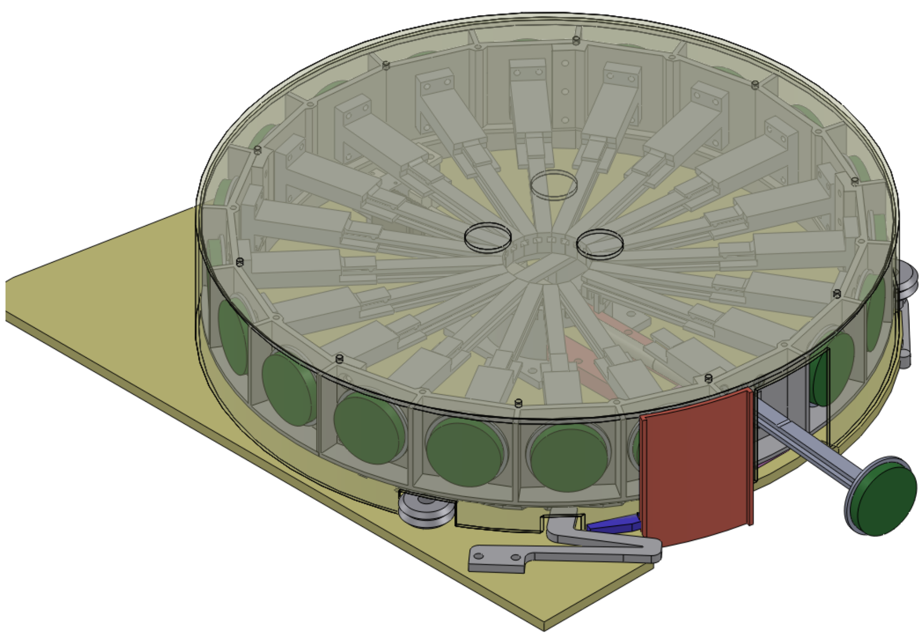


Figure 36: Modified smear sampler taking sampler.

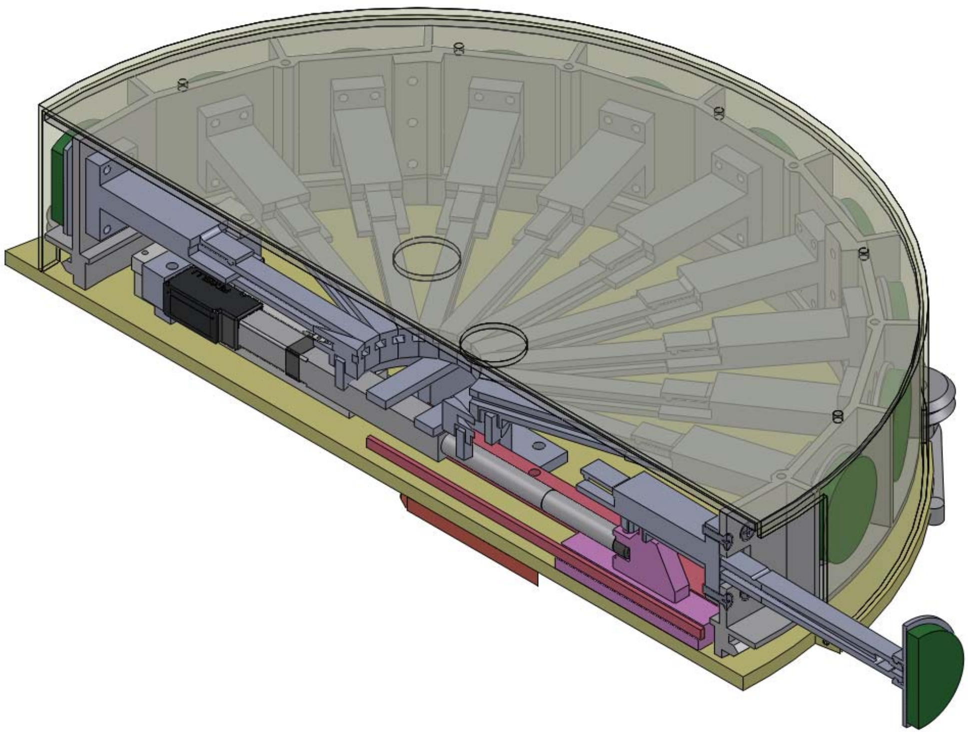


Figure 37: Section view of smear sampler.

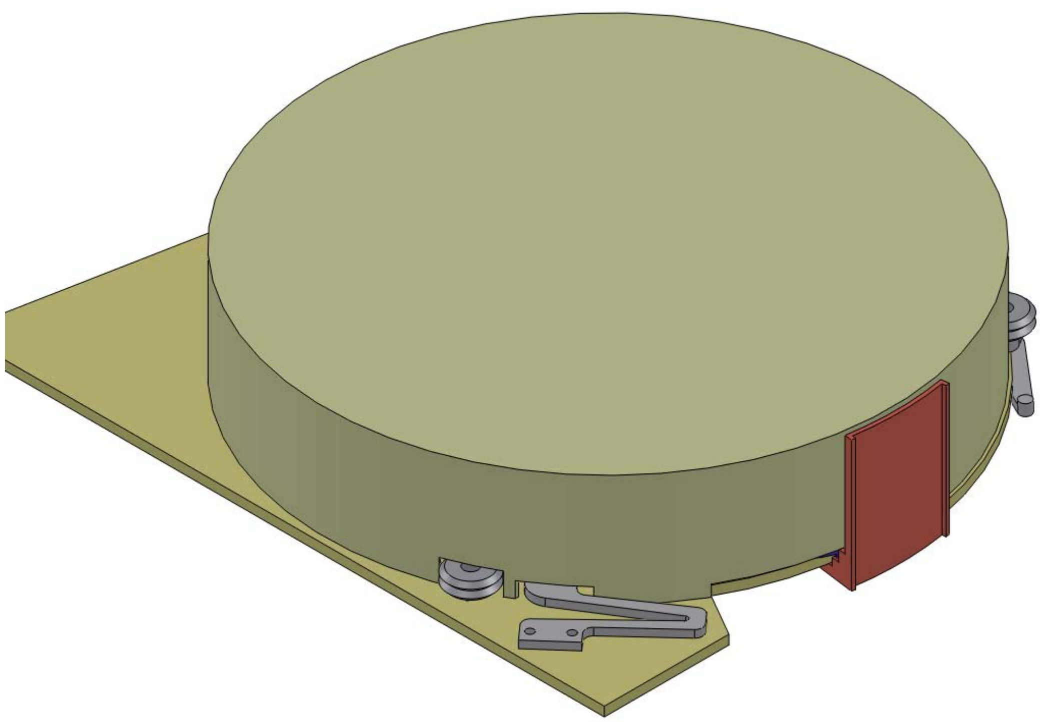


Figure 38: Smear sampler with cover.

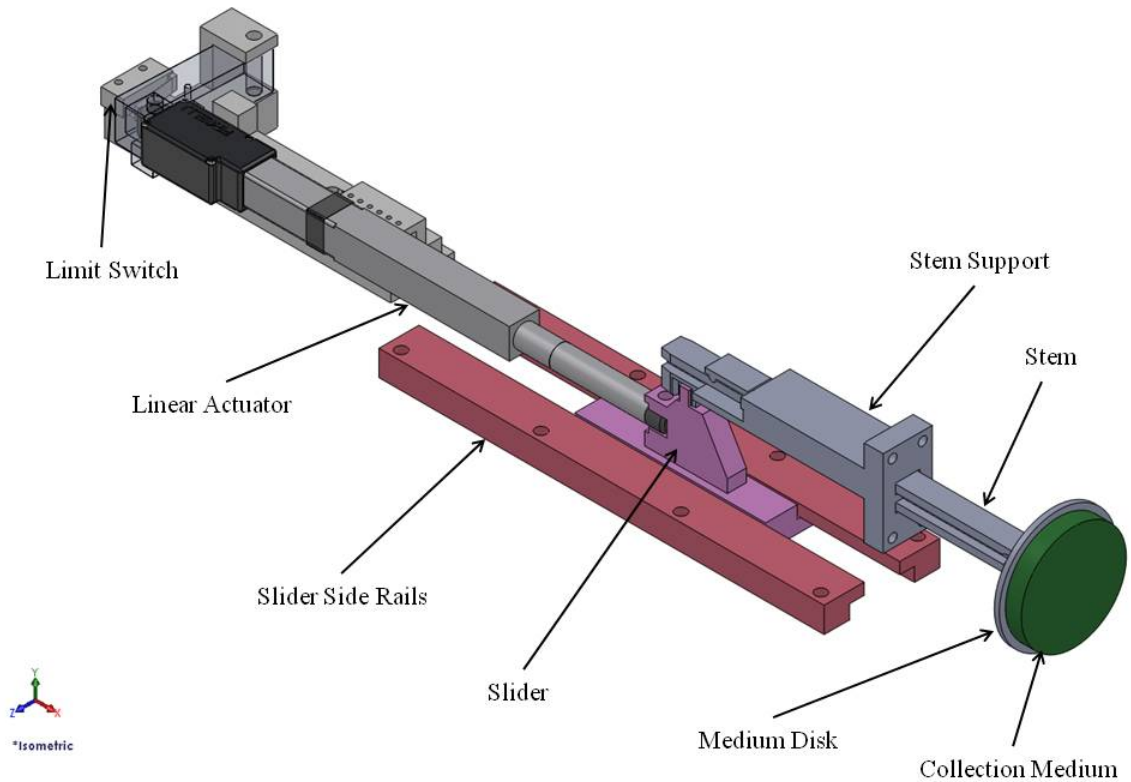


Figure 39: Detailed view of stem, slider and actuator assembly.

The actuator is a Fergelli miniature linear drive motor that exerts a peak force of 3.4 lb for either the pulling or pushing force. The slider is connected to the linear drive motor and the stems are rotated into position so that they make contact with the slider. Figure 39 shows how the stem lines up with the slider. When energized, the actuator will push out the stems until the limit switch is tripped at 1 lb. The limit switch is tripped when the pad has reached the surface to be surveyed. Figure 6 illustrates how the parts need to be lined up in order to take a sample of the surface. Figure 7 shows the complete smear sampler assembly with the carousel cover but without protective cross contamination shield. The second illustration in Figure 7 shows how it will look when it is taking a sample with the access door open and the stem extended out.

Figure 28 showed how the first section of the carousel would look, the segment along with four supports and stems were printed to check the accuracy of the printer when compared to the design models. The remaining four arc sections were not printed, instead the new sections was added to the existing carousel. Because the dimensions were kept the same, one of the original sections was replaced. The supports were fastened to the segment with 16 8-32 screws; each support needs 4 screws (Figure 40).

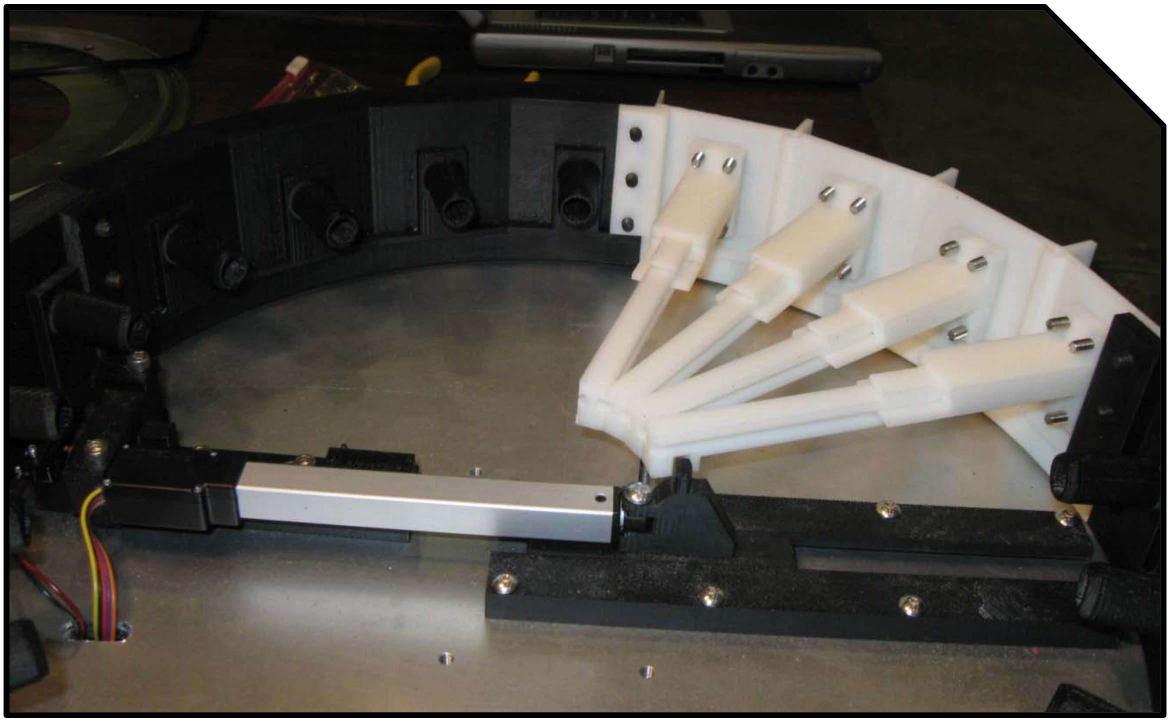


Figure 40: Modified arc segment on original carousel.

Figure 41: Modified arc segment front view.

The new segment was tested on the original carousel; a few components on the sampler base needed to be changed to accommodate the modified segment. A new slider needed had to be printed as the original was too high and did not allow the stems to rotate without colliding with it. In the original carousel design, a stem guide was added to guide the stems as they rotate around and to keep them from slipping in and out. The support detent replaced it because the stems would make contact with the stem guide, resulting in added friction and side force on the stems. The stem guide was not taken out of the design but left in as a secondary component to prevent the stems from sliding out in case a violent hit occurred while the carousel is inside the instrument bay. The stem guide is located in the center of the sampler base. Minor changes needed to be made to the stem guide to accommodate the new stems.

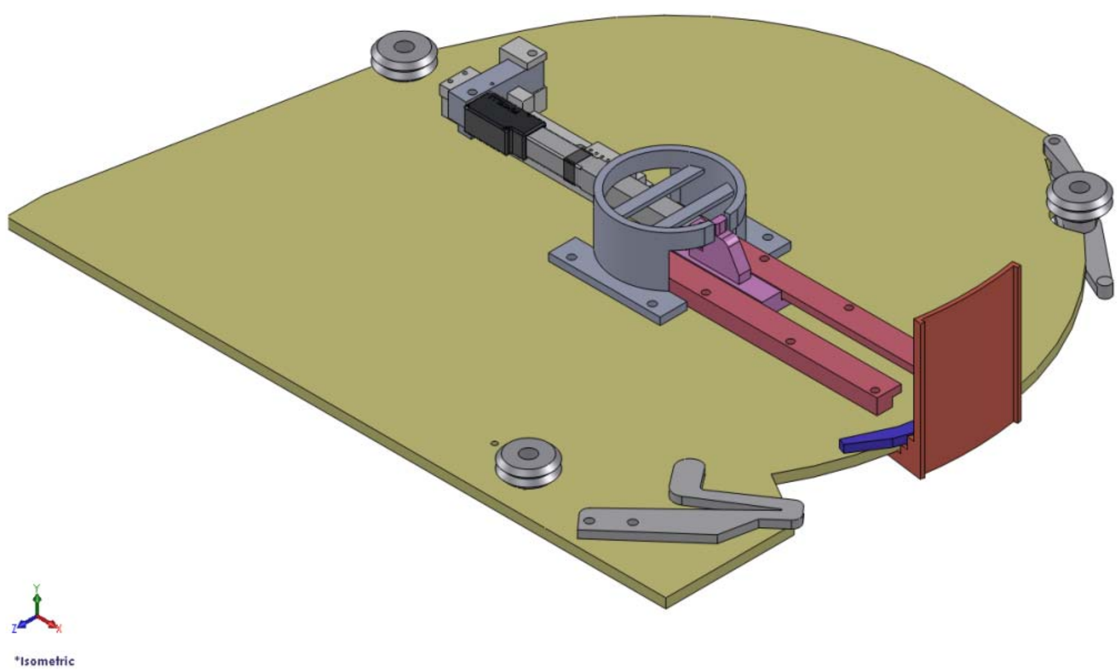


Figure 42: Sampler base.

The new stem guide is lower than the original, a change that was needed after it was noticed that the stems would rub on the guide during testing of the modified arc segment after it was added to the original carousel. After the preliminary testing of the modified segment, the remaining segments were printed. Figure 42 shows the new parts printed from the new designs. All the parts in white were designed and printed during the summer internship, along with the new slider shown in gray.

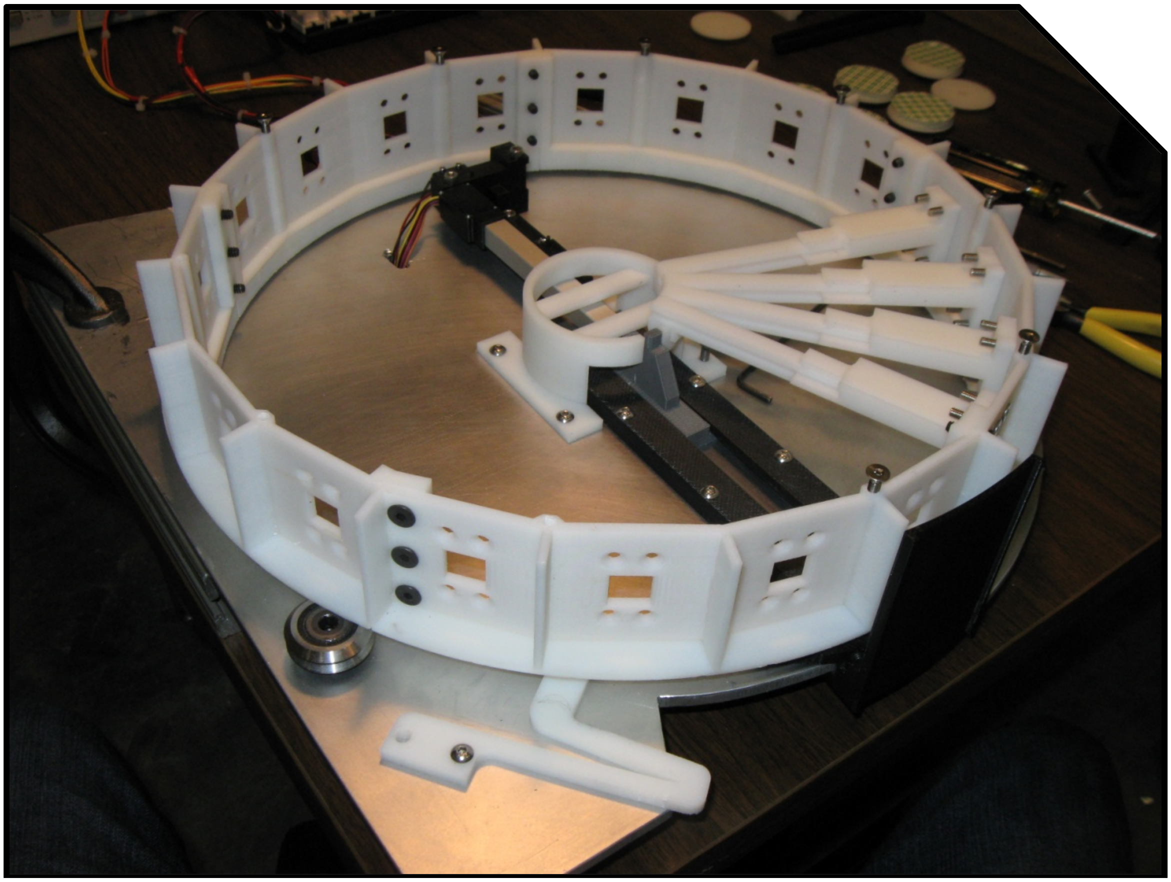


Figure 43: Modified smear sampler.

White is the new chosen color for the sampler. As shown in the CAD model, Figure 38, a cover will protect the entire sampler from cross contamination. During cold testing of the system, it will be observed whether or not any dust or debris is able to make its way past the cover. The white color of the carousel will make it easier to detect where any dust will collect in the unit.

After printing the new parts, a new base detent was printed to see if it could be optimized to provide more stability to the carousel. The detent is the one located on the sampler base, not to be confused with the detents located on the stems. Figure 43 shows the work completed on the sampler at the end of the internship. The remaining supports and stems could not be printed before the internship was over due to software issues between the rapid prototyping machine and the computer that controls it. The remaining components will be printed by the Robotics and Energetic Systems group when the software problems are resolved.

Once the new sampler is assembled, it will be cold tested and any modifications needed will be made. Once the group is satisfied with the sampler's performance, the number of samplers to be included in the SCS will be decided. The group originally estimated between one and three samplers, depending on what the ORNL HP's decide is appropriate.

3.4 Core Drill

A core from the inside of the stacks may be needed. The SCS will have several cameras and a radiation detector located inside its instrument bays. The detectors and cameras will provide real time data back to the operators; if a location is found to have a high level of radiation, a core sample will be taken from the wall. Also, if the onsite HP decides that a particular location needs to be cored, a sample will be taken.

Current core drills are motorized units that are able to core to a certain distance. Almost all core drills are operated by workers and are able to take one core at a time. A core sample within the stack needs to be taken remotely; no unit has been found that is able to take samples remotely or able to take more than one sample. During the summer 2010 internship, most of the work for the first half was involved in designing a core drill mechanism capable of retrieving six core samples. A total of eight core drill designs were created. After the first design, a second better design was created; that process continued until the eighth and final design was completed.

Preliminary components for the core drill were provided by the group at the beginning of the internship. The core drill design needs to be modeled using initial dimensions for the components that will be used. Figure 44 corresponds to the dimensions for the 2 horsepower iron-horse motor that is the first choice motor for the Robotics group. Figure 45 corresponds to the Firgeli linear actuator. The actuator is capable of providing 200 lbs of force for pushing and pulling actions. The entire drill assembly needs to be 24 inches long and the bits need to core 6 inches into the concrete.

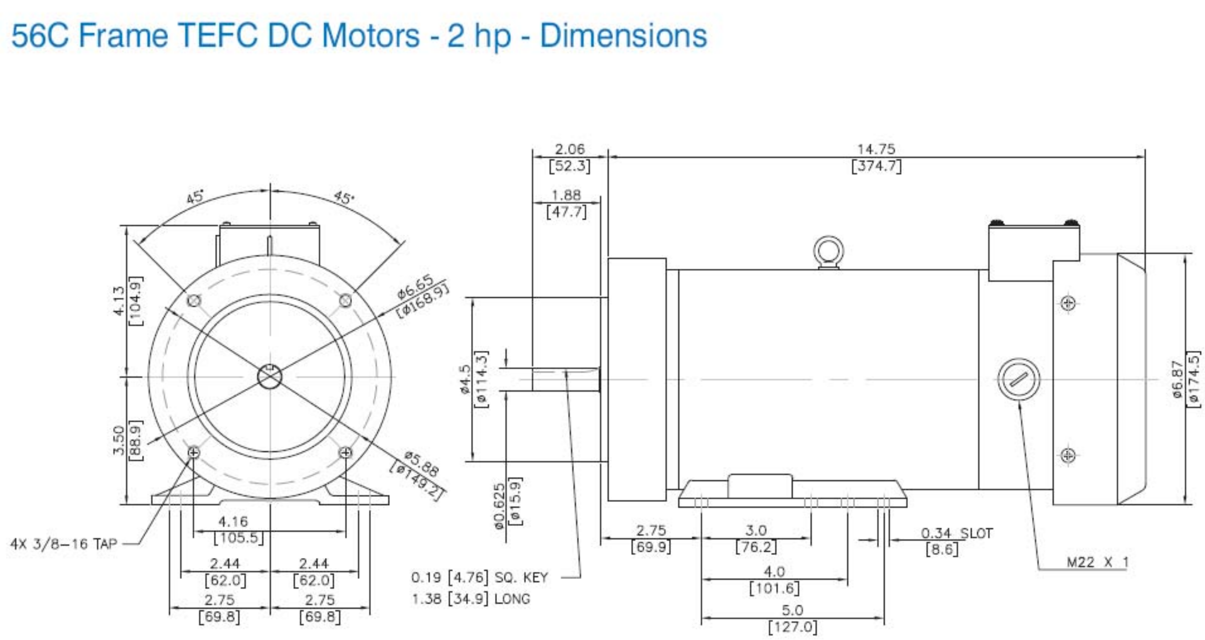


Figure 44: 2 HP iron horse motor dimensions.

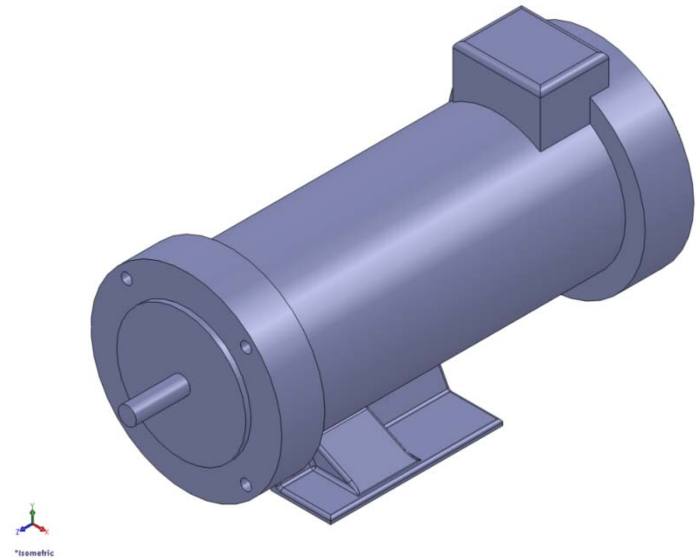


Figure 45: Motor modeled on SolidWorks.

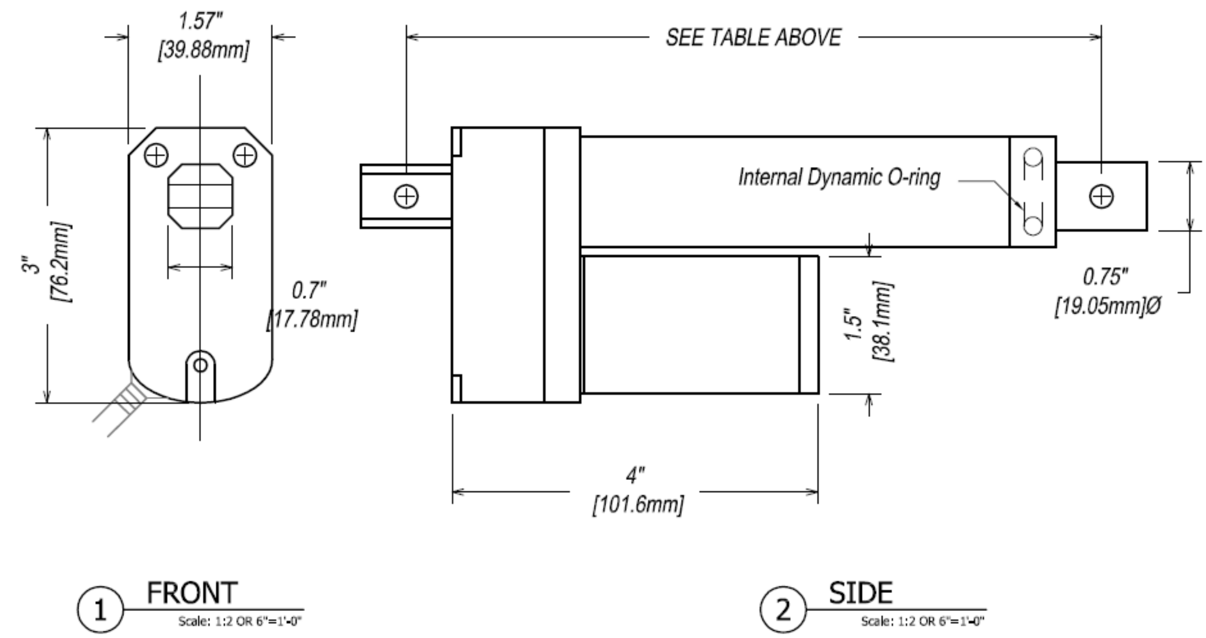


Figure 46: Fergeli 200 lb force linear actuator dimensions.

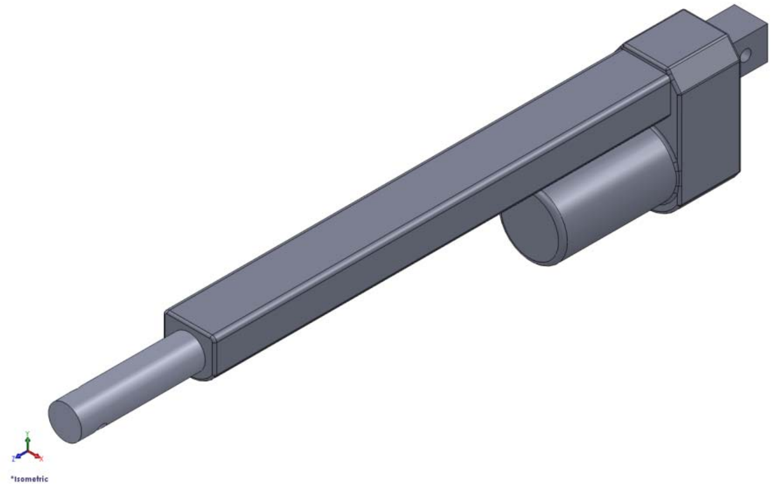


Figure 47: Actuator modeled on Solidworks.

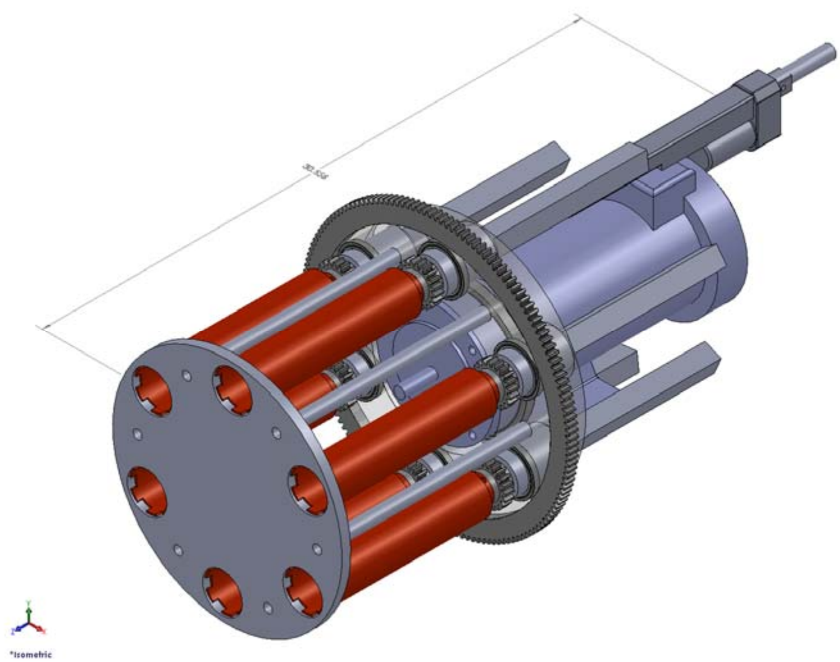


Figure 48: Initial core drill design with retracted core bits.

The first core drill design has the drive motor located towards the back of the assembly (Figure 48). The six core drills are mounted to two plates that are capable of revolving around the central axis with the aid of a cross roller bearing. The bearing is located on the outer housing of the motor. Each core bit is driven by a gear that can only be engaged by the central gear on the drive motor. Only one core drill gear can be engaged at a time. One larger gear is located on the outside of the plate that holds the core bits. A second motor will drive the gear allow the core bits to rotate in the clockwise direction. Once the core bit is ready to drill, it will be engaged by the drive motor and will be advanced forward by the 200 lb linear actuator, as shown in Figure 49.

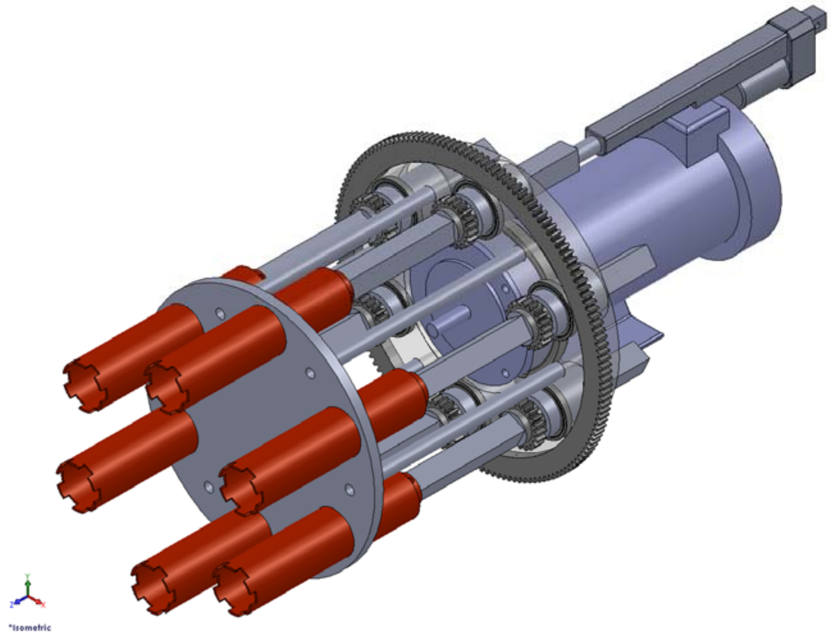


Figure 49: Initial core drill design extended core bits.

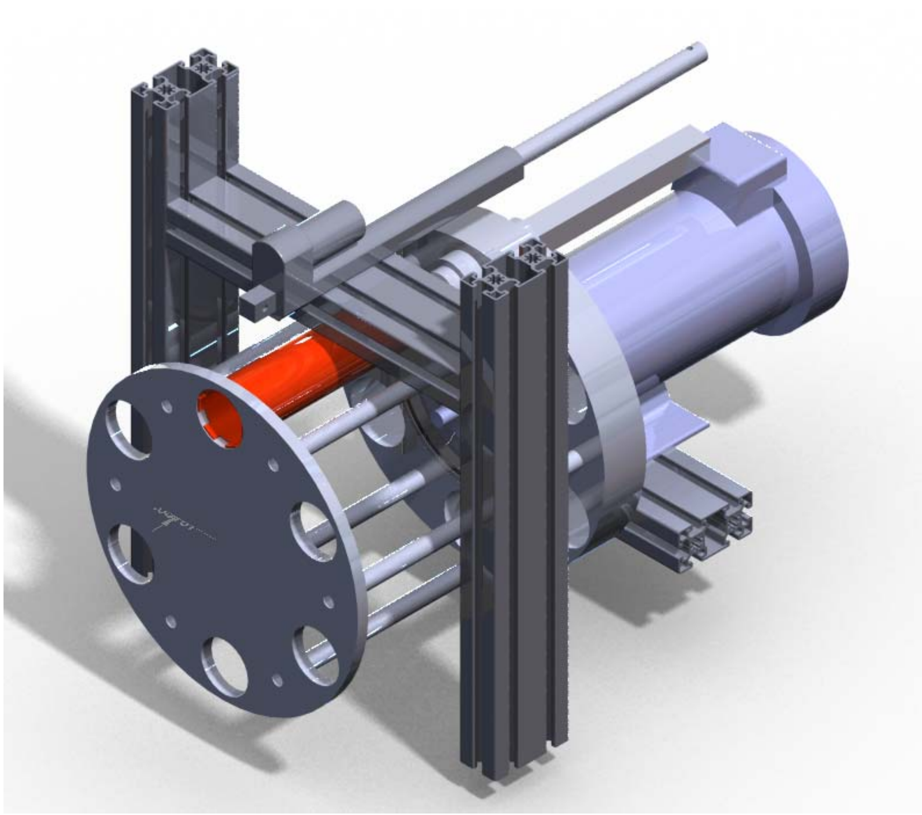


Figure 50: Core drill on mounting frame.

Figures 48 and 49 illustrate the design created for the drill but due to the length of the whole assembly, 32 inches, the linear actuator needs to be repositioned. Figure 50 shows one attempt with the actuator above the core bits and the motor. In this figure, there are 8020 extruded aluminum struts to support the motor and the actuator. Figure 51 illustrates the 5th design of the core drill. This design has the motor placed between the plates. The plates are used to hold the core bits and then guide them in a linear path as it beings to drill into the concrete. Design 5 reduced the overall length of the system, now at 25 inches at its maximum length. The design also has a connection made between the back end of the shaft and the linear actuator. Also, core bit guides were added to the end of the core bits that allow the core bits to stay in the retracted position as they spin around the drive motor. Around the middle of the drive motor, an aluminum circular plate is mounted so that the core bit guides can rotate around.

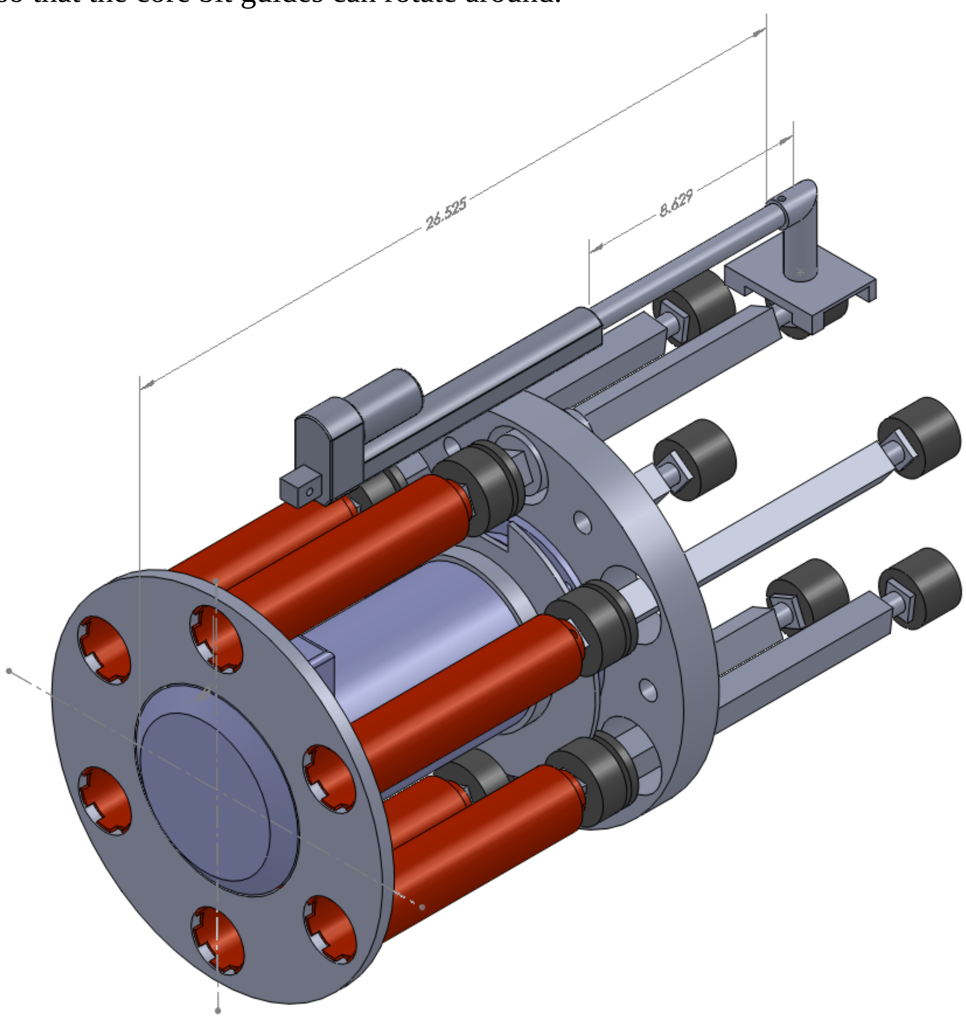


Figure 51: Core drill design #5.

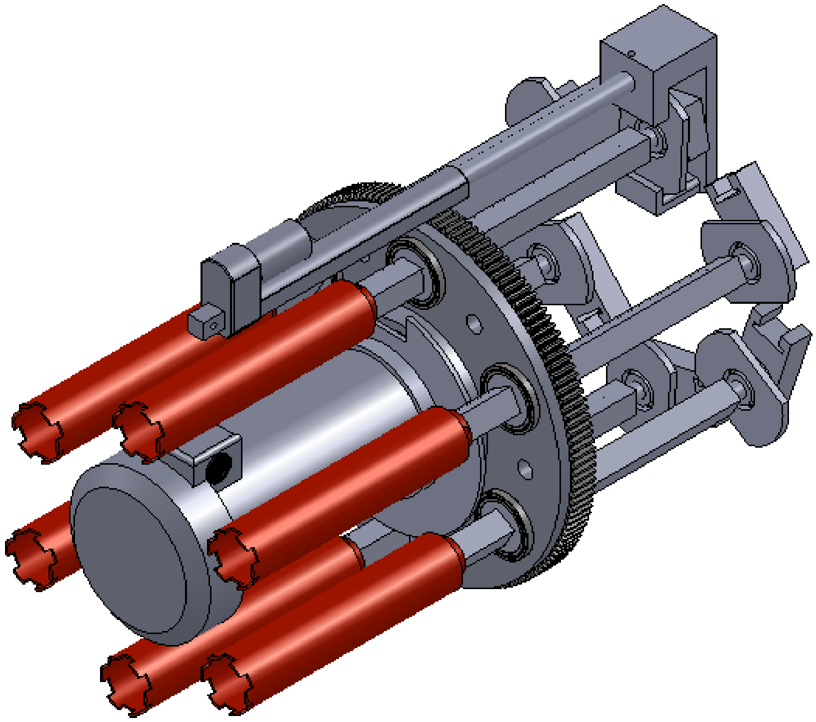


Figure 52: Core drill design #7, isometric view.

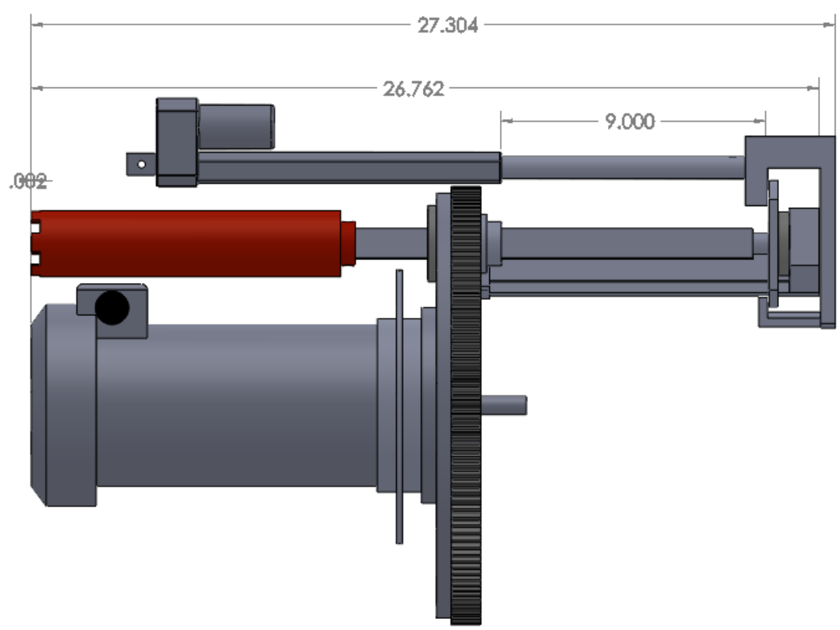


Figure 53: Core drill design #7 with 9 inch linear stroke.

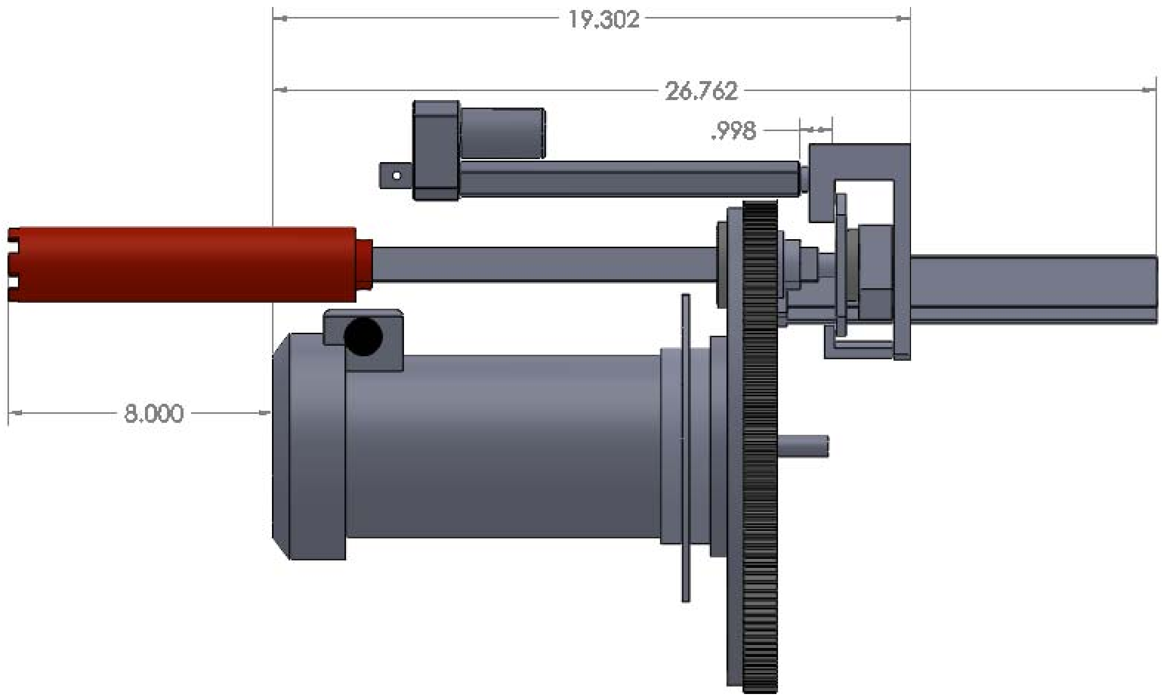


Figure 54: Core drill design #7, view with 8 inch drill bit extrusion.

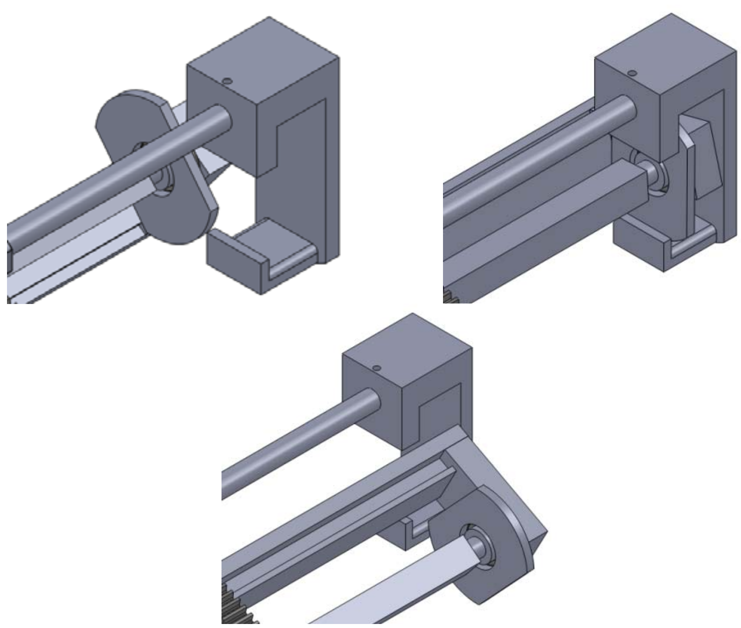


Figure 55: Linear actuator pusher.

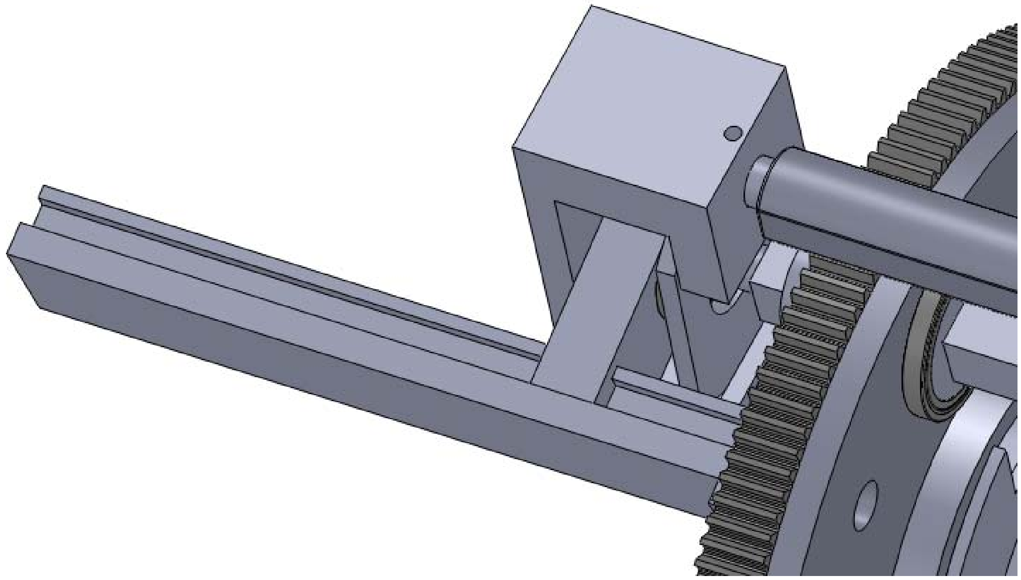


Figure 56: Slider connection.

Figure 52 shows the seventh design of the core drill. Though the design does not differ much from the previous ones, it does have an improved actuator connection. The connector (Figure 55) allows the drill bits to move forward and back along the slider configuration (Figure 56) added to the back of the turret. The slider is added to remove any additional stresses and moments from the linear actuator. In other words, the linear actuator will only need to move the bits forward and back while the slider holds them in place. Each drill bit has its own slider and pushing plates as it can be seen in Figure 52. The pushing plates are what will be pushed back on when moving the drill bit back into its original position by the linear actuator connector. When moving the bits forward, the connector will push on the back of the slider (Figure 54). Figure 59 shows the dimensions of the core drill; the drill needs to core 8 inches into the wall and a 6 inch core needs to be recovered for a proper sample.

After the core drill reaches its 8 inch depth into the concrete, the core sample needs to be removed from the wall. Because the drill is coring in the horizontal direction, the core needs to be broken off and held in the core bit while the bit is being retracted to its initial position. In order to achieve the needed outcome, a combination of a break-off tool and a vacuum will be used. The vacuum will ensure that the dust created from the drilling is not allowed to spread inside the stack and further contaminate the SCS or cross contaminate the other core samples. The break-off tool is a stainless steel wedge that will be actuated in order to break the end of the core sample from the wall (Figure 57).

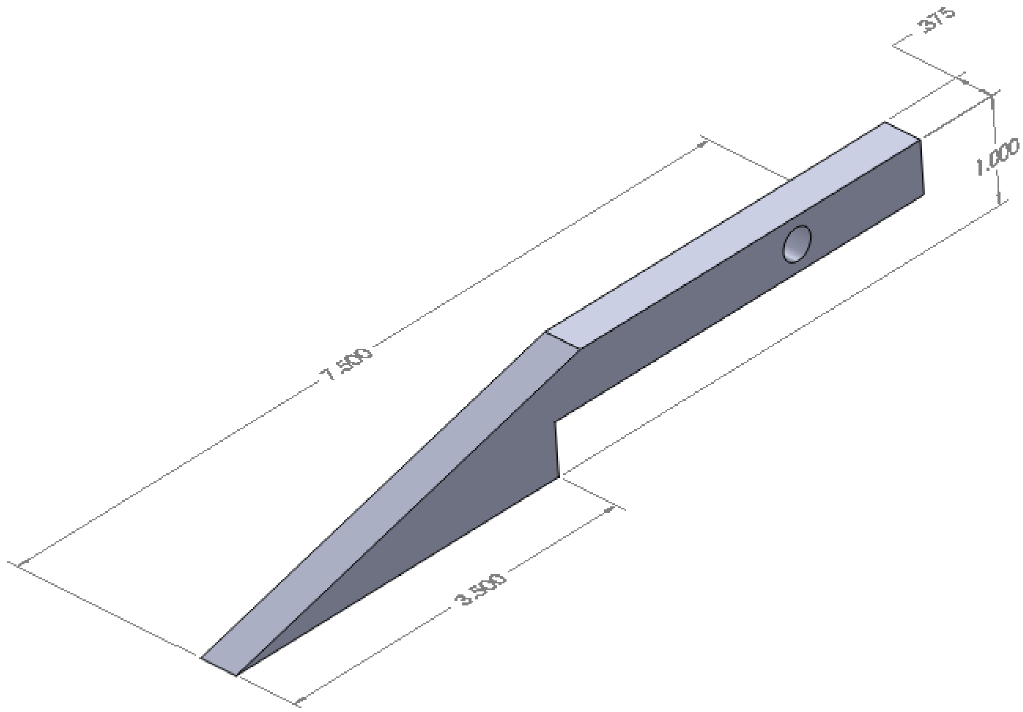


Figure 57: Break off tool.

The break-off tool is currently located inside the core bit. Once the required depth is reached, the tool will be advanced using another actuator. Its actuator needs to provide enough forward force to wedge the tool underneath the core sample and lift it as the tool advances forward. The tool needs to have a stroke of 2 inches. The actuator should have a pushing force of at least 30 lbs.

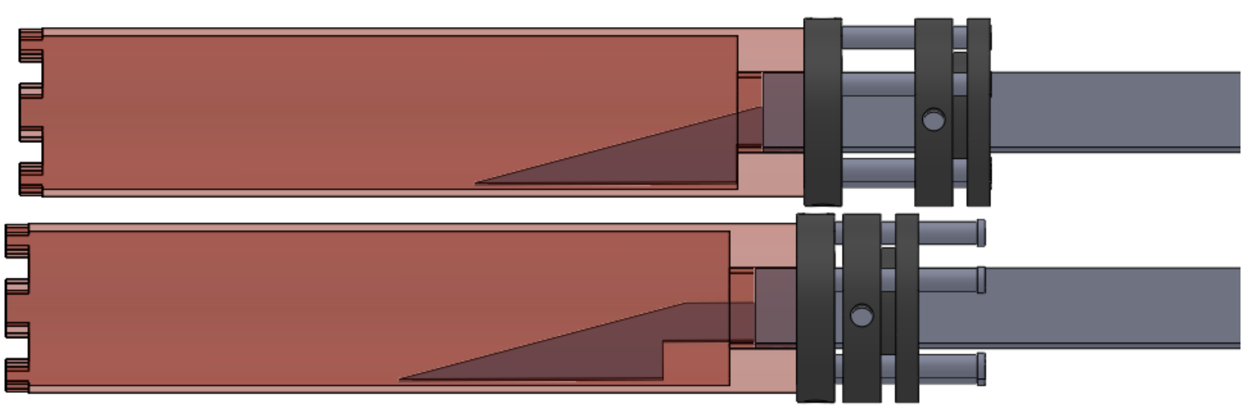


Figure 58: Break-off tool advancement.

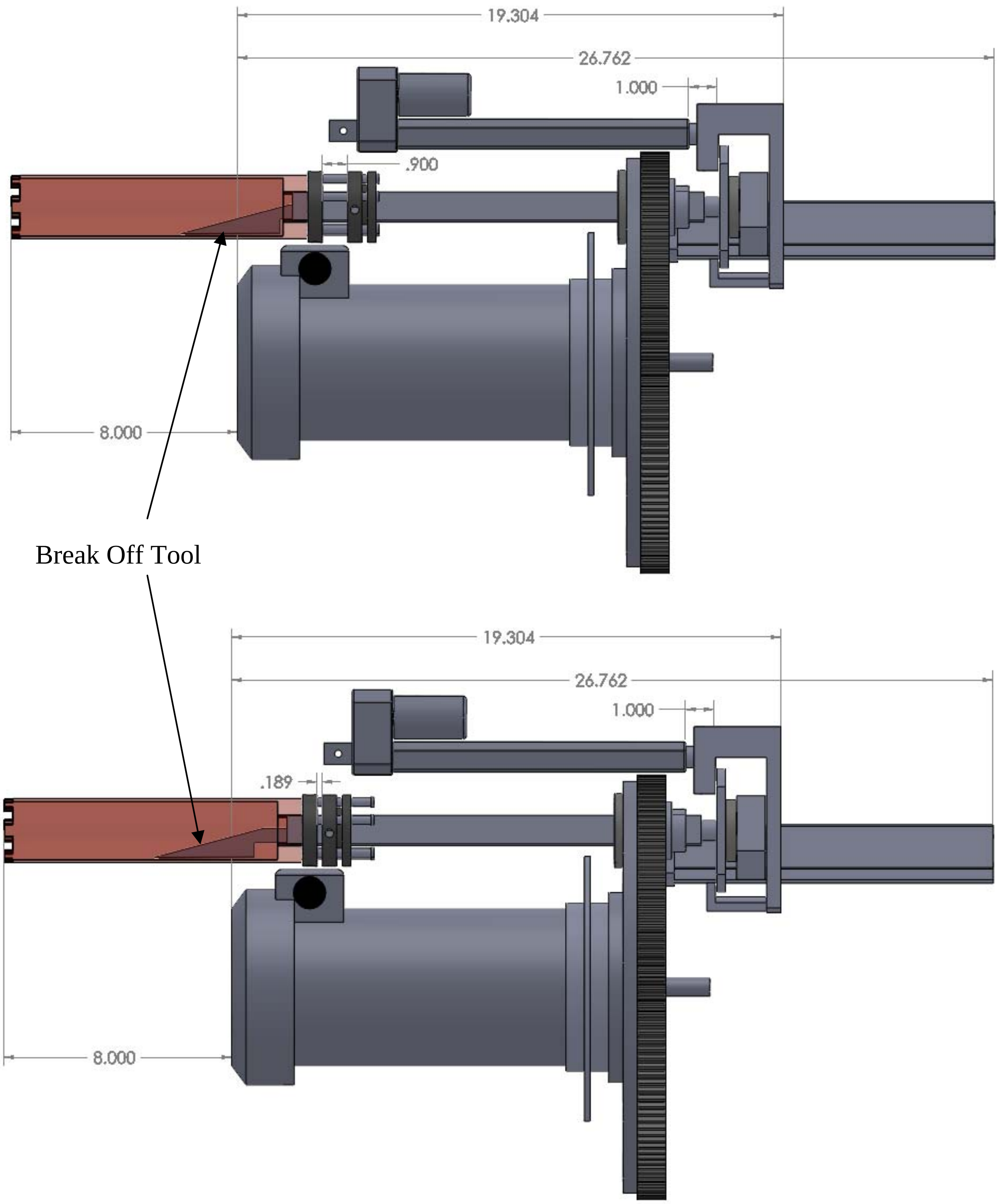


Figure 59: Core drill with break-off tool.

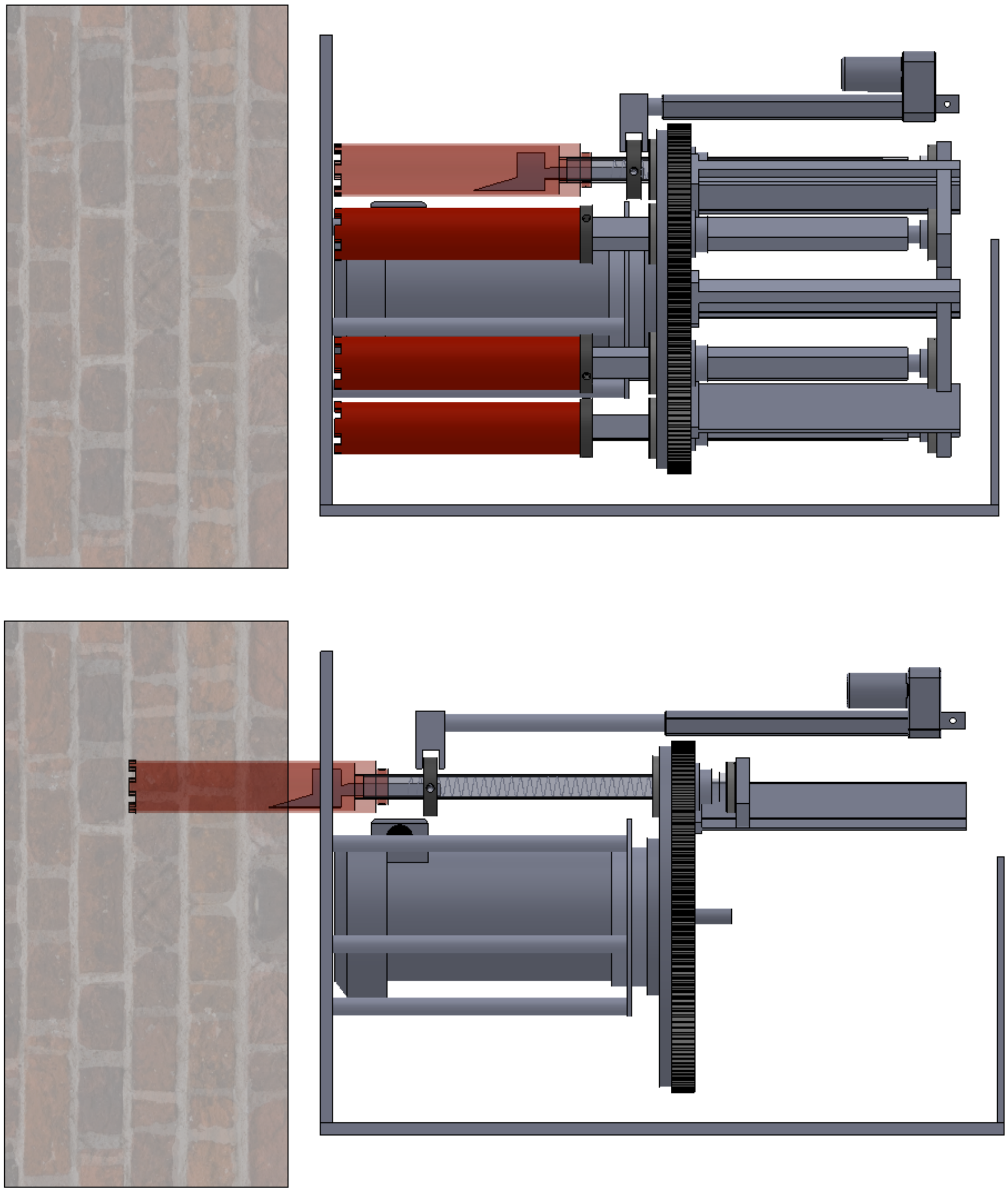


Figure 11: Updated core drill design.

The SCS will run on batteries so an update to the core drill design had to be made by reducing the need for a linear actuator. The same actuator that controls the position of the core bit will also move the wedge forward. A pre-loaded spring has been added inside the core bit shaft. The spring will be pre-loaded to 50 lb. As the actuator moves the shaft forward, using less than 50 lb, the entire core bit assembly and wedge will move forward. When the desired depth has been achieved, the actuator will apply more than 50 lb force; the shaft and core bit will not move but the wedge inside will begin to move forward because the pre-loaded tension of the spring will have been exceeded.

4. RESULTS AND ANALYSIS

During the summer internship, experimental tests were conducted on the material needed for collecting the loose material on the surface walls of the stacks. As discussed in the collection material experimental test section, the collection materials were tested on different types of surfaces. The material that performed the best was the double-sided adhesive foam tape. The adhesive foam tapes are rigid enough to collect a good amount of material and the double-sided sticky ends of the tapes serve their own purpose. One side of the tape will adhere to the disk located at the end of the stems and the other sticky side is the side that will collect the loose material.

During the testing with the double-sided tape, it was observed that if a clean surface were encountered, the adhesive would stick to the wall itself. With a lack of loose material to collect, the adhesive pad would not be able to be removed from the wall with the three pound actuator, potentially stalling or burning out the actuator. To reduce the risk of losing the actuator during sample collection, a snap-off feature was added to the disk to ensure that if the pad could not be removed from the wall, the disk would snap off, allowing the actuator to retract.

After testing the collection material, the double-sided sticky tape was added to the original prototyped sampler and the carousel was put to its first field test. The visual results from the field tests concluded that the pads would collect any loose material on the concrete surfaces and that the snap-off feature worked as designed. The overall design of the sampler was sufficient in producing a mechanism capable of retrieving surface samples.

5. CONCLUSION

The summer internship provided a chance to assist an in-progress project that requires the work of different engineers and engineering disciplines. The work completed during the internship included a core drill design capable of retrieving six core samples, a design for a radiation detector deployment mechanism, re-designs to a currently designed mechanism capable of collecting loose material from concrete surfaces and experimental testing to determine the best collection material for the sampler.

Before the end of the internship, a re-design for the smear sampler was created, modeled in a 3D CAD software and actual fabrication and assembly of the carousel took place. Once the remaining components of the carousel are printed, it will be retested and updates to the design will be evaluated.

The core drill design was completed and, along with lessons learned on the design, was used on a final design completed by the head mechanical engineer of the Robotics and Energetic Systems group.

6. REFERENCES

1. International Atomic Energy Agency, *Dismantling of Contaminated Sacks at Nuclear Facilities,* Technical Report Series Number 440
2. International Atomic Energy Agency, *Radiological Characterization of the Shut Down Nuclear Reactors for Decommissioning Purposes*, Technical Report Series Number 389
3. Taboas, A.L., A.A. Moghissi, and T.S. LaGuardia, , *The Decommissioning Handbook*, The American Society of Mechanical Engineers (ASME), 2004

APPENDIX A: RADIATION DETECTOR PRODUCT SHEETS

Model 44-88 Pancake G-M Detector

Ludlum Measurements, Inc.

PART NUMBER:47-2356

INDICATED USE: Alpha beta gamma survey; Sample counting
DETECTOR: Pancake type halogen quenched G-M
WINDOW: 1.7 plus or minus 0.3 mg/cm^2 mica
WINDOW AREA:
Active - 15 cm^2
Open - 12 cm^2
EFFICIENCY(4pi geometry): Typically 5%-C-14; 22%-Sr-90/Y-90; 19%-Tc-99; 32%-P-32; 15%-Pu-239
SENSITIVITY: Typically 3300 cpm/mR/hr (Cs-137 gamma)
ENERGY RESPONSE: Energy dependent
DEAD TIME: Typically 80 microseconds
COMPATIBLE INSTRUMENTS: General purpose survey meters, ratemeters, and scalers
OPERATING VOLTAGE: 900 volts
CONNECTOR: Series "C" (others available)
CONSTRUCTION: Aluminum housing with beige polyurethane enamel paint
TEMPERATURE RANGE: -4° F(-20° C) to 122° F(50° C)
May be certified for operation from -40° F(-40° C) to 150° F(65° C)
SIZE: 2.3" (5.7 cm) Diameter X 2.8" (7 cm)L
WEIGHT: 0.5 lb (0.2kg)

P.O. Box 810, Sweetwater, Texas 79556 / http://www.ludlums.com
800-622-0828 / 325-235-5494 / Fax: 325-235-4672 / E-mail: ludlum@ludlums.com

Model 43-1-1 Dual Phosphor Alpha/Beta Scintillator

Ludlum Measurements, Inc.

Part Number: 47-2336

INDICATED USE: Alpha-beta survey
SCINTILLATOR: ZnS(Ag) adhered to 0.010" thick plastic scintillation material
WINDOW: Typically 0.8 mg/cm² aluminized mylar (1.2 mg/cm² recommended for outdoor use)
WINDOW AREA:
Active - 83 cm²
Open - 75 cm²
EFFICIENCY (4pi geometry): Typically 30% - Pu-239; 30% - Sr-90/Y-90; 5% – C-14
BACKGROUND:
Alpha - Less than 3 cpm
Beta - Typically 300 cpm or less (10 microR/hr field)
NON-UNIFORMITY: Less than 10%
CROSS TALK:
Alpha to Beta - Less than 10%
Beta to Alpha - Less than 1%
COMPATIBLE INSTRUMENTS: Model 2224, 2225, 2929
TUBE: 1.5"(3.8cm) diameter magnetically shielded photomultiplier
OPERATING VOLTAGE: Typically 500 - 1200 volts
DYNODE STRING RESISTANCE: 100 megohm
CONNECTOR: Series "C" (others available)
CONSTRUCTION: Aluminum housing with beige polyurethane enamel paint
TEMPERATURE RANGE: -4° F to 122° F (-20° C to 50° C)
May be certified for operation from -40° F to 150° F (-40° C to 65° C)
SIZE: 4.8" diameter X 9.8"L (12.2 X 24.9cm)
WEIGHT: 2 lb (0.9 kg)

P.O. Box 810, Sweetwater, Texas 79556 / www.ludlums.com
800-622-0828 / 325-235-5494 / Fax: 325-235-4672 / E-mail: ludlum@ludlums.com

APPENDIX B: DEPLOYMENT MECHANISM PART SHEETS

PRODUCT INFORMATION Mini Linear Actuators

FIRGELLI AUTOMATIONS

Shipping Warehouse: 1465 Slater Road, Ferndale, WA 98248
Corporate Head Office: Suite 201, 3020-152nd Street Surrey BC Canada V4P 3N7
Tel, 1 866 226 0465 Fax 1 866 226-1649
E-mail: sales@firgelliauto.com www.FirgelliAuto.com

- Low noise design
- Enhanced corrosion resistance
- Aluminum outer and inner tube
- Zinc alloy housing
- Powder metal gears
- Lubrication for longer life
- Mini compact Design
- Low Price

Specifications

Model	FA-MS-8-12-xx" (High Speed)	FA-MS-15-12-xx" (Standard Force)
Input Voltage	12 VDC	
Load Capacity	8 lbs	15lbs
Static Load	2 x max load capacity	
Stroke Length	2" to 12"	
Speed at No Load	1.5"/sec	3/4"/sec
Size	1" x 1.25" Square	
Clevis Ends	0.22" diameter	
Screw	ACME screw	
Gear Ratio	5:1	20:1
Duty Cycle	20%	
Operation Temperature Range	-26°C~65°C (-15°F~150°F)	
Limit Switch	Built-in (Factory Preset) Not movable	
IP Grade	IP54 (dust and splash proof)	

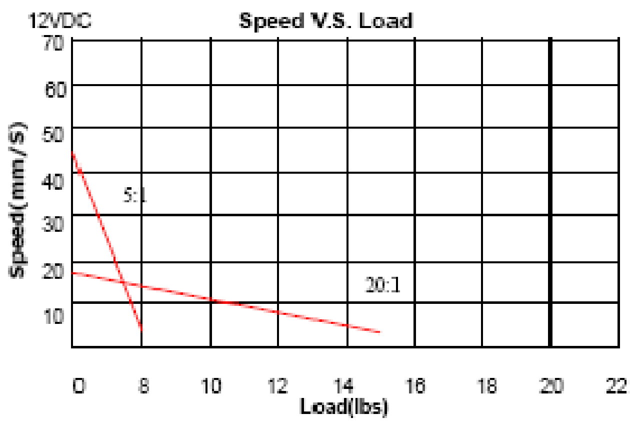
MB4 bracket set (2 brackets) fits only the mini style actuators

PRODUCT INFORMATION Mini Linear Actuators

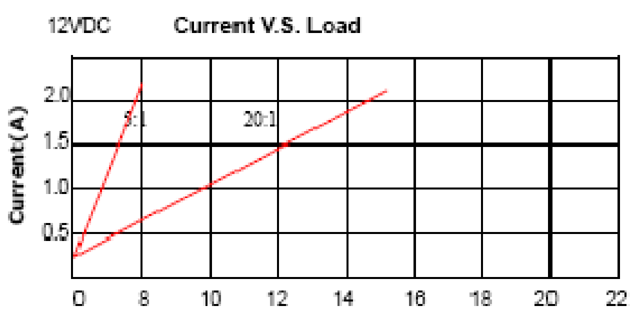
Stroke/weight

stroke length	weight
2"	385g / 0.85lb
4"	430g / 0.95lb
6"	475g / 1.05lb
8"	520g / 1.15lb
12"	610g / 1.35lb

LOAD/SPEED



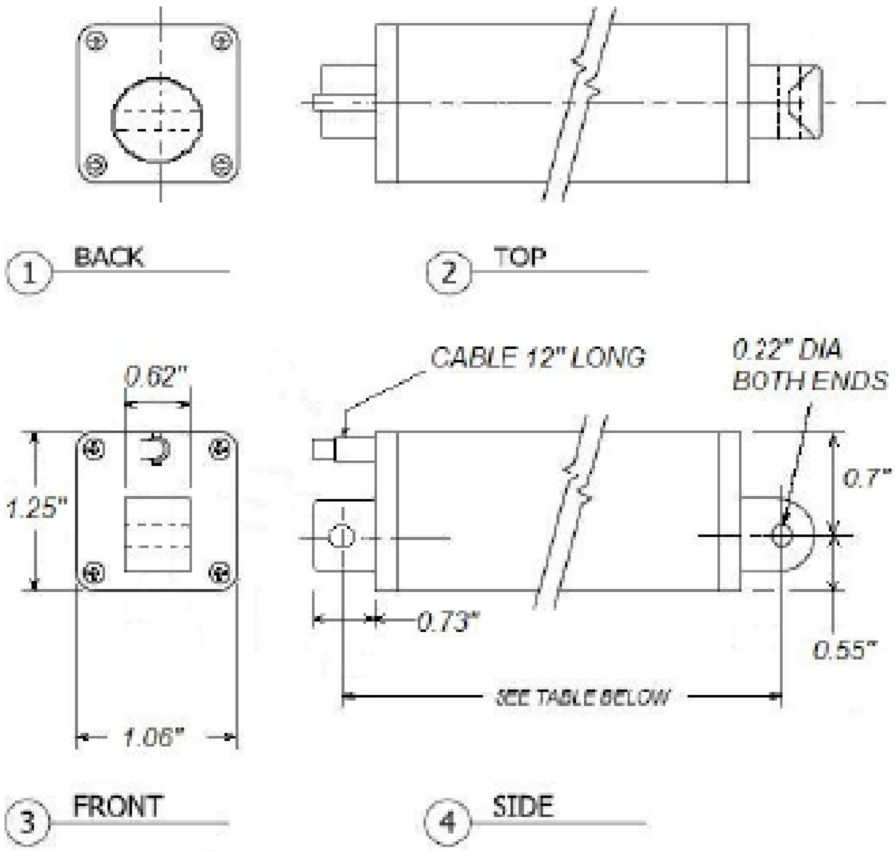
LOAD/CURRENT



PRODUCT INFORMATION Mini Linear Actuators

Load (lbs)

Dimensions:

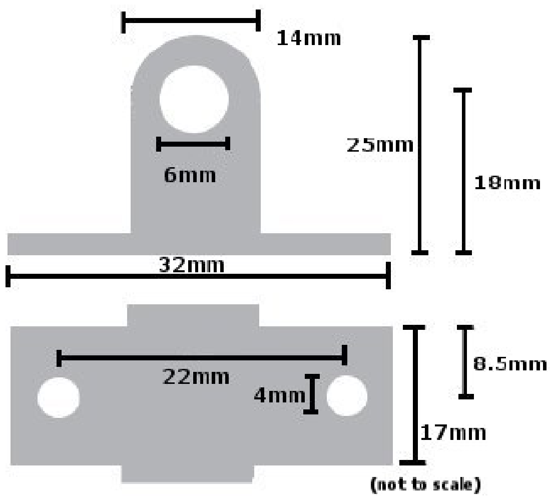


Stroke	Closed Length	Open Length
2"	7.9"	9.9"
4"	9.9"	13.9"
6"	11.9"	17.9"
8"	13.9"	21.9"
12"	17.9"	29.9"

- This model actuator uses Firgelli Automations MB4 Brackets on both ends of the actuator.

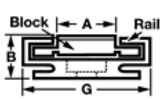
Please visit our website for latest prices and to purchase
www.FirgelliAuto.com

- low profile
- light weight
- add approximately 1/2" to the length of the actuator when installed
- chrome plated steel
- free to rotate almost 180 degrees
- each set comes with 2 brackets and 2 cross pins



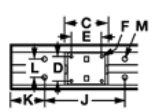
Low-Profile PTFE-Lined Plain-Bearing Guide Blocks and Rails


11-, 112-, and 157-lb. Cap. Guide Block and Rail (Sold Separately)



11-, 112-, and 157-lb. Cap. Block and Rail (End View)


225-lb. Cap. Guide Block and Rail (Sold Separately)



225-lb. Cap. Block and Rail (Top View)

Low profile, low friction, and low maintenance. Recommended for light to moderate loads, and high speed and acceleration applications where tight tolerances are not required. Max. temp. is 176° F.

Guide Blocks— Zinc-chromate steel (unless noted) with a PTFE liner, so they ride smoothly and quietly on the rail. They resist dust, dirt, and water, and are self-lubricating. Blocks have two threaded mounting holes (except for **6723K11**, which has two unthreaded holes and 6723K13, which has four threaded holes).

Rails— Are anodized aluminum. **To Order:** For rails, please specify length from choices listed in the table.

Note: Guide blocks and rails are sold separately. Guide blocks can only be used with rails listed on the same line in the table.

Static Load Cap., lbs.	Guide Blocks (Dimensions in mm) (A)	(B)	(C)	(D)	(E)	Mtg. Holes, Dia. x Dp. (F)		Each	Rails (Dimensions in mm) (G)	(J)	(K)	(L)	Mtg. Holes (M)	Available Lengths		Per mm
11	9.6	6	20	___	14	M3 x 5	6723K9‡	$5.08	17	60	40	___	M3	500, 1000, 1500, 2000	6723K5	$0.06
112	14	9.5	40	___	20	M4 x 5	**6723K11**	7.74	27	60	40	___	M4	500, 1000, 1500, 2000	6723K2	.07
157	23	9.5	50	___	20	M4 x 8	6723K12	18.02	40	60	40	___	M4	500, 1000, 1500, 2000	6723K3	.09
225	57	12	80	45	56	M4 x 7	6723K13	24.57	80	150	25•	40	M4	500, 1000, 1500, 2000	6723K4	.12

‡Guide block is plastic with zinc-chromate steel mounting plate. Dimension (K) is 20 mm on 1000-mm long rails; 30 mm on 1500-mm long rails.
•Dimension (K) is 50 mm on 1000-mm long rails; 75 mm on 1500-mm long rails.