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MECHANICAL ENGINEERING

In Situ Analysis between Reinforced Fibers
100% Senior Design Report

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Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of JEAN PAUL ARROYO and EDUARDO ESCOBAR and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract

The American Society for Testing and Materials (ASTM) currently has a defined standard for measuring the coefficient of friction between yarns. However, this standard is not recommended due to a lack of precision among different laboratory testing. This variance can likely be attributed to slight differences in environment as well as natural human error.

Brisk Engineering has decided to take on the task of re-creating this testing standard, and modifying it in such a manner that the previously-mentioned "lack of precision" would be a problem of the past. The proposed design will take the current testing standard, and miniaturize it to the point of being fit for analysis under a scanning electron microscope (SEM). Other features planned for the design are the additions of remotely-adjustable input tensions and yarn collection speeds.

The team will be working in collaboration with Dr. Benjamin Boesl, who specializes in the implementation of the novel experimental testing procedures as well as the computational methods. This project has the potential to have a much broader impact than simply rubbing strings together. By updating the testing standard, other researchers will be able to conduct similar experiments and achieve precise and comparable results. This project should serve a useful purpose to anybody in the field of Material Sciences.

Problem Statement

The design of an updated model of the ASTM standard is required in order to maintain precision among laboratory tests, and thereby deserve the recommendation by ASTM for practical and accurate use. The goal is to standardize this model by creating one small universal testing apparatus, as well as incorporating SEM imaging for further precision.

Because of the intent to use a scanning electron microscope, the testing apparatus must be SEM-compatible. This means that, ideally, all materials used in the device must be electrically conductive. In addition, all moving parts accountable for the movement of components (the motor and actuator) must be vacuum compatible. Aside from challenges in selecting proper materials, another task is to select components that, when assembled, will still be smaller than the allotted testing chamber of the SEM. This means that the entire testing device must have dimensions of approximately 170mm x 120 mm x 50 mm.

Finally, since the device will be inside a vacuum chamber, it is essential to have digital measurement readings that are accessible from the outside of the SEM for the input and output tensions, as well as for the speed at which the yarns will be moving. In addition to being accessible, the input tension and rotation speed should also be remotely adjustable in order to maximize testing time.

Motivation

The motivation behind this project is to create a globally-accepted standard that measures the friction coefficient between yarns in a precise and controlled manner. It is rather evident that there is room for improvement when the ASTM announces on its own website that the current testing standard that it suggests is not recommended.

The use of this device goes beyond the scope of simply calculating friction coefficients. Understanding the manner in which the hundreds of different kinds of these fibers react to one another may open the door to the development, testing, and analysis of reinforced and enhanced fibers with much better and stronger material properties.

Once the design for the device is complete and a prototype is manufactured, further research can be done to understand the impact of surface coating on fiber friction. The project's research can benefit many different applications; with the potential in improvements from military apparel to commercial clothing and athletic gear. There is an intellectual merit of this proposed project, providing a possible pathway to publishing any findings generated from conducting experiments using the apparatus. It will require knowledge and research in the dynamic progressive failure analysis of 3D woven composite systems.

Literature Survey

In Situ Friction Analysis

We will be working on the twisted strand method for this design. “Based on the measurement results, effects of yarn axial tension, angle between yarns, yarn sliding speed and temperature on the yarn-to-yarn friction are investigated and discussed. “[1] We will be measuring the mean input tension (T_1), mean output tension (T_2), the apex angle (α), and zero twist tension (ΔT). The number of wraps in the twisted strand method, input and output tensions, and apex angle are known before the test is conducted. This information will allow us to find the coefficient of friction (μ) by the use of the equation in **Figure 1**. By this we can understand the behavior of these fibers and this test can be used to predict the shear response and failure mechanisms in analytical and numerical models. To understand the science and theory behind our design we first had to go over some terminologies and definitions. The following definitions come from the journal STANDARD TEST METHOD FOR COEFFICIENT OF FRICTION, YARN TO YARN, written by ASTM INTERNATIONAL.

- *Boundary friction, n—friction at low sliding speeds (0.02 m/min or less) where lubrication occurs under thin-film lubricant condition.*
- *Coefficient of friction, n—the ratio of the tangential force that is needed to maintain uniform relative motion between two contacting surfaces to the perpendicular force holding them in contact.*
- *Friction, n—the resistance to the relative motion of one body sliding, rolling, or flowing over another body with which it is in contact.*
- *Radian, n—the plane angle between two radii of a circle which intersects the circumference of the circle making an arc equal in length to the radius.*

- *Stick-slip, n—a phenomenon occurring when boundary lubrication is deficient, manifested by alternative periods of sticking and slipping of the surfaces in contact.*
- *Discussion—At the specified sliding speed, in yarn friction testing, stick-slip cycles are long enough that they can be readily recorded. During sticking, the frictional force slowly rises to a peak value, at which the slipping occurs with the frictional force rapidly decreasing to a minimum value.*
- *Wrap angle, n—in yarn friction testing, the cumulative angular contact of the test specimen against the friction inducing device, expressed in radians.*

$$\mu = \frac{\ln \dfrac{T_2 - \Delta T / 2}{T_1 + \Delta T / 2}}{2\pi n \alpha}$$

Figure 1: Equation used to calculate friction coefficient

It is recommended [1], while using the twisted strand method, to use a wrap angle of 15.71 radians. This test varies from lab to lab. So this test is not recommended for commercial uses at this time. We hope to change this with our apparatus by use of SEM integration. When labs decided to use this test for commercial uses, the buyer and supplier of the product tested, would both have labs that would test their product. They would try to make their specimen homogeneous. There would be an average taken of the results. If there would be a bias from either lab they would find out what that bias was and make adjustments.

Apparatus

The following description of the twisted method apparatus has been taken from the journal STANDARD TEST METHOD FOR COEFFICIENT OF FRICTION, YARN TO YARN, written by ASTM INTERNATIONAL.

(Twisted Strand Method)—A schematic diagram of the elements required for twisted strand friction measurement is shown in Fig. 1. The yarn is run over upper pulleys and under a lower pulley and is intertwisted between these pulleys. One end of the yarn (output) is taken up at a controlled rate. The other end of yarn (input) is maintained at a controlled tension. The number of intertwisting wraps, the apex angle between the input and output yarns, and the input and output tensions are precisely known or recorded. From these data the coefficient of yarn-on-yarn friction is calculated.

The required elements are:

- *Friction Testing Apparatus (Indirect)3—Apparatus in which the input tension is measured, or controlled to a set value, the output tension is measured, and the coefficient of friction is calculated within or outside the apparatus.*
- *Yarn Input Tension Control—Ameans of controlling the yarn input tension to the nearest 5 % is required. A demand-feed apparatus tensioned with a fixed weight is suitable.*
- *Yarn Input Tension Measurement—The yarn input tension is measured to within 65.0 mN (60.5 gf), using a suitable tension gage producing an electrical signal. The signal is recorded as millinewtons (grams-force) or is used in combination with the yarn output tension measured to calculate the coefficient of friction. If a demand-feed apparatus*

tensioned with a precise, known fixed mass is used, the yarn input tension need not be constantly measured and recorded.

- *Yarn Output Tension Measurement—Yarn output tension is measured to within 65.0 mN (60.5 gf), using a suitable tension gage producing an electrical signal. The signal*

  is recorded as millinewtons, (grams-force), or is used in combination with the yarn input tension setting or measurement to calculate the coefficient of friction.
- *Friction Testing Apparatus (Direct)4—Apparatus in which the ratio of output to input tensions are compared directly and the coefficient of friction is indicated on a scale.*
- *Auxilliary Equipment (Indirect and Direct):*

  Guide Pulley Arrangement—The upper and lower pulleys shalls be of the same diameter. The recommended pulley diameter is 38 mm (1.5 in.). The separation distance between the upper pulleys, 2 H, shall be 140 6 2 mm (5.5 6 0.1 in.). The separation distance between the axis of the lower pulley and a line connecting the upper pulley axes, V, shall be 280 6 2 mm (11 6 0.1 in.). All pulleys shall be in the same plane. The lower pulley may optionally be mounted so that it can be swiveled around an axis at right angles to its axis of rotation and then fixed in position in the same plane as the upper pulleys.
- *Drive Unit—The yarn takeup shall run between 2 and 100 mm/min (0.75 and 4.0 in./min).*

Material & Component Selection

Because it is in a SEM all materials should be conductive. We propose that our design to be made from aluminum. This includes the pulleys, the testing platform, actuator and tension gauges. The proposed design that will be covered later will have aluminum plates welded together or screwed together to create the testing platform. This platform must be sturdy enough to handle the vacuum environment of the SEM. The vacuum pressure will be 10^{-5} millibar. The drive unit will be a servomechanism motor, with variable speed, whose height must be smaller than 50mm. This motor will be attached to a pulley which will take up the yarn between 2 and 100 mm/min. There will also be an actuating system to that is needed to increase the tension of the yarn or fiber. This too will be implemented by use of a servomechanism motor attached to an arm that will pull down on the yarn to increase the tension.

Table 1: Material Properties

Material Properties						
Material	Aluminum		Titainum		Steel 4000 series	
Units	English	Metric	English	Metric	English	Metric
Density	2.6989 g/cc	0.097504 lb/in^3	4.50 g/cc	0.163 lb/in^3	7.80 g/cc	0.282 lb/in^3
Modulus of Elasticity	68.0 Gpa	9860 ksi	116 Gpa	16800 ksi	205 Gpa	29650 ksi
Shear Modulus	25 Gpa	3630 ksi	43.0 Gpa	6240 ksi	78.5 Gpa	11400 ksi
Hardness, Vickens	15	15	60	60	36.0 - 614	36.0 - 614
Heat Fusion	386.9 J/g	166.4 BTU/lb	435.4 J/g	187.3 BTU/lb	no information	no informaition
CTE,linear	24 µm/m˚C	13.3 µin/in˚F	8.90 µm/m˚C	4.94 µin/in˚F	10.4 - 14.6 µm/m˚C	5.78 - 8.11 µin/in˚F
Specific Heat	0.900 J/g˚C	0.215 BTU/lb˚F	0.528 J/g˚C	0.126 BTU/lb˚F	0.473- 0.477 J/g˚C	0.112 BTU/lb˚F
Melting Point	660.37˚C	1220.7˚F	1660˚C	3020˚F	1370 ˚C	2500 ˚F

Conceptual Designs

The concepts thought of during the early phases of design all coincided with the ASTM's current standard, testing method D3412, which is pictured below. As shown by **Figure 2**, the test consists of a singular long thread of yarn passing through multiple pulleys, eventually interacting with itself in a helix before being recovered by another rotating spool. There are also gauges used to measure the tension in the yarn before and after the helix interaction. Finally, preceding the input tension gauge is some sort of adjustable input tension device.

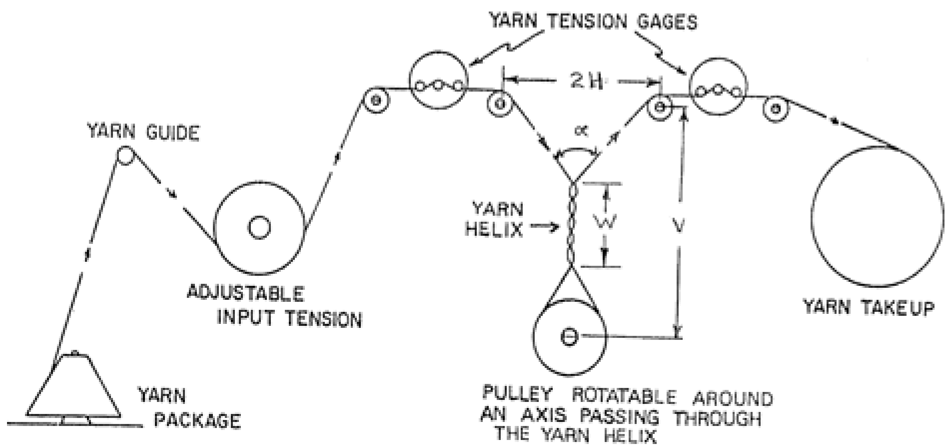

Figure 2: ASTM Testing Method D3412

While this testing method is an excellent starting point towards creating a final design, several modifications would be required in order to create an ideal testing device. Most of the current available testing devices are far too large for the intended purpose of this project. As shown in **Figure 3** below, the LH-402 Dynamic Tensile Tester is just one of the many existing machines capable of conducting the D3412 testing method. It has all of the necessary components to run an effective test. However, with dimensions of 119cm x 152cm x 160cm, this device is at least 10 times larger in each dimension than anything that can fit within the testing chamber of an SEM.

Figure 3: LH-402 Dynamic Tensile Tester

Another similar design exchanges the input tension device for an adjustable hanging weight, as shown in **Figure 4**. By changing the amount of weight at the beginning of the yarn, the tension going into the helix can be calculated, and the friction coefficient can then be calculated as usual. While a simpler design in theory, the problem lies not only in the inability to quickly and remotely change the weight, but also in the fact that a device of this type would require much more space in order to conduct a good amount of experimentation. Therefore, this design is impractical for this project's intentions.

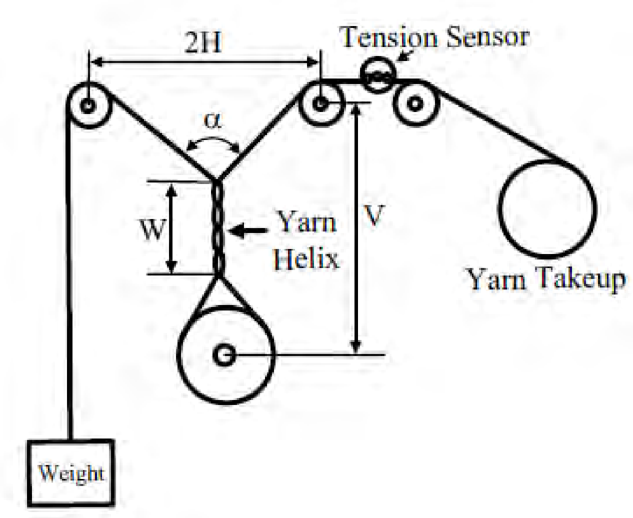

Figure 4: Weighted Conceptual Design

Proposed Design

After taking into consideration the advantages and disadvantages of previous designs, as well as the required components in the testing device, a compromise was finally achieved between size and function. The final product, shown in **Figure 5** below, utilizes the maximum amount of space allotted (170mm x 120mm x 50mm) in order to include all of the necessary components.

The goal of this design is to utilize all available space effectively, making the measuring components as small as possible while maximizing the size of the spools. By having larger spools, more yarn can be stored, and therefore more testing can take place. In addition, by making the two spools of the same size, it allows for interchangeability once a full spool of testing has taken place.

The proposed design was made using Solid Works. The model consists of three pulleys, a small servomotor to spin the spool collecting the yarn at a rate of .75 – 4 inches per minute), two tension gauges (before and after the helix interaction), and an actuator (to adjust the tension going into the helix). The yarn will be wrapped in a helix around the center pulley, where the fiber will rub against itself through multiple points in the helix. The ability to view multiple interactions under an SEM, as opposed to only seeing the change in tension through one point, will give researchers a much greater understanding of the interactions that take place among these yarns interacting with each other.

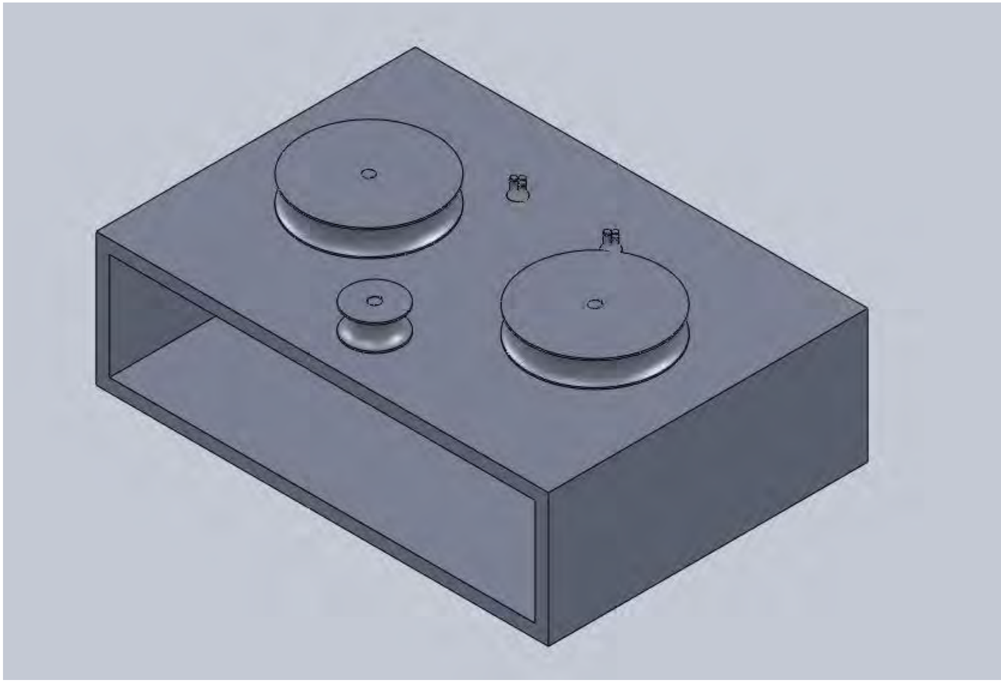

Figure 5: Proposed Design (Isometric View)

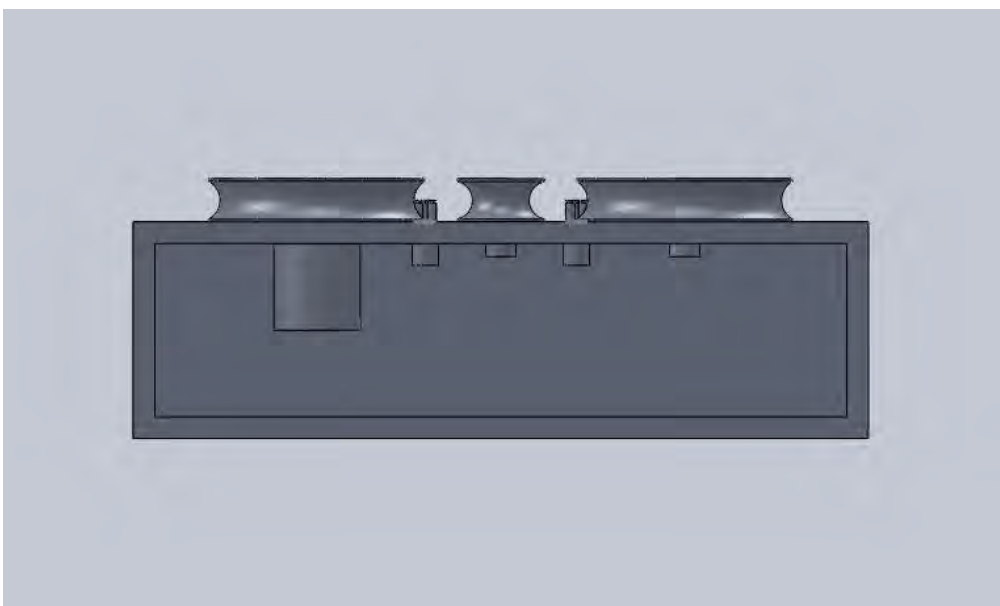

Figure 6: Proposed Design (Front Sectional View)

Major Components

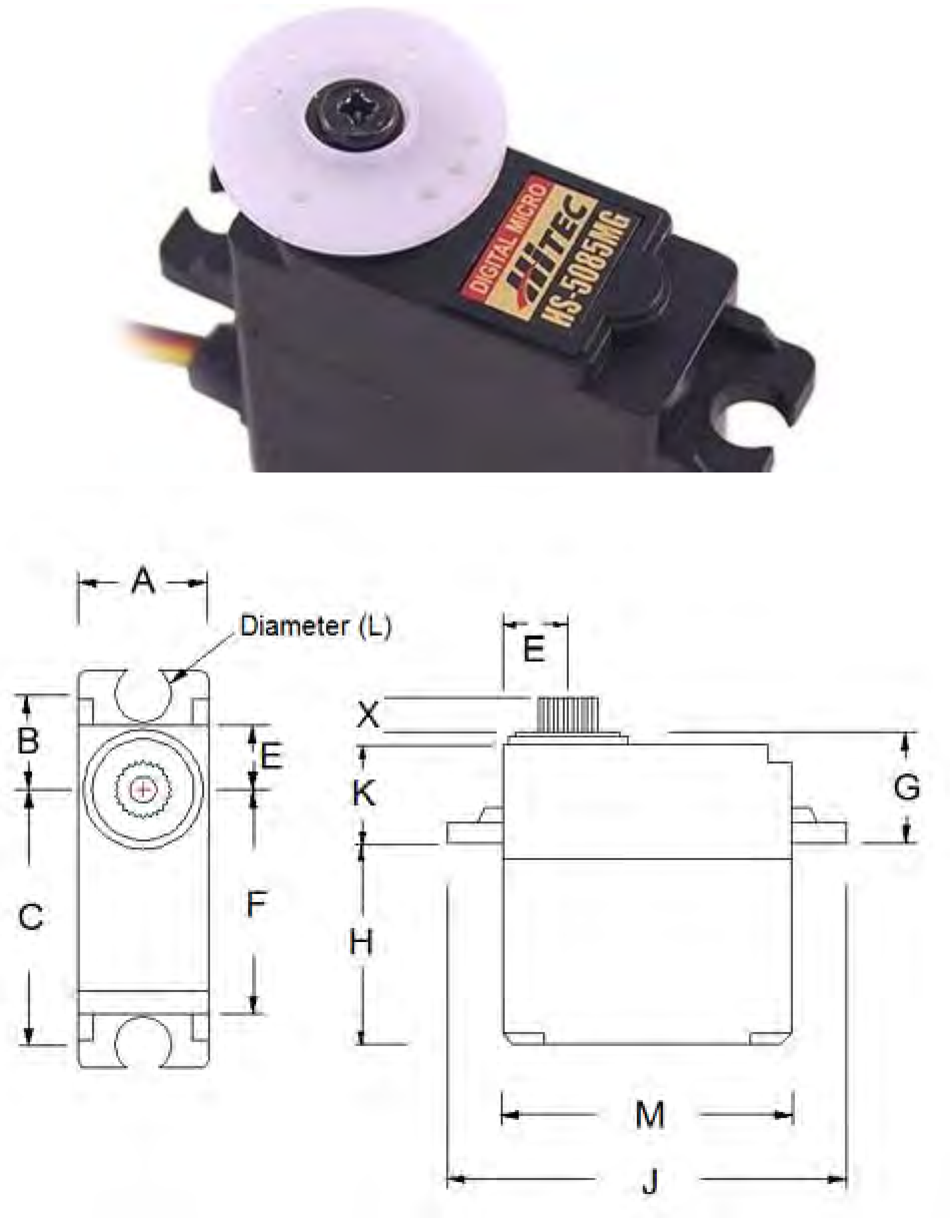

Figure 7: HS5085MG Servo Motor with continuous rotation for yarn collector

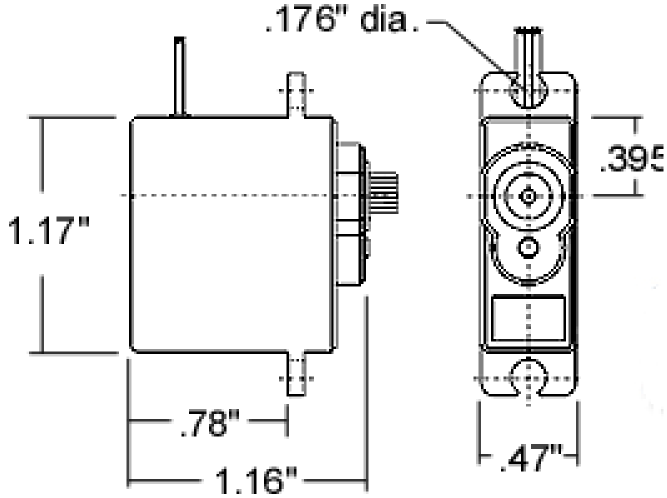

Figure 8: HS82MG servo motor for adjustable input tension

Figure 9: Dual Manual Servo Driver

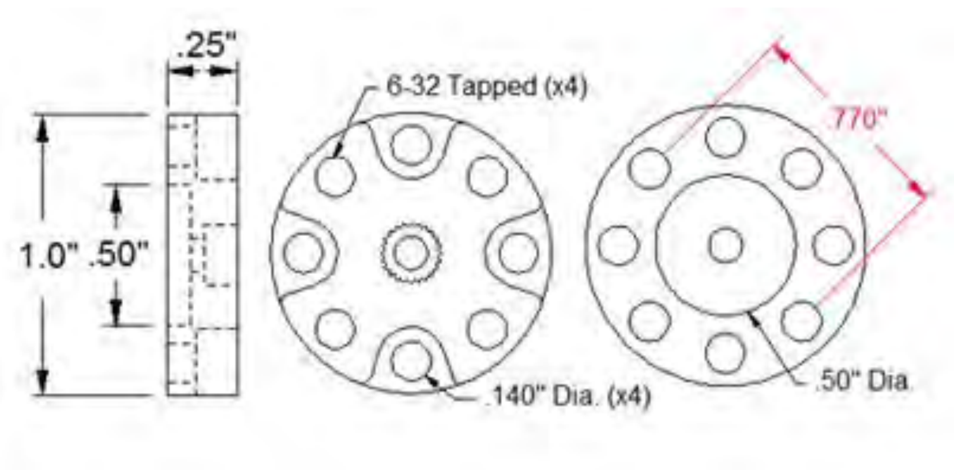

Figure 10: Aluminum Hub Horn

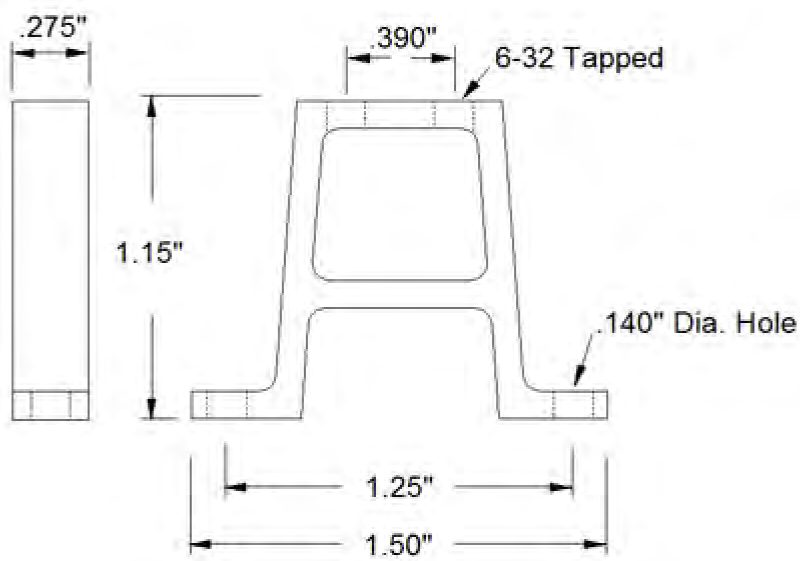

Figure 11: Aluminum Mounting Brackets

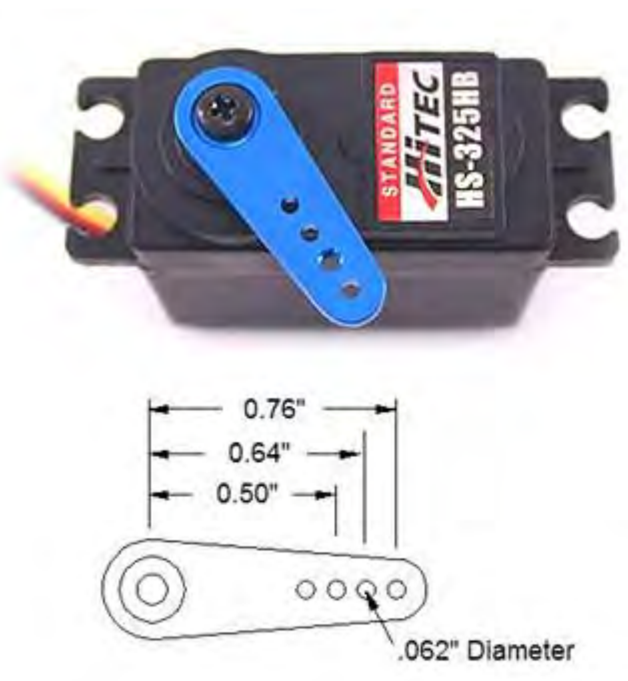

Figure 12: Aluminum Servo Arm

Figure 13: DC Power Supply

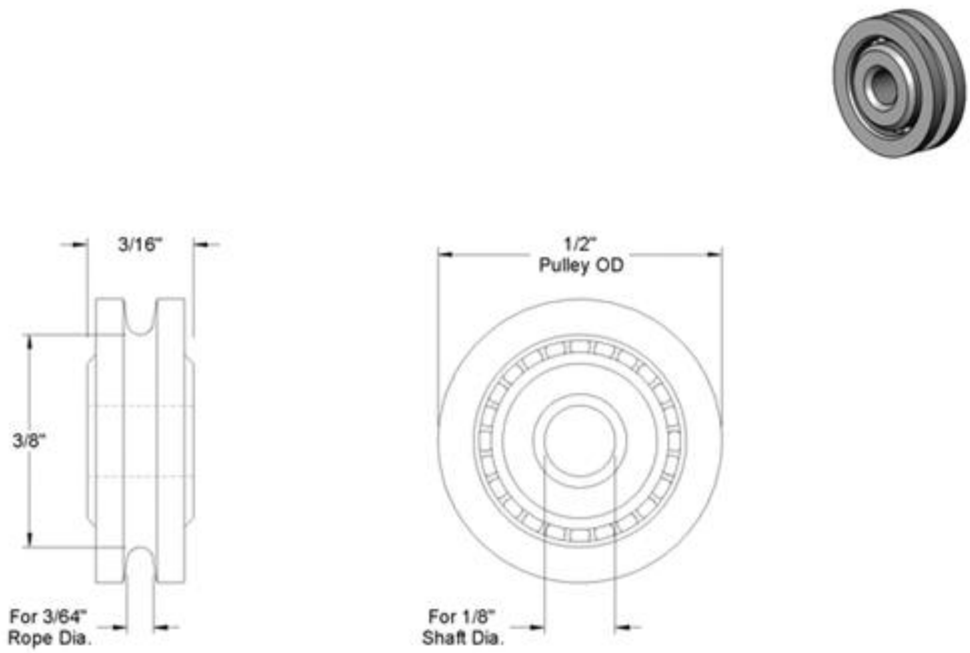

Figure 14: Guiding Pulleys

Figure 15: Assembly Hardware (6-32 Socket Cap and 4-40 Round Head Machine Screws)

Timeline and Project Organization

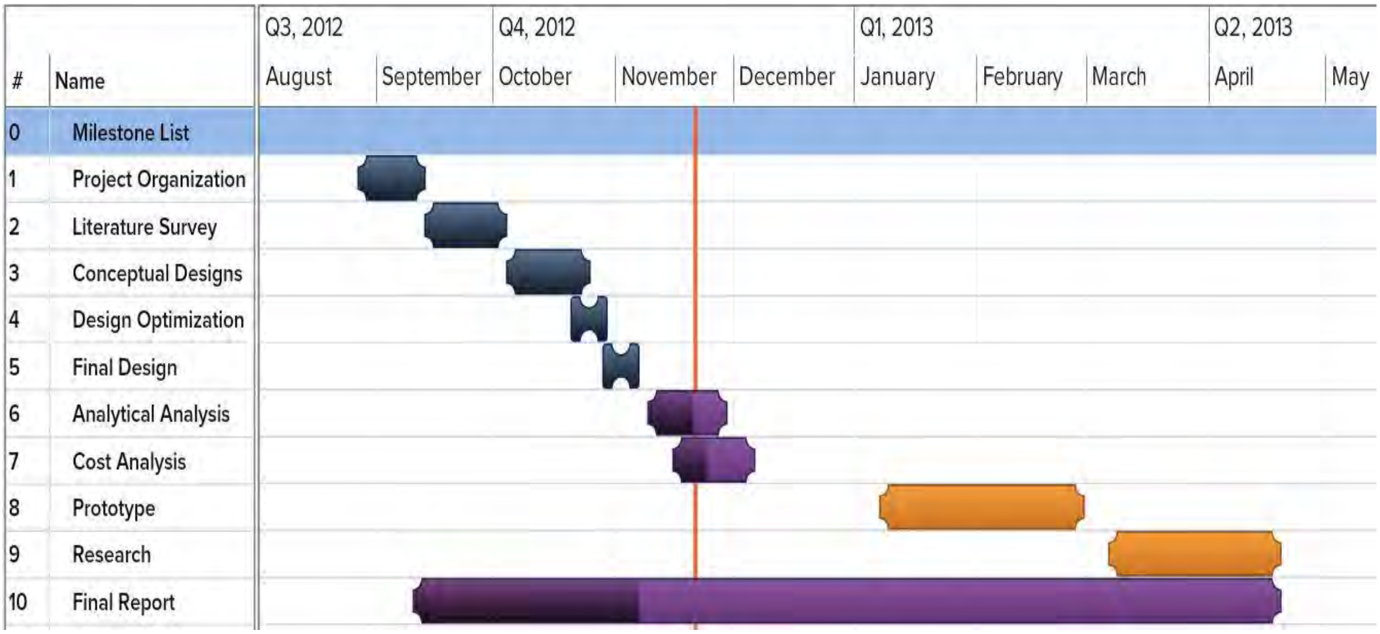

Figure 16: Gantt Chart

Individual Tasks

While both members of the team were involved in every step to some extent, each member was mainly responsible for a key component of the design project. Jean Paul was the main designer of the CAD model (as well as its subsequent redesigns). He was also the main organizer of the report and presentation. With suggestions and advice given by Eduardo, Jean Paul enhanced the overall quality of the written and visual materials.

Eduardo was the principal manufacturer of the prototype. He was given the task of primarily being involved in the purchasing components and materials, building a testing stage out of the material, and installing components into it to turn it into a functioning prototype. Given suggestions on the components to use and where to find them by Jean Paul, Eduardo was able to successfully locate the required materials and manufacture them together.

Analytical Analysis

While it will be necessary to conduct motion studies in Solid Works, or stress and thermal analyses using ANSYS, there are no extreme conditions in which the proposed design should have a risk of failing at other than the condition of being inside of a vacuum. Therefore, for initial simplified and more realistic results, the best method for confirming that the device works is to build a prototype and attempt to test with it.

In an ideal situation, every component would function properly and the design would not require any additional changes. However, constant modifications and improvements are a part of life-long learning. As further testing takes place, ideas may arise for small changes that will improve the quality of the final product. Once all foreseeable modifications have been made, and the SolidWorks model has been updated, analysis using available CAD software will be possible, and more accurate.

One thing to note about the fibers that will be tested is that they have hierarchical structures starting from the macro. The components to be analyzed for friction have combinations of the meso and micro scale of the fiber. The meso and micro scale are important to investigate because of relationship they have. Changes in the micro level will cause change in the meso level. Understanding the effect of friction and stress on these different levels will help predict the deformation of the fiber in question, which in turn help find the most efficient strategy to improve the qualities of macro.

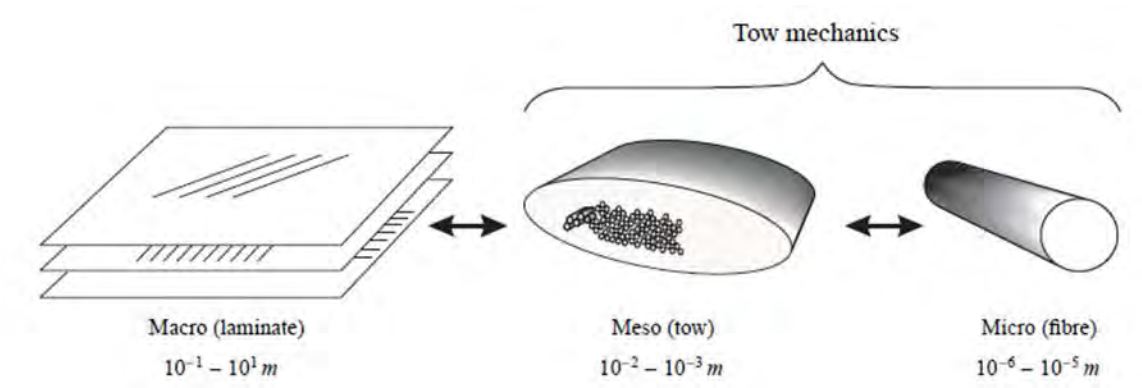

Figure 17: Hierarchy of Fiber

Plan for Tests on Prototype

The prototype will be tested in the FIU laboratory at the Engineering Center. The machine's capabilities and functions will also be tested. The machine will be given a series of tasks to complete. All materials of the machine must be conductive in order to have a visual reading of the fiber. The design needs to function and have the capability to increase the tension of the fiber. This will be implemented by the help of a servo motor and an aluminum arm to adhere to the SEM's requirement of conductive components. Another servo motor with an aluminum pulley has to reel in the fiber at approximately 1 inch per minute, or slow enough to conduct approximately 4-5 minutes of constant testing. Each major component of the machine must be vacuum-compatible; meaning that each component should be purchased after conducting an investigation to ensure that it will be able to properly perform under a pressure of 10^{-3} Pa. We will achieve this by using a dual manual servo motor controller. The tension gauges have to give a digital reading of the tension in the fiber. We will also test integration of the machine with the SEM. If the machine functions properly we can then run different tests analyzing mechanical fractures and friction occurring between fibers.

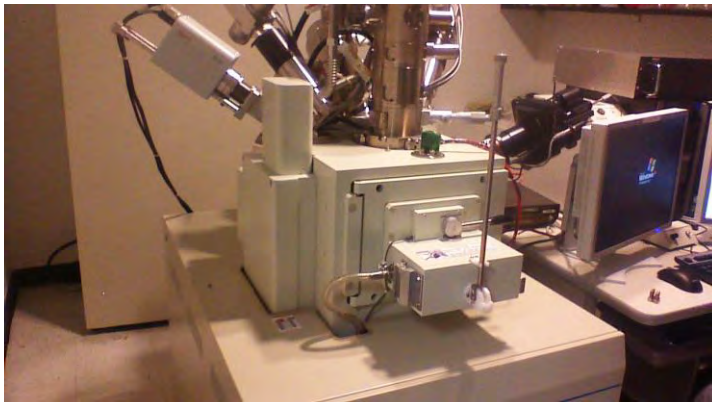

Figure 18:SEM

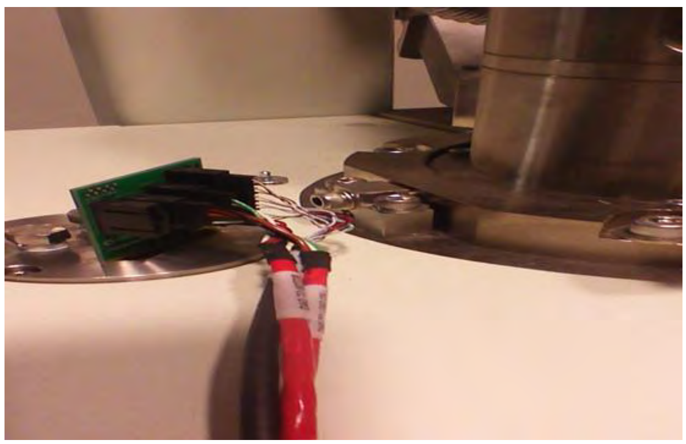

Figure 19: Pass through wires for servo controller

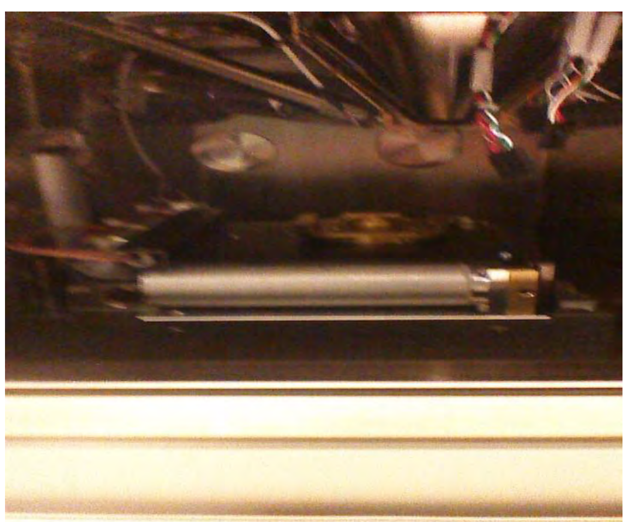

Figure 20: SEM platform

Cost Analysis

While the final mechanisms have yet to be installed, work has nearly finished on the project, and therefore a cost analysis can be estimated, while the remaining components and labor can be estimated within a reasonable degree.

The part of this project that should account for a majority of the labor cost is in the construction of the main stage, where all of the additional components will be placed either on top of or within this box. Rather than locating and purchasing a pre-assembled box, it was decided to construct a box out of raw materials according to the exact space requirements allotted.

After contemplating several options of readily-available materials for the box, the resulting alloy chosen was Aluminum 5052. This material is an excellent compromise between strength, durability, and pricing. Above all, this material meets the requirement of being vacuum-compatible and SEM friendly. Checking multiple sources for pricing, the required material was finally purchased from Simmons Surplus, a local business specializing in hardware and metal sales.

Based on the dimensions of the model, which required a total surface area of approximately 1 square foot, a total of 2 square feet of material was purchased (in order to account for any changes or mistakes in the manufacturing of the part). At a cost of $19.30 per square foot for a plate with thickness of ¼ inch, this totals to $38.60 for the materials needed to construct the box.

Although the prototype has not been completely constructed yet, there is enough information about the manufacturing process to estimate a total labor cost. It is estimated that in order to hand-machine the box from scratch and install the interior components, it would take approximately 23 hours of labor. A breakdown of individual tasks is given in the below table. Assuming a standard rate of $15.00/hour for manufacturing, the total cost of labor for the box is estimated to be $345.00. While this amount may seem staggering for the development of a prototype, it must be kept in mind that many changes can be made in order to reduce the production time, not to mention that subsequent prototypes would not require as much modifying or slow machining.

With the addition of the components listed below, it is estimated that the final cost of constructing the prototype will be approximately $700. The total approximate cost is slightly more than the initial estimated cost, yet it does not include the cost of the tension gauges that would be required for the testing device. However, when considering the fact that the price of the stage itself is nearly the price that was considered, the estimation was not too far off. Also, being that this cost takes into account most of the brainstorming and research required to develop the prototype, it can be safely assumed that future products will have a significantly smaller cost to produce. Certain measures can be taken to further reduce the cost down to an even more appropriate level, including more efficient machining and assembly, more cost-efficient sources for parts, and buying components in bulk. There is plenty of room for cost-reduction. However, for the purposes of this project, everything was created from scratch with only basic collegiate knowledge at the disposal of the project members involved.

Table 2: Labor Cost Breakdown

Labor Breakdown	
Item	**Time (hrs)**
Rough Cut Box Sides	1.5
End Mill Box Sides (1)	2.5
End Mill Box Sides (2)	2.5
Drill Holes for Screw Placement	1.5
Thread holes for Screws	1.0
Assemble Box	1.0
Finishing	0.5
Adding Pulleys	1.0
Creating Model for CNC	1.0
Programming CNC	1.0
Execution of Program	1.0
Adding Internal Components	2.0
Modifications and Enhancements	5.0
Final Product Preparation	1.5
Total	**23.0**
Hourly Cost of Labor	$15.00
Price of Labor	$345.00

Table 3: Component Cost Breakdown

Parts Breakdown			
Item	**Quantity**	**Unit Price**	**Extended Total**
1/4" Thick Aluminum 5052 Plate (ft^2)	1	$18.30	$18.30
6-32 x 3/4 Socket Cap Screw	20	$0.39	$7.80
4-40 Round Head Screw	8	$0.15	$1.20
Spools	2	$9.14	$18.27
Small Pulley	7	$4.53	$31.71
Servo Motor for Spool	1	$59.99	$59.99
6V, 3.5A Power Supply	1	$24.99	$24.99
Servo Motor for Input Actuator	1	$19.99	$19.99
Aluminum Single Arm	1	$6.99	$6.99
48 Pitch Aluminum Gear	1	$22.99	$22.99
48 Pitch Metal Pinion Gear	2	$6.99	$13.98
Manual Motor Speed Control	1	$79.99	$79.99
Servo Motor Controller	1	$49.99	$49.99
Labor (hrs)	23.0	$15.00	$345.00
Total			**$701.19**

Manufacturing

While it may not be the most economical or time-efficient choice to construct the main stage from scratch, it served as a valuable experience to acquire some hands-on practice with modern day machinery (not to mention it would allow for customized dimensions that would precisely cater to the needs of this particular project). Therefore, the first step towards the manufacturing of this project was to construct the main testing area, otherwise known as the box where all components would be stored.

Initially, from the large plate of aluminum, a vertical saw was used to cut out pieces of roughly the required dimensions. This process took little over an hour to accomplish. Next, a knee mill was used to trim the pieces to their exact required dimensions. The process took a total of approximately 5 hours to complete.

In order to maximize accessibility and convenience, a modification was made from the initial proposed design. Rather than have one side face of the box missing to reach the interior components, the top surface of the box was designed to come off with the quick removal of a few screws. Initially, the idea of a slide-top box came to mind. However, it was soon quickly realized that this would be impossible, due to the fact that several components needed to be attached to the top plate, obstructing the path to get slid back in.

Finally, the sides of the box needed to come together through the use of several properly-placed screws. The use of screws, rather than welding or the use of any other adhesive, allows for quick and easy disassembly in the event that such actions should be required. Due to the thickness of the plates, it was decided that the appropriate size screw for this particular task was #6-32 x 3/4”. Because of the fact that the thickness of the plate was too small, flat-head screws (which would have left the entire box flush when fastened) would not fit completely flush into the plates. Therefore, it was decided to sacrifice an additional fraction of thickness in order to incorporate the equally aesthetically-pleasing socket cap screws.

The socket cap screws used to join the sides together were purchased from Home Depot, at a cost of approximately $0.39 each. A total of 16 screws were required for this step, which creates a total of $6.68 for the necessary hardware in this step. The process of drilling holes for the screws, threading the holes, and subsequently joining the sides of the box together with screws took approximately two hours to complete.

Once assembled, the attention can turn to the inclusion of the pulleys on top of the box that will act as the holding units for the fibers. A spool will be next to a continuously rotating servo motor, and will be connected through the use of a gear and pinion system. The spool will collect incoming yarns, while the other will stand on the opposite side of the box. This second spool requires the ability to freely rotate in order to allow yarn to travel to the rotating spool, so the use of a small needle thrust bearing was required. Aside from the main spools, other pulleys are required to stabilize the materials running between the spools, in order to prevent tangles and other obstructions.

Searching for the smallest possible pulleys for the limited space allotted (at an affordable price), the ideal component was finally located on the website of hardware distributing company Mcmaster Carr. At a diameter of only half an inch and a width of under ¼ of an inch, these pulleys were selected due to their small size and affordability. With each pulley costing $3.82, a total of 7 pulleys were purchased. Adding the cost of shipping, the total for the order was $31.68.

After receiving the pulleys, the inside diameter was measured to be 1/8 of an inch. Referring to a drill size chart in the machine shop, it was determined that a size 43 drill bit would be necessary to create the proper holes. Once the desired markings were made on the top plate, a milling machine was used to create the holes for the pulleys. Once completed, the holes needed to be tapped in order to create the threads for a screw to properly secure a pulley. The holes were threaded in a way that allowed a size 4-40 screw to perfectly secure the pulleys on to the top surface. The entire process of adding the holes, threading them, and installing the pulleys took approximately one hour to complete.

Finally, the top surface needed some holes to be cut in order to allow the two servo motors to pass through even when the box was sealed. A circular pocket was required for the yarns to travel underneath the top plate and into the continuously rotating spool below, while an arched pocket was needed to allow space for the aluminum servo arm to freely rotate and thereby allow the adjusting of the input tension. Through the use of Solidworks, a model of the top surface of the stage was recreated, including the location of the required pockets and additional enhancements. Taking note of the points at which these pockets occur, a program was generated for use on a CNC mill. This allowed for quick and accurate generation of the required pockets. A total of 3 hours were required for the generation of the drawing, the writing of the program, and the execution of the program onto the part.

Once the exterior of the project has been completed, the focus can turn to the interior. The first important parts of the interior components are the servo motors. One of these servo motors will control the input tension that will affect the material entering the helix, while the other servo is responsible for steadily pulling the material across all of the pulleys and helical interactions. Using aluminum mounts, these servos were attached to the base plate of the box, while the top plate created the necessary openings for these components to pass through and become exposed on the top surface. Attaching these components to the base took under an hour to complete.

Once the physical components are settled in, the project can enter the final stage of manufacturing- wiring. While it would normally be simple to connect the servo motors to the appropriate controller, the fact that the entire device will be inside of an SEM will serve as a potential challenge. Fortunately, the SEM being used in this particular scenario includes connection ports that can link components within the testing chamber of the microscope out to the exterior of the microscope, without compromising the conditions within the vacuum-sealed testing chamber of the microscope. While the connection types have yet to be validated, the fact that the connector pins are very standard, it can be safely assumed that the device will be able to operate with little to no modification of the electrical components.

The overall process of manufacturing the device is a tedious yet simple experience. In fact, the simplicity of the design is what makes this a suitable alternative to the already-available machines found in the market today. However, with the incredibly expensive price tag that those machines have, the proposed alternative could be a more reasonable option, considering that the manufacturing process could be reduced significantly.

Conclusion

This design project has been presumably just like any project engineers would find themselves in throughout their careers. It begins as an ultimate goal they wish to accomplish. Through the use of a thought process, ideas are brainstormed and applied until a design has been made. From there, the design gets created, and the original problem is thereby solved. In an ideal world, designs would be that simple and processes would flow that smoothly. However, the world in which we live is not even remotely ideal.

As simple as any project may be, there will always be obstacles. Whether they come in the form of sudden ideas, necessary changes, faulty equipment, broken parts, lack of organization, or anything else in between, the true test of an engineer is to see how he or she adapts to sudden problems and handles the situation.

Throughout the course of the past several months, many obstacles and challenges stood in the way of the design group. Many revisions of the design had to take place before one final design was made. Even throughout the manufacturing process, several ideas would suddenly spring themselves upon the group. Whether these ideas were for enhancements to the design, or structural problems that required immediate attention, these thoughts served as a challenge to see whether or not, as engineers, the team was able to adjust their current thought process.

From the initial phase of cutting a sheet of aluminum into exactly-measured sizes, to the inclusion of components on the top surface of the testing stage, every step has had its difficulties. However, rather than to be overwhelmed by it, the challenges were embraced, since this project has served as an indispensable tool for learning about the challenges of becoming an engineer.

While this project may not have an incredible amount of complexity to it, it is in fact the simplicity of this design that makes it practical for more standard use. The proposed project is a small device with the potential to have a much broader impact in the researching world. This also leads to the potential application of this future research on the development and improvement of many material products.

Scientists are taught to engage in life-long learning, meaning that there is always room for research and improvement. Using this proposed design, those researchers will have one more tool that will allow them to continue this learning, and have an impact on the world.

Recommendations

The past 8 months have proven to be an incredibly valuable learning experience. This design project, while rewarding, has had a multitude of difficulties. In order to not repeat the same mistakes for future iterations of this project, there are several recommendations that should be considered.

First and foremost, it has been observed that working in a team of two has proven to be difficult. Frequently, a lack of ability to establish mutual meeting times has led to a lack of productivity. By adding a third team member, there is a greater chance of at least two members being able to meet to input ideas and carry out necessary plans.

On the note of communication, there was often a lack of communication between the team members and its group advisor. Without constant guidance and suggestions, the team was occasionally stuck and did not have many ideas on where to continue. The establishment of mandatory weekly meetings would have helped continue a steady pace of progress, as well as maintain proper communication with the advisor.

Another simple idea occurred to the team during the end of the project. During a design project of this magnitude, it is often easy to lose track of all of the little tasks that were completed, whether it's brainstorming with teammates and the group advisor, purchasing or manufacturing components, assembling the design, making simple modifications, or even writing this report. These small details, when added together, create a lot of material necessary for writing a detailed report. Therefore, it is recommended to keep an activity log from day one. From the initial topic selection to a summary of each and every meeting (whether with group members, the advisor, or both), having a record of everything will come as a tremendous benefit in the long run.

In terms of the actual project, the simplest suggestion to improve the overall quality of the project is to begin everything earlier. Aside from having frequent and regular meetings, starting earlier would not only give the group some much-needed momentum, but it would break down larger tasks into manageable pieces that could be accomplished even with other simultaneous responsibilities.

While there are probably other things that could have made the project flow more smoothly, it is the general consensus of the group members that these three initial points that were brought up would have had an incredibly positive impact on the entire experience. Engineers interested in recreating and enhancing this project in the future should keep these ideas in mind in order to make great advances on the project currently being discussed here.

References

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