FAMU/FSU College of Engineering

Department of Mechanical Engineering

<u>Midterm 1 Report</u>

Team #20

High Cycle Fatigue of Electroactive Membranes

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Abstract

This report outlines the design analysis of three design concepts: a solenoid actuated mechanism, a crank slider driven mechanism, and a cam driven mechanism. The analysis of the designs included concept details, analytical calculations, advantages and disadvantages, manufacturing considerations, and risks associated with each design. Each design concept was constructed in Creo Parametric 2.0 to provide a visual representation of the concept. The equations for the forces that will be exerted on the components have been developed. A decision matrix was developed based on the design and performance specifications for the mechanism. Using the decision matrix and the design analysis, the three concepts were ranked in order of best choice. The crank slider was ranked the highest followed by the cam driven design and the solenoid design, respectively. Based on these considerations the crank slider and cam mechanisms will be focused on for the final design for the project. Detailed analysis will be conducted on these designs and dimensions will be finalized. Force and fatigue analysis will be conducted to choose the best materials for the mechanism and to ensure proper functionality. By the end of the semester, the final design will be selected, and the components will be ordered and drawings will be submitted to the machine shop.

1 Introduction

Currently electroactive membranes are being studied for implementation onto robot legs to provide more efficient mobility. Little research has been performed on the fatigue of electroactive membranes [1]. Dr. William Oates and Dr. Jonathon Clark are sponsoring our team to build this machine to test specimens that they have been developing in the past couple of years. This project's goal is to develop a high cycle test mechanism to quantify the fatigue of these membranes so the design can be optimized. The project requires the fatigue mechanism to be implemented onto the MTS machine to simultaneously measure membrane loads and displacement. The frequency of the fatigue and the stroke distance are to be variable. Multiple design were considered with two designs being chosen for further analysis. Research must be conducted to determine which will optimize the goal of the project. Once a choice is made for a design, materials selections and force analysis must be performed to determine the best solution. The contact information and individual roles for the group is shown below in Table 1. Any questions should be directed to the team.

This report will discuss the three designs and analysis performed, their evaluation, the general strategy in which the project will proceed, and final design selection. The three designs being considered in this report are a solenoid driven concept, a cam driven concept, and a crank slider concept. The type of analysis at this stage is purely preliminary. This means that final dimensions and material selection for each design are not finalized. This allows a focus on force analysis that the mechanism undergoes during operation. Specifically, attention to the maximum forces and torques that are experienced are looked at to determine whether the design is robust and which design will provide optimal performance. From this, and an initial look at the cost of components, evaluation with be conducted to choose a design that will fit the customer's needs.

Table 1. Group Contact Information

Role	**Name**	**Email**
Team Leader	Adriane Guettler	aeg12b@my.fsu.edu
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Webmaster	Matthew Drys	mcd10c@my.fsu.edu
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2 Project Definition

2.1 Background Research:

This project is to develop a machine to test high fatigue cyclic loading on electro-active membranes. Dr. Clark in the STRIDe lab has previously built a robot that functions similar to that of a cockroach, known either as "Sprawlita" or "iSprawl". Figure 1, shown below, shows the current iSprawl platform. This robot at one point in time was the fastest robot per body length when it was running around on flat surfaces. At this point in time Dr. Clark is directing his attention towards making the robot be able to run or walk on multiple types of surfaces, and potentially be able to jump from certain heights. This is where Dr. Oates' research comes into play, he researches smart materials. He and his researchers have been working to develop a membrane that can be implemented into the iSprawl robot. An example of the membrane and a schematic of the set-up of the membrane can be seen below in Figures 2(a) and 2(b). The membrane is made of VHB 4910 which is an adhesive tape which produces a great strain and elastic energy density [2].This allows the material to be very compliant. This membrane will be added to each one of the six legs and may be used alone of in pairs stacked together on one leg. Our team has been given the task to build a machine or mechanism that can be used in Dr. Oates lab to test the fatigue on various membrane specimens that have been created. The machine also must be able to adapt to testing on membrane at a time versus testing a stack of them, as they may be used in this manner on the robot.

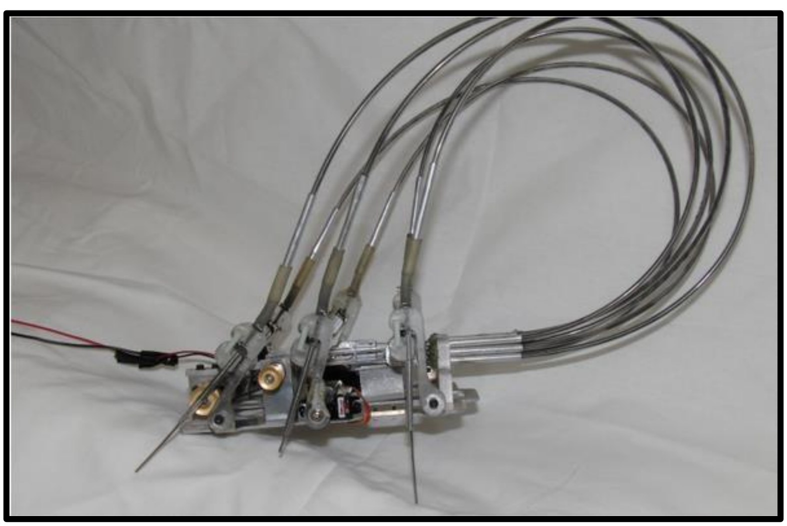

Figure 1: The image above is the current iSprawl platform that the membrane will be implemented onto. The robot is a 0.3 kg hexapod that is able to run at 2.5 ms^{-1}. [3]

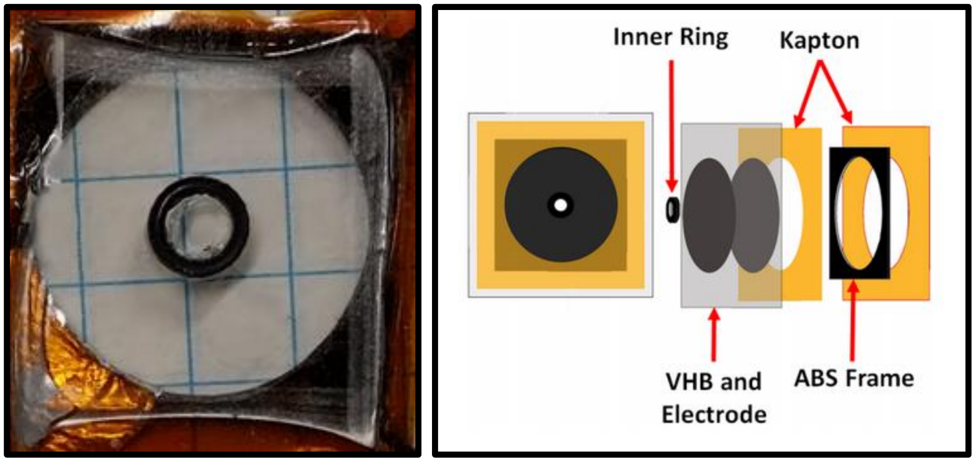

Figure 2(a) and 2(b): The figure on the left is an actual sample of the membrane. The figure on the right is a schematic of the setup of how the membranes are assembled. [3]

Previous work on the machine, which our team is in charge of designing and constructing, has not been completed. Much of the background information, in regards to the reasoning behind implementing this membrane on the robot comes from a thesis paper published by a graduate student from the FAMU-FSU College of Engineering named Jason Newton. Newton describes that his work "focuses on the development process of a dielectric elastomer based variable stiffness mechanism as a replacement for traditional springs on a legged hexapedal robot." [3] The idea behind this comes from how biological systems rather than mechanical ones operate, "biological systems show reliance upon their capability to adapt limb stiffness as a means to achieve dynamically similar locomotion over a wide range of terrains." [3]

2.2 Need Statement:

The purpose of this project is the design and implementation of a fatigue mechanism for electroactive membranes in a MTS machine. There is insufficient data on the fatigue behavior for electroactive membranes. It is desired to optimize the design of the membrane to handle repeated mechanical cycling over a range of frequencies and displacement.

There is a lack of information on the fatigue of electroactive membranes.

2.3 Goal Statement & Objectives:

Goal Statement: Design and build a device that produces high cycle sinusoidal mechanical fatigue of electroactive membranes.

To complete the overall project goal, several objectives have been established. All of the following objectives must be accomplished for the project to be considered successful.

Objectives:

- Accurately measure the fatigue placed on the specimen
- Produce various frequencies of cycling
- Produce varying stroke distances to displace the membrane
- Allow for tracking of the displacements controlled by the fatigue machine
- Measure the load associated with the stroke by implementing with the MTS machine

2.4 Constraints

The fatigue mechanism design must meet the following constraints to be considered successful. If these constraints are not met, the design will not be a plausible consideration for production.

- System should be a tabletop mechanism that is mounted to the MTS machine
- Fatigue machine must have a 10mm stroke to displace the membrane
- System must be able to produce frequencies ranging from 0 Hz to 100 Hz
- System should produce consistent functionality for various specimens
- Overall design should be completed within the budget (to be defined after further analysis)

3 Design and Analysis:

3.1 Functional Analysis

The fatigue mechanism design must meet the following requirements before implementation into a product. The dimensional constraints for the design are shown in Figures 5 and 6 of the Appendix.

- Fit current VHB specimen frame
- Fit into MTS mounting connection
- Withstand a load of 5N both statically and dynamically
- Weigh less than 10kg
- Powered by DC power supply
- Be mobile to be removed from MTS and attached to table top

The mechanism must be able to perform the following constraints to meet the customer's needs.

- Variable frequency from 0 Hz to 100 Hz
- Variable stroke distances up to 10mm
- Measure load and displacement of membrane
- Low noise
- High resolution for measurements
- Variable number of specimens able to be tested at a single time
- Use a GUI
    - Input functions
    - Output data (graphically and files)

3.2 Design Concepts

Three designs were developed for further evaluation. These designs include a solenoid actuated device, a crank slider mechanism, and a cam driven machine. The support platform to hold the specimens during the test has been designed. This design is capable of attaching to any of the three concepts. The assembly of the platform, with the VHB frames, is shown in Figure 10 in the Appendix. The support platform consists of two parts: the support and the clamp. These are shown in the Appendix in Figures 11 and 12. When less than five specimens are to be tested, empty frames will be stacked above the specimen to allow the clamp to secure the specimen.

<u>Solenoid Concept</u>

Concept: This design uses a linear actuated solenoid to provide a force, generated by thrust, to move a platform holding the electroactive specimen. This platform is guided by a track from the lower housing in which the platform is placed upon. There will be springs that apply a compressive force to bring the platform back to zero after actuation. The solenoid is controlled by the user interface to vary the frequency and stroke. This design is shown in Figure 7 of the Appendix.

Analytical: The force exerted from the deflection of the specimen is expected to be 5N. The weight of the platform will also generate a force that the solenoid must overcome to perform the proper motion. The springs attached to outer housing will also generate a force that will affect the solenoid. Therefore, the force exerted by the solenoid to move the platform 10mm (the maximum stroke) must be greater than 5N plus the weight of the platform and the force of the springs. This exact force will be determined after a final platform dimensions and materials are decided. To select the solenoid for use, the manufacturer suggest using a safety factor of 1.5 [4]. The thrust the solenoid exerts decreases with increased stroke length; therefore, the thrust at 10mm stoke must exceed the load applied. The safety factor will be applied to the total load applied to the solenoid for selection of a proper solenoid. The calculations for the force are shown in the Appendix.

Advantages & Disadvantages: A major advantage the solenoid design utilizes is simplicity in its operation to optimize performance. Systems that involve complex assembly often result in high maintenance and is susceptible to failure more frequently than that of simple construction. The solenoid itself meets every performance requirement of this project. It can vary its stroke length as well as operate at a broad range of frequencies. Also, the price of a solenoid is relatively inexpensive compared to that of DC motors.

Although it is capable of these things, there are tradeoffs. The longer the stroke that the solenoid produces, the smaller the thrust it is capable of yielding. Also, the performance specifications for solenoids reduce as the duty cycle is increased. Since the mechanism to be designed should operate continuously, any solenoid used should be able to operate at 100% duty cycle. This means that the solenoid will be performing at its minimum capacity.

Other considerations for the solenoid design that may be considered weaknesses is whether the electromagnetic field that it produces will affect any sensors on the MTS machine or the device itself. Also, the life of the component will only last anywhere from 1-25 million cycles depending on the type of solenoid chosen. Another possible weakness may be the solenoid heating over prolonged use.

Manufacturing Considerations: The manufacturing of the components for the solenoid design are fairly simple. A solenoid should be selected to meet the required displacement distance and provide enough thrust to overcome the force needed to move the specimen and the weight of the platform. The cylindrical base for the solenoid will be machined to fit securely to the MTS base. An outer housing will be machined as a hollow cylinder to fit over the inner base that will act as the platform. A Teflon sleeve, or something comparable, will be attached to the track used as a guide inside of the outer housing to reduce friction. Since the solenoid will control the displacement distances, the tolerances on the machined components are not as critical, making the manufacturing process for the components relatively simple.

Uncertainty and Risks: The design relies on level and smooth operation via tracks on the housing used to guide the platform. If the track does not have suitable tolerances in the fit between the platform and the housing, then improper operation will result. If the track is too loose then the mechanism will “wobble” and if it is too tight then it will create additional friction in the system. Also, failure in this design will most likely occur in two places. It will be due to the springs that apply a resistive force against the solenoid shaft motion in which they may break; or it may be due to the solenoid exceeding its life expectancy.

Crank Slider Concept

Concept: This design uses a crank slider, resembling that of a piston, powered by a DC motor to move a platform holding the electroactive membrane to produce a sinusoidal motion. The angular velocity of the motor will provide the desired frequency to displace the membrane and will be controlled by varying the voltage through the user interface. The stroke would be varied by altering the location of the platform. This design is shown in Figure 8 of the Appendix.

Analytical: The motor that rotates the crank to produce the sliding motion must provide sufficient torque to perform the desired motion and displacements. A torque will be induced from the force exerted by the specimen and the weight of the platform. The motor must have a torque larger than this torque. If the motor rotates in a counterclockwise direction, a maximum torque should be observed at 0°. This will be taken into consideration when selecting a motor. A factor of safety of 1.2 will be used to ensure the system will perform if it were unexpectedly loaded more than calculated. This factor of safety was chosen because it provides a safe operating range without greatly limiting the motor selection. The motor must also provide a sufficient angular velocity to produce the motion at the maximum frequency of 100 Hz. The calculations for the torque and angular velocity are shown in the Appendix.

Advantages & Disadvantages: The advantage of the crank slider design is how it exploits rotational motion and translates that into reciprocal motion. This allows the use of a DC motor, which can provide a wide range of torques and angular velocities. With a given applied load and frequency needed, a motor can be selected upon this criteria. The life of DC motors exceed that of solenoids making the maintenance of lower importance when considering part replacement. However, the cost of the DC motors relative to that of the solenoid is considerably more expensive.

A weakness of the crank slider design is that the zero position of the stroke must start at a specific position such that no load is applied before testing is conducted. This would require the user to manually set the start position of the mechanism before each test is conducted. Also, for there to be stroke variation the platform that holds the membrane must be able to move manually by the user before testing is performed.

Manufacturing Considerations: The manufacturing of the crank slider design requires fairly complex processes. A DC motor will be selected to produce the required angular velocity and torque as calculated in the Appendix. Due to the small displacements required by the design, high resolution tolerances are necessary for the machining of the crank slider mechanism. The design will require a platform that sits within a housing to keep it level throughout operation as the disc is rotating. This will require tight tolerances between the platform and housing to minimize any motion that might occur. A Teflon sleeve, or something comparable, would be attached to the housing to minimize the friction between the two components. Another platform would be manufactured to support the specimen. This platform would have to be attached to guides so the height could be varied and the stroke displacement could be variable.

Uncertainty and Risks: Failure for this design may occur in multiple places. Locations that utilize pins such as at the disc or where linkages connect may have a possibility to shear if over stressed or after prolonged fatigue from use. Considering the small size of the components of this design, there is a possibility of damage during assembly or maintenance. This would cause the mechanism to operate incorrectly and give rise to the possibility of giving inaccurate data.

Cam Driven Concept

Concept: This design uses a cam powered by a DC motor to move a platform that holds the electroactive specimen. The frequency of the motion will be controlled by varying the voltage supplied to the motor through the user interface. The stroke distance will be varied by changing the cam size. Therefore, multiple cams will be needed to provide various stroke distances. This design is shown in Figure 9 of the Appendix.

Analytical: A motor must rotate the cam to produce the desired motion. The motor must provide a torque greater than the induced torque from the membrane force and the weight of the platform. A factor of safety of 1.2 will be used to ensure the system will perform if it were unexpectedly loaded more than calculated. This factor of safety was chosen because it provides a safe operating range without greatly limiting the motor selection. The motor must also provide a sufficient angular velocity to produce the motion at the maximum frequency of 100 Hz. The calculations for the torque and angular velocity are shown in the Appendix.

Advantages & Disadvantages: The cam design is similar to that of the crank slider. It will also utilize a DC motor and provide a piston like motion to accomplish the necessary motion. The advantage the cam design has over the crank slider design is that it's simpler in construction. The sinusoidal motion is provided by the shape of the cam itself which requires no adjusting of the position of the membrane to supply the needed displacement. However, to vary the stroke, a different cam must be placed onto the mechanism each time the user wishes to displace the membrane different distances. This will generate additional costs to the design since multiple cams will be needed to accomplish this.

Manufacturing Considerations: The cam design would require a DC motor to provide the rotation of a cam. The motor will be selected to produce the required angular velocity to rotate the cam and move the follower with the load of the platform. For the cam design, the various sized cams would need to be manufactured. The cams must have tight tolerances to provide variable displacements in 1mm increments. The roller for the follower must also be considered in the manufacturing process. Bearing would be needed to allow the follower to roll freely with the cam. A platform for the specimens would be machined along with a housing that the platform would move along. This would be similar to a piston design; therefore, it would require a Teflon sleeve, or something comparable, to reduce friction between the two components.

Uncertainty and Risks: In this design there are not many foreseeable ways that one could see failure. The follower guide offers one location in which if there are not proper tolerances that the follower could "wobble" and cause it to jam and cease operation. This would result in the possibility that the motor would stall and burn out.

3.3 Evaluation of designs

The team developed a decision matrix shown in Table 2 to be used as a tool to guide the decision for a final design. The decision matrix used the key design and performance specifications as categories. The criteria and method of creating the decision matrix is explained below.

Table 2. Decision Matrix.

Team 20 Design Decision Matrix						
Design	**Safety**	**Low Cost**	**Ease of Use**	**Reliability**	**Performance (vary stroke & frequency)**	**Total**
	0.20	**0.05**	**0.10**	**0.20**	**0.45**	
Solenoid	5	5	5	3	3	**3.7**
Crank Slider	3	3	1	5	5	**4.1**
Cam	3	3	3	5	5	**4.3**

3.3.1 Criteria, Method

The decision matrix shown in Table 2 was created after discussing with the sponsor his requirements and desires for the system. The sponsor communicated that he wanted a robust system that would perform well. This led to performance, the ability of the system to vary the stroke and frequency effectively, to have the highest importance therefore being weighted the highest at 45%. Reliability and safety were rated the next highest at 20%. Reliability is an important quality when justifying a robust system. The mechanism reliability is dependent upon several factors: life of the components, cost to replace the components, and ease of access to the components. The mechanism should require little maintenance so it can be operated over long periods of time without extensive attention to servicing. As with all devices, safety is important to protect the operator and surroundings. Ease of use was weighted at 10% because the system must be easily controlled to coordinate the various functions of varying stroke and frequency. Cost was weighted the lowest at 5% because it was determined that the mechanism should perform the desired functions with little regard to the cost due to its application in the research field instead of industry. The initial cost of components were used for basis of cost performance excluding the materials costs because each design will use nearly the same amount of materials. The designs were ranked for each category based on their ability to meet the desired criteria. A ranking of 1, 3, and 5 is used with 5 being the best, 3 being adequate, and 1 being poor. The design total was then calculated using the weight values. This gave a basis for which design would perform best.

The solenoid design received top scoring across the board with the exception of reliability and performance since the solenoid has a limited lifetime of operation and thrust. The cam and the crank slider designs ranked near equally to one another based on their relative complexity to that of the solenoid design. The crank slider design scored slightly lower though than the cam design in ease of use due to the nature of its operation which would require more user input.

3.3.2 Selection of Optimum Ones

From the analysis of each design and the decision matrix, the three designs were ranked. The crank slider design was chosen to be the optimal design based on ranking and preliminary analysis. This design is very complex and requires multiple components; however, it will perform the required the tasks.

The next best design was determined to be the cam design. This design had the best score in the decision matrix showing it would also meet the desired specifications fairly well. However, based off preliminary analysis this design would complex to manufacture. The cam design is more complex than the solenoid design but is still fairly simple. This was a key factor in ranking the cam design.

The solenoid design was ranked as the lowest design. The thrust exerted by the solenoid is limited and would be insufficient to provide the needed performance. Though it is the simplest design to manufacture, the design would not perform. These were key factors in ranking the solenoid as the lowest overall design.

Considering the rankings of the three designs, the cam and the crank slider have been chosen to be focused on for further analysis. These designs may meet the customer's requirements. Further detailed analysis will be performed on these designs so that the best design will be chosen and it is manufactured to withstand the conditions it will be operated in. Upon analysis, if these designs do not meet the customer's needs, we will return to the customer for possible reduction in constraints. Preliminary discussions with the customer has indicated that the frequency of operation could possibly be reduced.

4 Methodology:

For our goals to be achieved, we will develop a system that can run the specimen through a standard fatigue test but also be able to count how many oscillations occur to determine the life of the specimen. Additionally, we have taken measurements of the MTS machine so that our device can accurately mount onto it while maintain dimensional stability with minimal vibrations and movement.

To come up with the type of system we would like to implement for the fatigue testing, we have developed multiple designs and created a decision matrix comparing each option. The decision matrix is shown below in Table 2. When we conclude the type of system that we want, we will make technical drawings of the entire system that fit to the dimensions of the MTS machine. Once the drawings are completed, they will help us determine what types of materials and parts we will need to start building the system. Before building a prototype though, we will consider making a design simulation using computer software to determine if we should move forward to a physical prototype. If the next step is to move forward with a prototype, materials will be collected and machining and assembly will follow. Some sample runs will be made once the prototype is completed to determine competency and accuracy in measurements. If everything is acceptable and up to par, if time permits, experiments can be carried out to determine the best fatigue material that could be implemented in the actual robotic legs. A flow chart of the project planning is shown below in Figure 3.

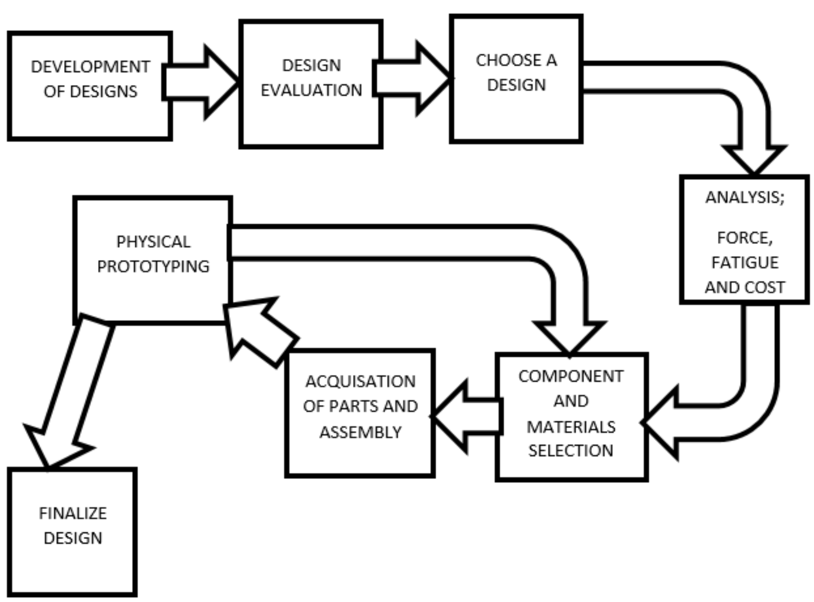

Figure 3. Flow chart of project plans.

4.1 Schedule

The Gantt chart shows the sections of the task the team must complete. It allows time management for the project to flow smoothly having completed one task before the next is performed. The project has been broken down into five stages for the entire year. These sections include Design of Machine, Analysis of Machine, Developing a User Interface, Assembly, and Testing. The Gantt chart is shown in Figure 4 of the Appendix. The final two stages are not included because the Gantt chart only includes tasks for the fall semester.

4.2 Resource Allocation

Specific tasks have been assigned to each team member. For each task, a primary and a secondary person have been assigned. This will ensure that the task will be completed on time if at any point the primary person cannot complete their designated task.

<u>Design of Machine</u>
Decision Matrix –Victor, Matt (4 days)
Dimensional constraints – Nick, Matt (1 day)
CAD drawings – Nick, Kristina (19 days)

<u>Analysis of Machine</u>
Force – Kristina, Nick (5 days)
Fatigue – Kristina, Nick (5 days)
Frequency to Velocity – Matt, Adriane (10 days)
Material selection – Adriane, Victor (10 days)
Motor and power source selection – Matt, Victor (10 days)
Cost- Nick, Victor (5 days)

<u>Developing of a User Interface</u>
Synchronized with LabVIEW – Adriane, Matt (48 days)
GUI – Adriane, Nick (48 days)

<u>Assembly</u>
Machining– Kristina, Nick (TBD in spring)
Mount to MTS – Victor, Matt (TBD in spring)
Connect to computer – Adriane, Kristina (TBD in spring)

<u>Test</u>
Repeatable trials – Matt, Kristina (TBD in spring)
Capable of data acquisition (displacement and force) – Adriane, Victor (TBD in spring)

5 Conclusion

This project is driven by the lack of information on the fatigue of electroactive membranes. By the end of the spring semester 2015, the team shall have completed the objectives stated and shall accomplished the task ahead. These tasks include devising a fatigue mechanism that provides sufficient data on the fatigue behavior of the electroactive membrane. Preliminary calculations were developed to determine the forces acting on the drivers for each mechanism. Further analysis will be completed when final dimensions are developed. A decision matrix was developed using the design and performance specifications given by the sponsor. This decision matrix was used to as guide to selection of the optimal designs. Along with the decision matrix and the design analysis two designs were selected. The designs chosen were the crank slider and cam designs.

Future work includes detailed analysis of the selected systems. Dimensions for each component will be finalized and FEM analysis will be completed. Material selection will be conducted simultaneously to produce the best performing system. Upon analysis, if the designs are unable to meet the customer's needs, we will reduce the maximum frequency that the system must produce to obtain a feasible device. A final design will be selected from the analysis. The components will be selected and ordered to ensure they arrive in time to complete the project. After complete analysis, ensuring the design will perform the required tasks and withstand the induced loads, the drawings will be submitted to the machine shop for machining.

6 References

[1] Oates, William and Jonathan Clark. “High Cycle Fatigue of Electroactive Membranes.” Florida A&M/Florida State University, 2014. Print.

[2] Kofod, Guggi, Peter Sommer-Larsen, Roy Kornbluh, and Ron Pelrine. "Actuation Response of Polyacrylate Dielectric Elastomers." *Journal of Intelligent Materials Systems and Structures* 14.12 (2003): 787-93. Web.

[3] Newton, Jason. "Design And Characterization Of A Dielectric Elastomer Based Variable Stiffness Mechanism For Implementation Onto A Dynamic Running Robot." Thesis. Florida State University - College Of Engineering, 2014. Print.

[4] “Ledex Tubular Linear Solenoids.” Johnson Electric. Product Specifications. Web.

Appendix

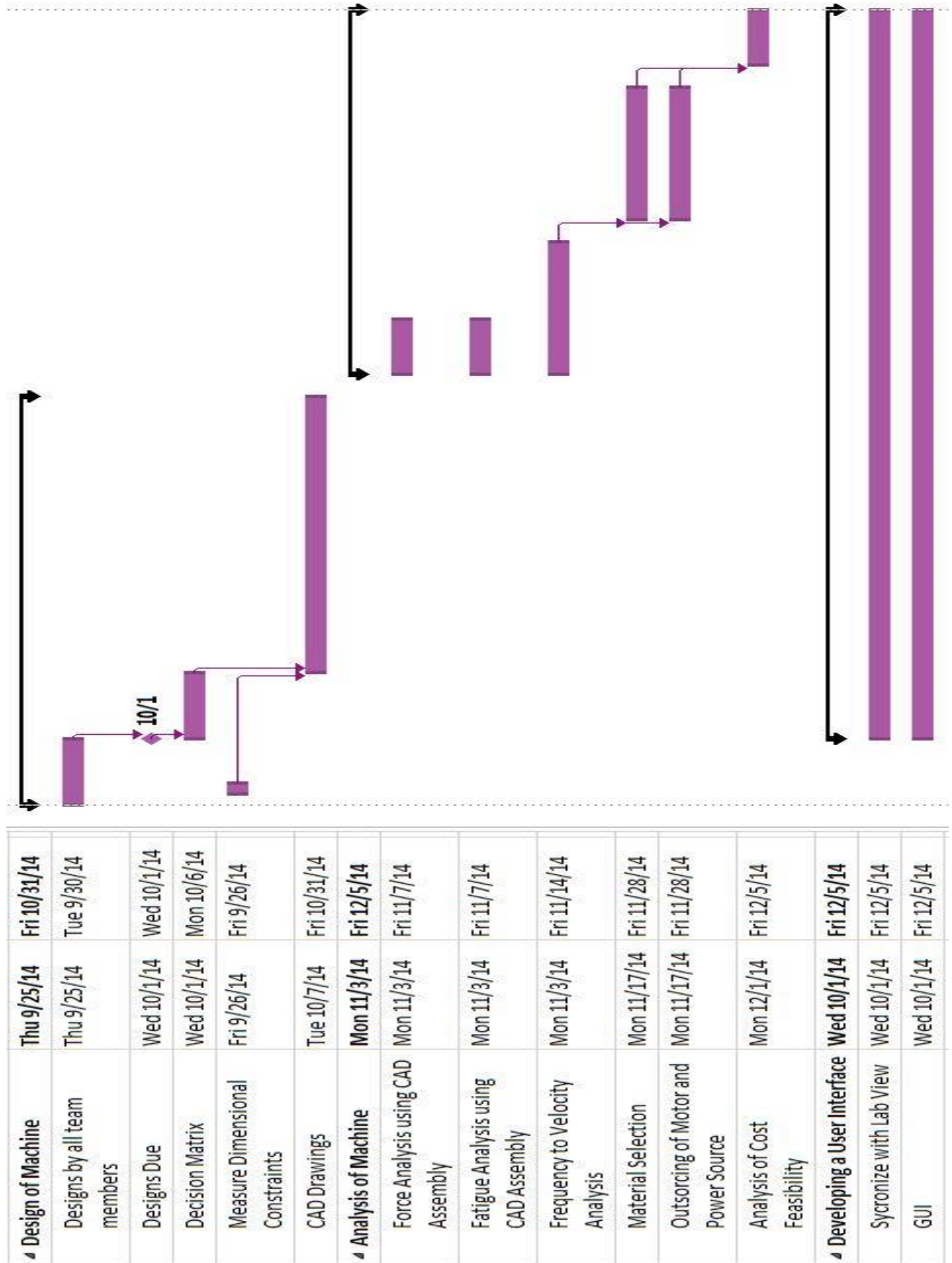

Figure 4. Gantt Chart.

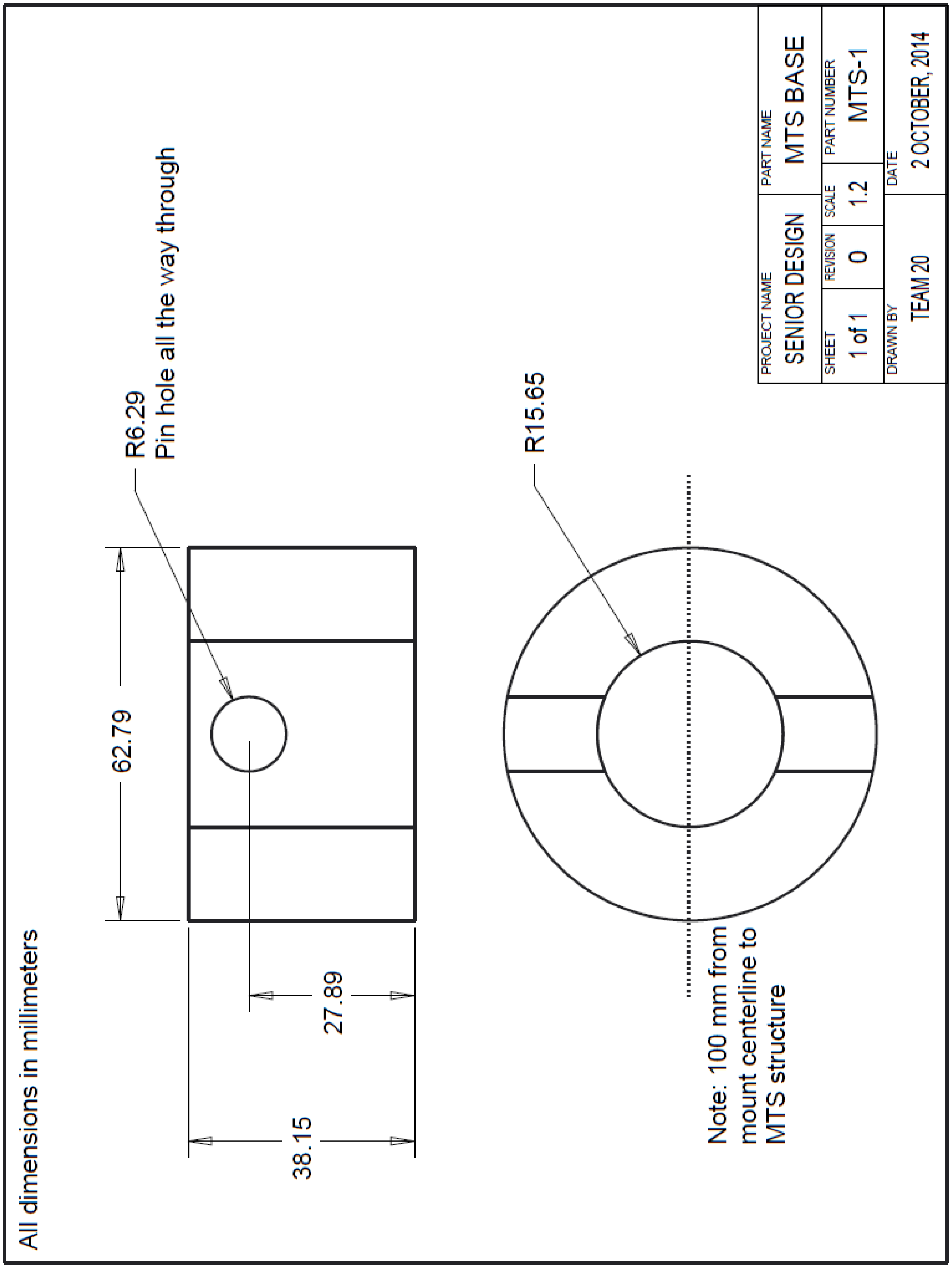

Figure 5. MTS base drawing.

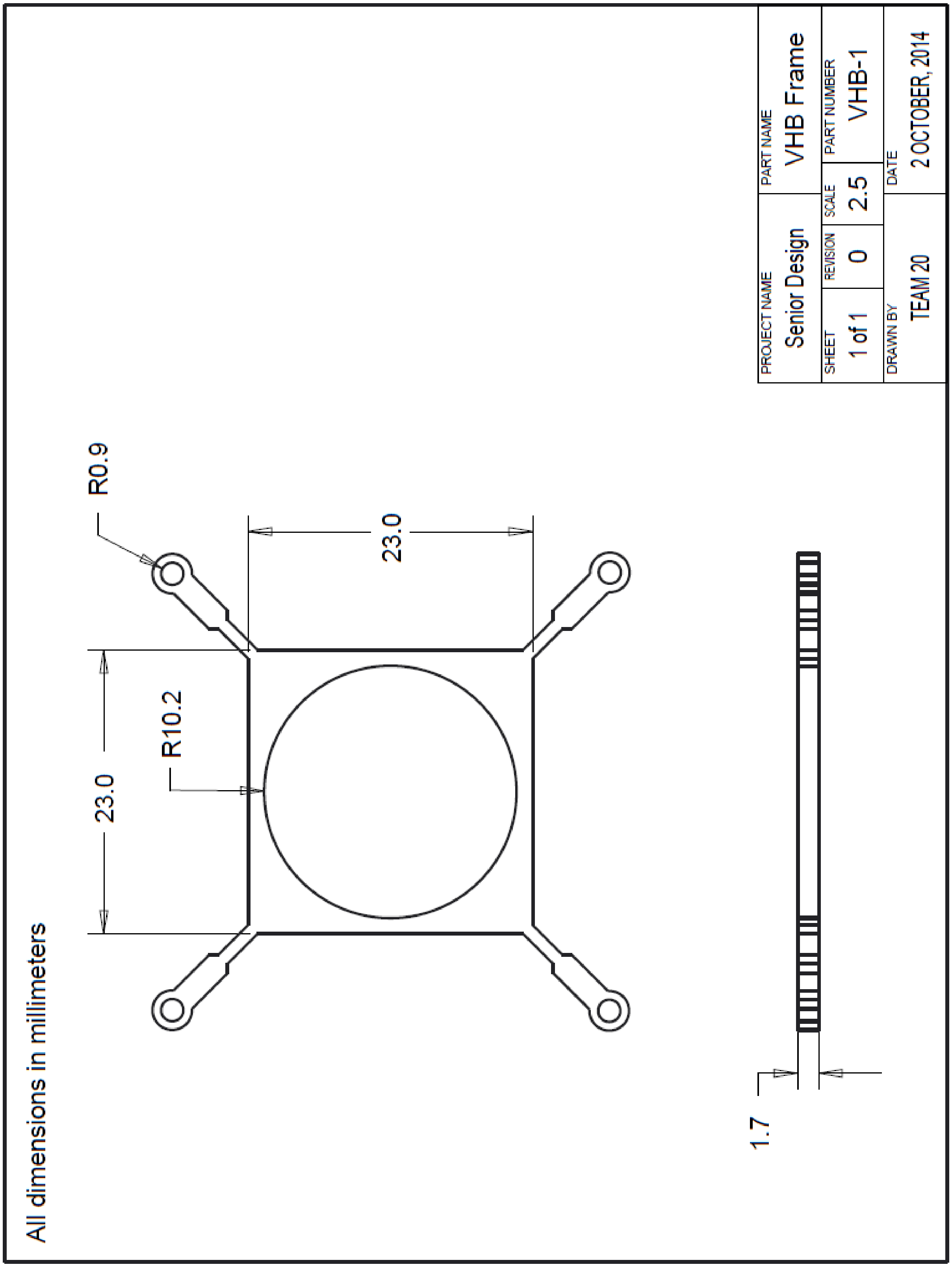

Figure 6. VHB frame drawing

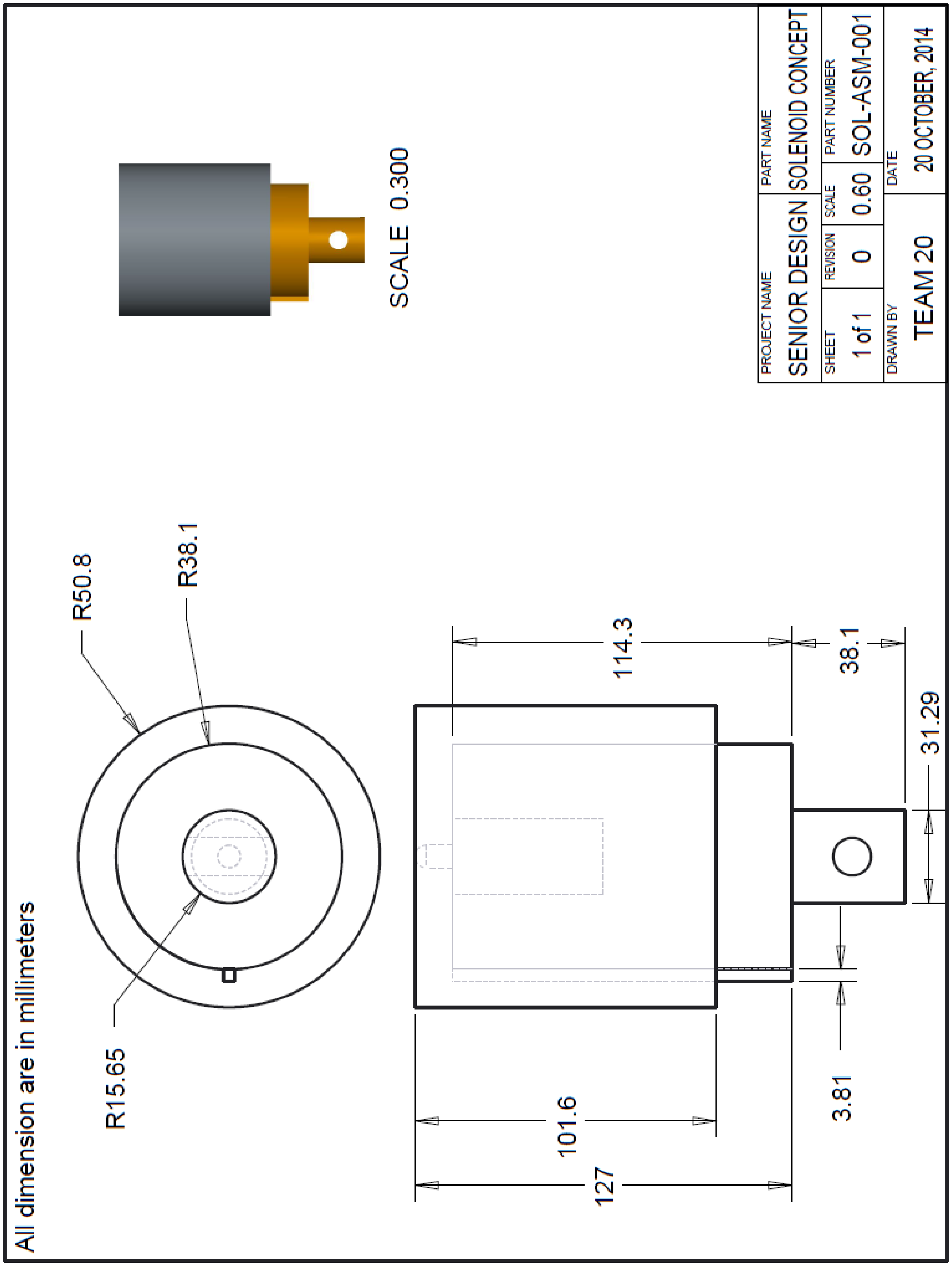

Figure 7: Solenoid design concept

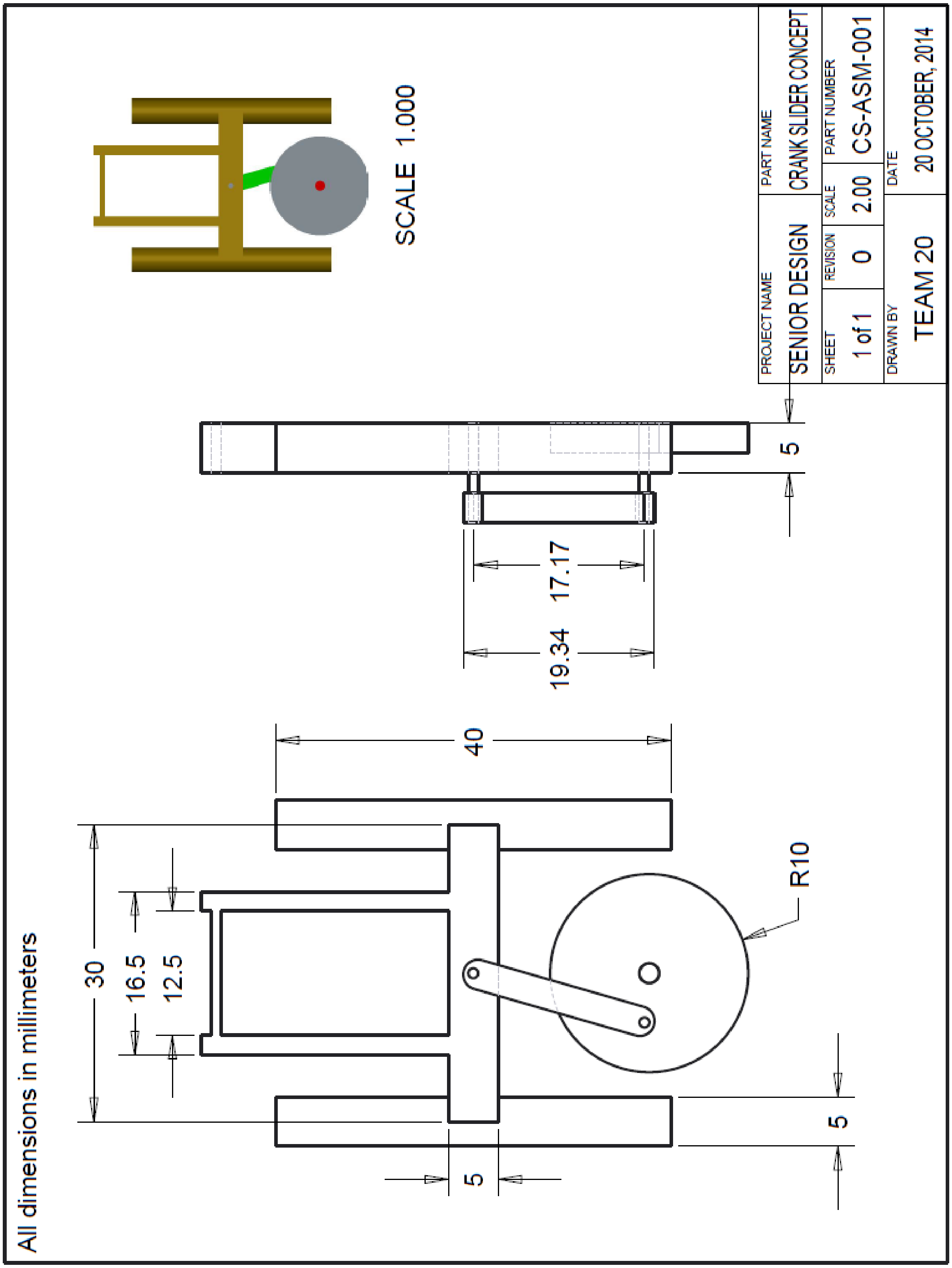

Figure 8: Crank slider design concept

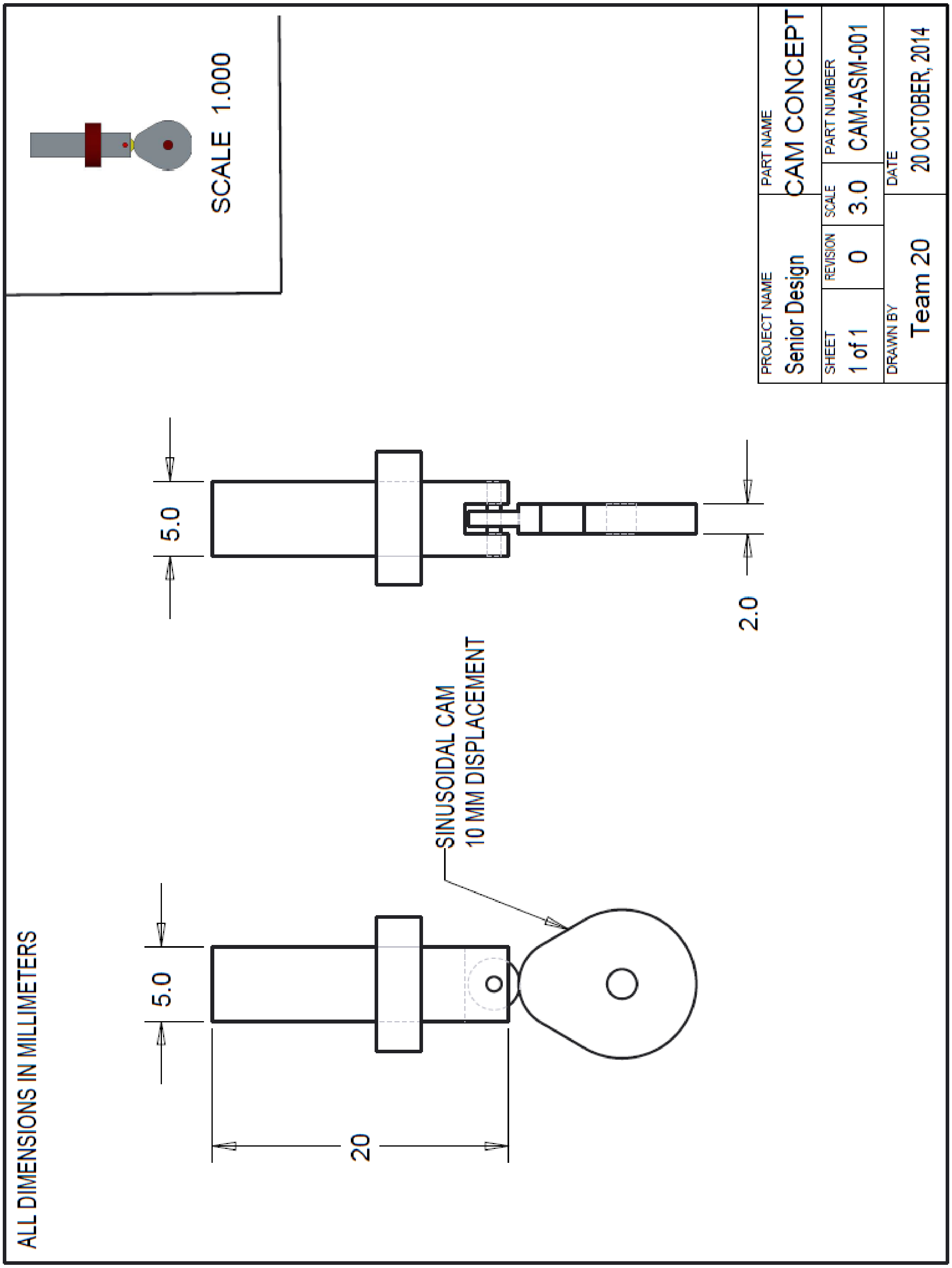

Figure 9: Cam Design Concept

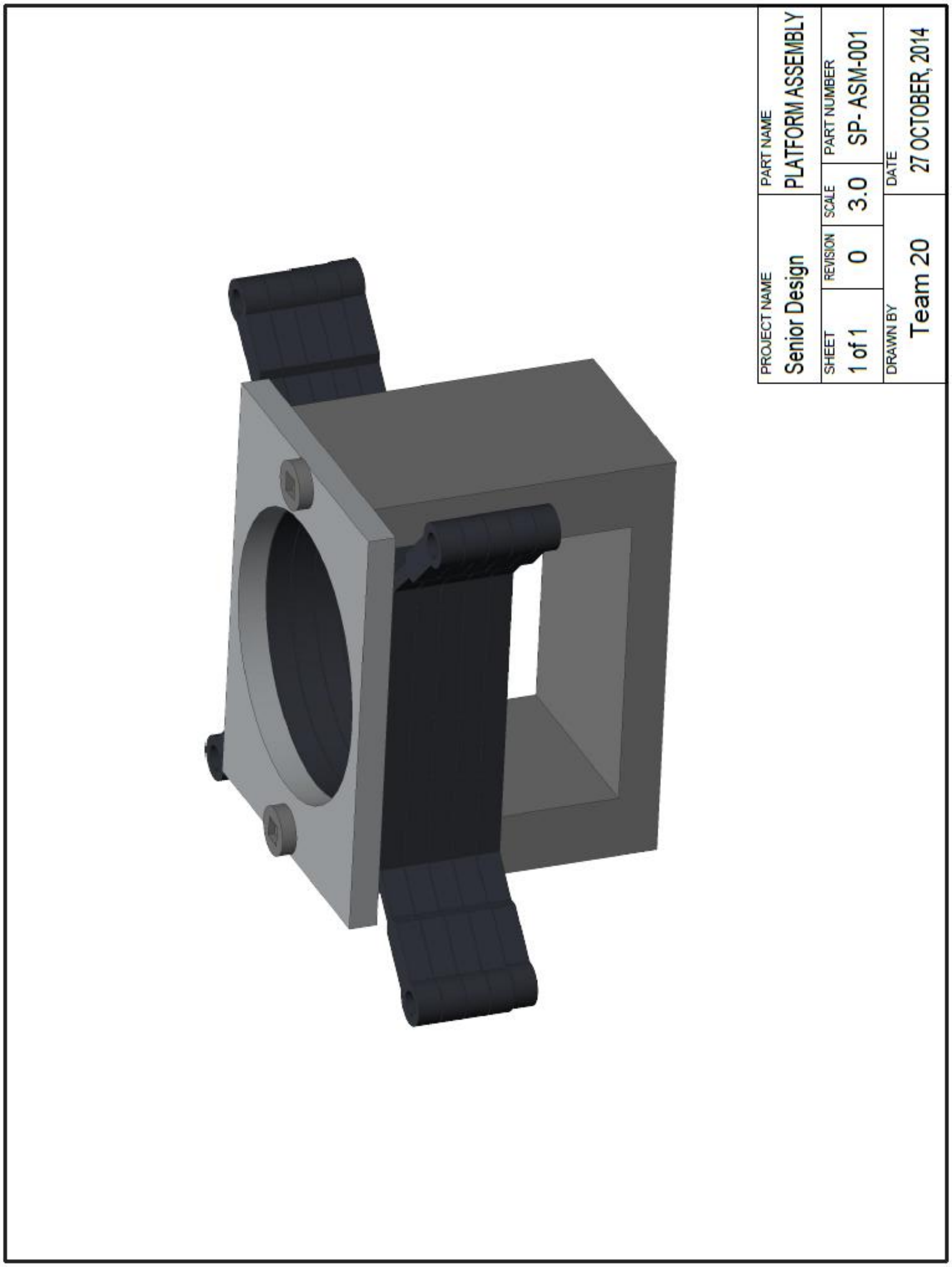

Figure 10. Platform assembly with frames.

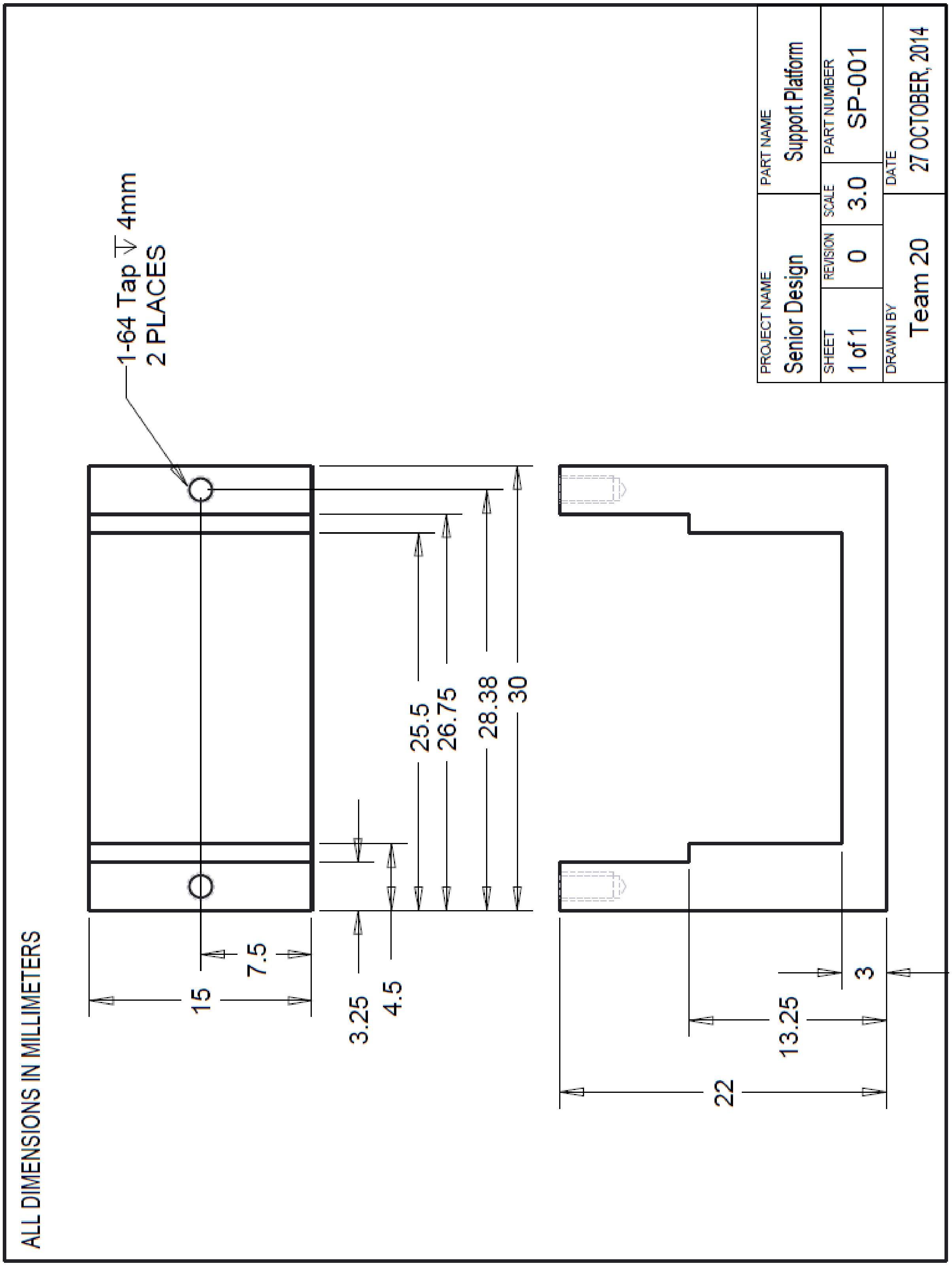

Figure 11. Platform drawing

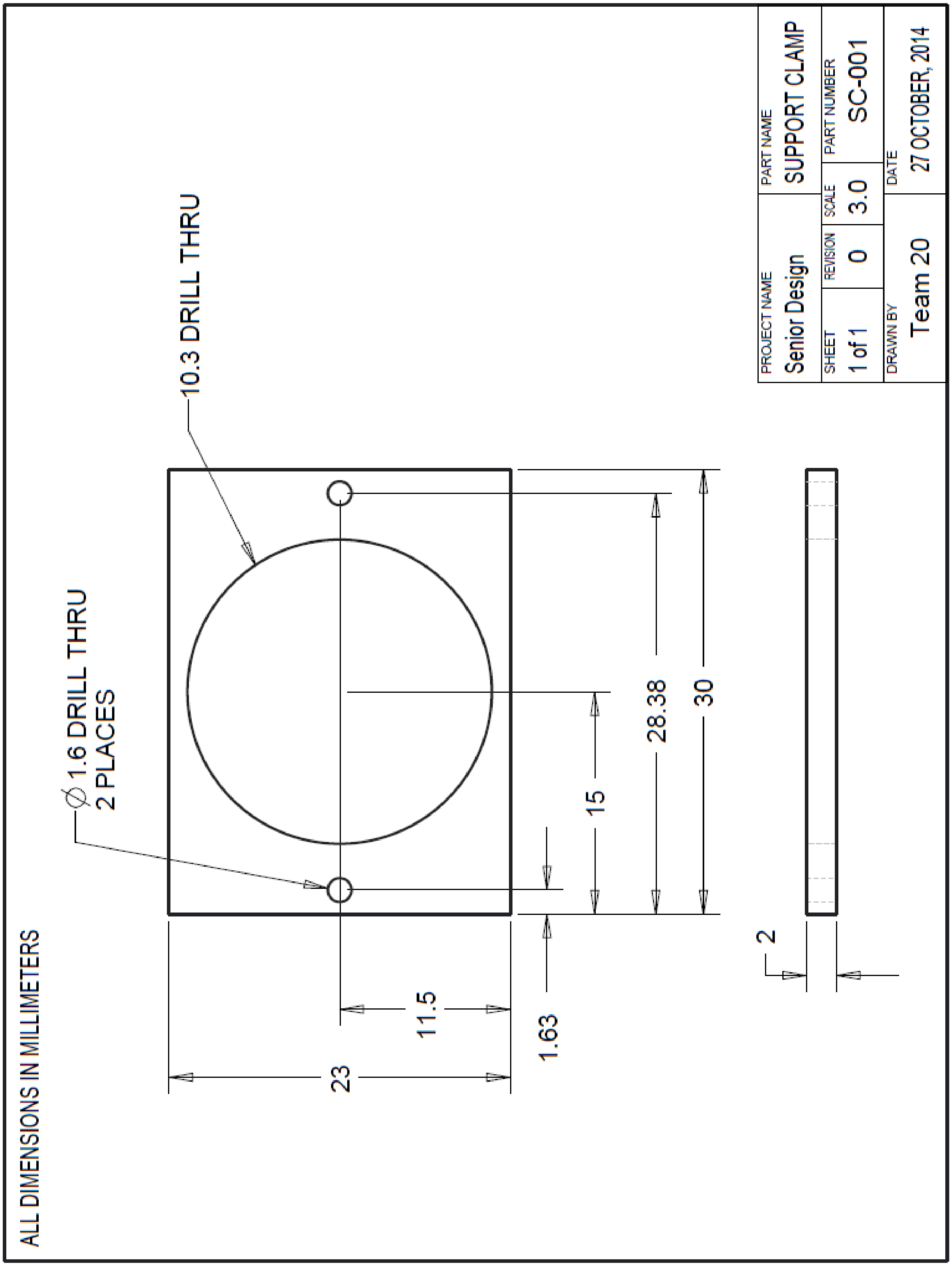

Figure 12. Support clamp drawing

Calculations

Forces due to friction are neglected

Solenoid Calculations

$\text{ForceMembrane} = 5N$ Expected force from displacement of membrane

$\text{PlatformWeight} = \text{mass} \cdot g$ Weight of platform

$\text{SpringForce} = k \cdot x$ Force from the springs were k is the spring constant and x is the distance the spring displaces

$\text{TotalForce} = \text{ForceMembrane} + \text{PlatformWight} + \text{SpringForce}$ Total force exerted on solenoid

$\boxed{\text{TotalForce} = 5N + m \cdot g + k \cdot x}$

Dynamic Loading

$m := 1kg$ estimated mass for device

$x := 10mm$ maximum displacement

$w := 100Hz$ maximum frequency

$x = x \cdot \sin(w \cdot t)$ sinusoidal displacment

$a = x \cdot w^2 \cdot \sin(w \cdot t)$ acceleration

$F = m \cdot a$ Dyanmic force

$\boxed{F := m \cdot x \cdot (w \cdot 2 \cdot \pi)^2 = 3.948 \times 10^3 N}$ Maximum force experienced during motion

Motor Calculations

$w = 2 \cdot \pi \cdot f$ Angular Velocity of the Motor

$f := 100Hz$ Maximum Frequency

$\boxed{w := 2 \cdot \pi \cdot f = 6 \times 10^3 \cdot rpm}$ Needed angular velocity of motor

$\text{ForceMembrane} = 5N$ Expected force from displacement of membrane

$\text{PlatformWeight} = \text{mass} \cdot g$ Weight of platform

$\text{TotalForce} = \text{ForceMembrane} + \text{PlatformWight}$ Total Force

$\text{radius} = 10mm$ Largest displacement

$\text{Torque} = \text{TotalForce} \cdot \cos(\theta) \cdot \text{radius}$

$\boxed{\text{Torque} = (5N + m \cdot g) \cdot \cos(\theta) \cdot \text{radius}}$

Where θ is measured from the motor shaft center of axis