Tabletop Mechanical Test Apparatus for Torsion Experimentation

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Submitted To: Dr. Helzer and Dr. Gupta

Authors: Brendan Keane, Logan McCall, Reggie Scott, Mark Swain

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Abstract

The Air Force Research Laboratory Munitions Directorate at Eglin AFB does thorough material testing for their products. A major material test they utilize is the torsion test. Their current machine is very large and is ineffective when testing small specimens. They have a need for a smaller, tabletop torsion tester. A smaller machine will produce much more accurate measurements when testing small specimens. After receiving all of the needs and constraints from the Air Force sponsor, multiple potential designs for the machine were created. Each component of the machine was analyzed separately in order to ensure the overall optimum design is chosen. Decision matrices for each component were used to choose the best option. Moving forward, detailed CAD drawings will be made in order to perform further analysis. Materials for each component will be chosen and part orders will be made in the future.

1 Introduction

Material testing is an essential part of designing new and improved products. Knowing how a material acts under certain conditions allows engineers to create an optimal design. The Air Force Research Laboratory Munitions Directorate at Eglin AFB is currently testing materials to use with their products. These products range from warheads to the frame of a fighter jet. In order to ensure optimal performance and user safety, many material tests are done. The current torsion machine at Eglin AFB is very large and is only effective when testing large specimens. They have a need for smaller, tabletop torsion testing machine. A smaller machine will lead to more accurate data when testing small specimens. These small specimens are used in order to test materials that are similar to the geometry of the product in the field.

In general, there are 4 major components of a torsion machine. These components include load generation, load application, load measurement and housing. Additionally, the Air Force sponsor has requested that the free end of the specimen has 1 degree of freedom in the axial direction. Each of these aspects can be designed in many different ways so it is important to form a decision matrix for each category in order to get an optimal overall design.

2 Project Definition

2.1 Background Research

The Eglin Air Force Base's Munitions Directorate has done extensive research in the field of testing mechanical properties of materials commonly used in projectiles. They are interested in how different materials react under different loads to simulate different scenarios of diverse mediums that the munitions will be fired at. This being said, the group is constrained to the size of the specimens that they can generate. The reason for limited plate thickness is not a matter of cost, however it is a matter of geometry. When the Munitions Directorate is fabricating components of the munitions they use raw stock that is as close to final shape as possible to conserve waste material. In order to properly characterize the materials that ends up in a product they have to test similar geometry in order the get accurate results. A representation on how the Directorate gets their samples is shown below in Figure 1. (1)

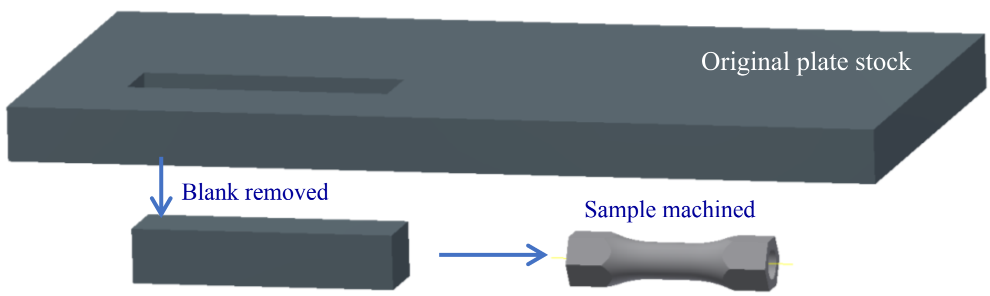

Figure 1 Example of sample production from plate stock (1)

Since materials of interest are often in the form of thin sheets or plates, this makes the specimen that is generated relatively small, having dimensions roughly the size of a human thumb. The exact dimensions can be seen below in Table 1, and a drawing of the specimen can be found in Figure 2.

Table 1. Specimen Dimensions

Dimension	Measurement (mm)
Total Length	58.4
Gauge Length	12.7
Width	14.3
Inner Diameter	9.09
Fillet Radius	27.9
Hex Length	10.4

For most common torsion testing the specimen is roughly a foot long and roughly an inch in diameter. But, due to the constraint of the thickness of the plate that they are machining the specimens from; problems arise from using equipment that test more common (larger) sample sizes. These problems normally come in the form of electrical noise in the signals they are receiving from the sensors they have testing. There becomes a point at which the data has no meaning because the signal has been extrapolated beyond its limits, or it is experiencing a low Signal-to- Noise ratio(SNR). (2)

In its most simple form the signal to noise ratio can be defined as the rms (root-mean-square) value of the voltage divided by the rms value of the noise. The higher this ratio is, the more accurate your results will be. As seen above in Figure 3 below, noise energy can be expressed over

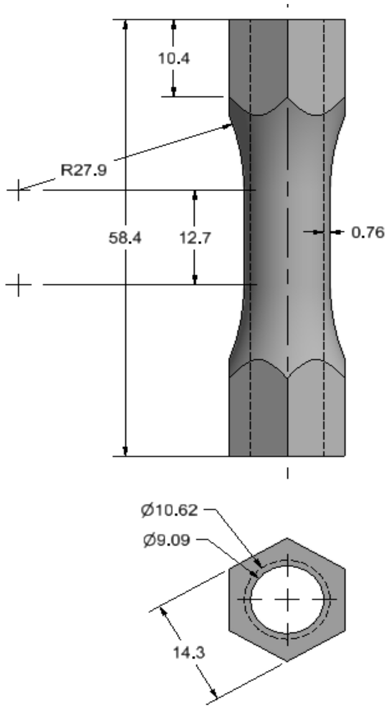

Figure 2: Actual dimensions of the samples given in millimeters. (1)

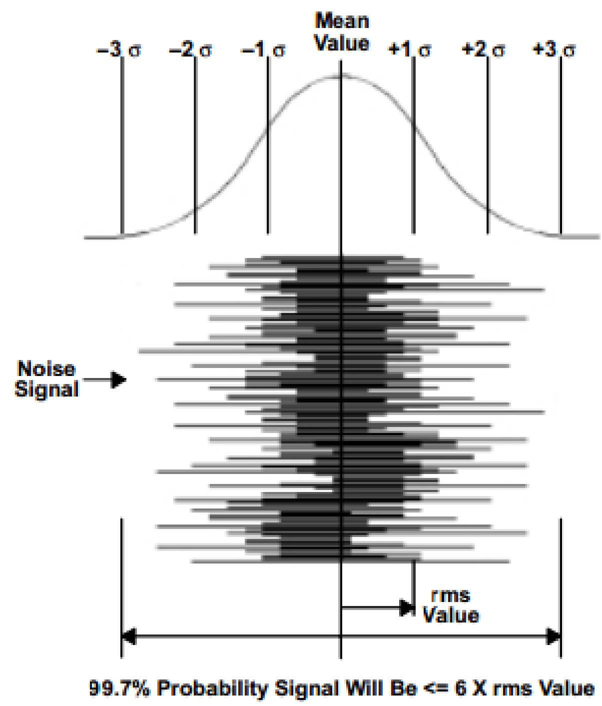

Figure 3: Gaussian Distribution of Noise Energy showing different standard deviations in relation to the mean value. (3)

the Gaussian Distribution of Noise Energy. In this case σ is the standard deviation of the Gaussian distribution and the rms value of the noise voltage and current. In this example data it is clear to see that when the data falls close to $\pm 1\sigma$ it is going to be fairly close to the mean value, which in this case is the true value from the signal. For this given data it will fall in $\pm 1\sigma$ 68% of the time. (3)

For material testing in the Munitions Directorate the accuracy of their data might be the difference in penetrating the target, or causing catastrophic damage to the surroundings, so the noise in their data needs to be minimized in their signal. Eglin is currently using a testing machine that only exerts roughly 2% of its total load capacity. This is due to the size and power of the machine that they are using to test the samples. Running at such a low torque causes the machine to send out an extremely small signal. In turn to actually understand, and see the signal the data has to be amplified, but since the data was taken from such a small range of the machine's ability; the data, once amplified, has a lot of noise.

To achieve a higher SNR Eglin has asked our group to design and build a much smaller, more accurate machine. This machine would run at roughly 20 to 40% of its capacity yielding data that would have much less noise associated with it the size and power of the machine. (1)

2.2 Need Statement

The Munitions Directorate at the Eglin Air Force Base is the sponsor for this project. Material testing is a crucial part in developing new and improved weapons and ammunition. Their current torsion-testing machine is unsatisfactory due to its massive size relative to certain specimens. For small specimens their current machine is highly inaccurate and wasteful.
"**The current torsion machine at the Eglin Air Force Base is inefficient and ineffective when testing small specimens.**"

2.3 Goal Statement & Objectives

In order to develop the proper machine that will satisfy Eglin Air Force Base's Munitions Directorate need, an overall goal statement and objectives were developed for the project.

"Design a more effective way of testing small specimens in free end torsion."

Objectives:

The objectives of this project include:

- Design a way to apply a torque to a material sample
- Measure the applied torsion to the sample
- Interfaces with existing 3D DIC system
- Construct small scale housing for the machine that can fit upon a tabletop
- Design a gripping mechanism that can hold cylindrical samples while testing and allows for axial linear motion
- Use materials that can be easily procured and machined
- Ensure that design is safe for operator

2.4 Constraints

From the background presentation delivered by the sponsor the following constraints for the project were developed:

- Max load on specimen to Max axial load ratio must be 20% or above. (Currently ~ 2.3%)
- Minimum of 50Nm axial loading by the machine
- Budget - $2,000 (Not including the motor)
- Max surface area of machine – 2ft x 3ft
- Must do monotonic (one direction), and cyclic (2 direction) Free-End Torsion Loading
- Free end has one degree of freedom (axial direction due to contraction/expansion of specimen)
- Must be compatible with the DIC

2.5 Design Specifications

Additionally, design specifications by the sponsor have been given. These specifications cover measurable design and engineering features of the final machine. The design specifications desired by the sponsor include:

- Max surface area of machine – 2ft x 3ft
- Minimum of 50Nm axial loading by the machine
- Max load on specimen to Max axial load ratio must be 20% or above. (Currently ~ 2.3%)
- Must be able to be moved by human (Max weight ~ 50lbs)
- Must have minimum strain rate of 1.5 degrees/s

2.6 Performance Specifications

Furthermore, performance specifications are expectations of performance during use. The performance specifications put forth by the sponsor are:

- Must be compatible with the DIC
- Must have digital or analog applied stress/force output
- Must be able to input desired cyclic displacement
- Lowest signal to noise ratio as possible

3 Design and Analysis

3.1 Functional Analysis

The figures below show the functional analysis of the tabletop torsion tester. These show the processes necessary to the design and what each component does.

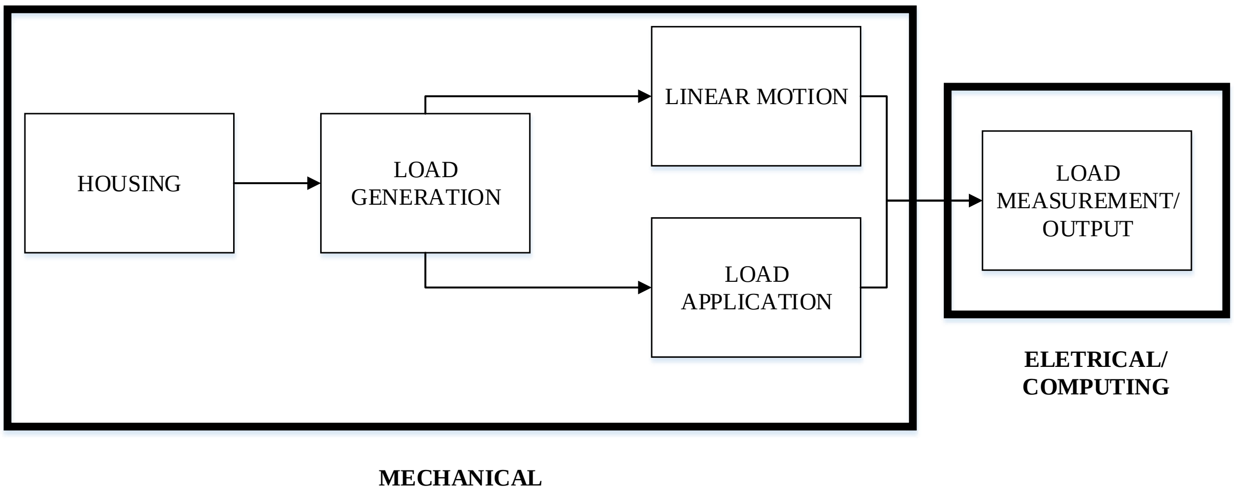

Figure 4 Flow Chart Depicting Relationship of Torsion Tester Systems

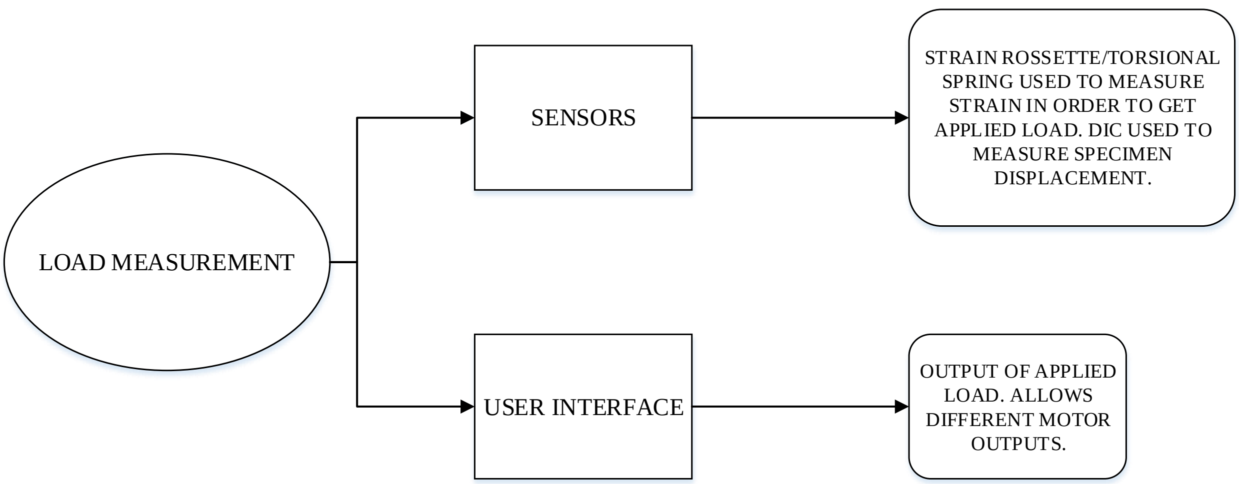

Figure 5 Functional Analysis of Electrical Components

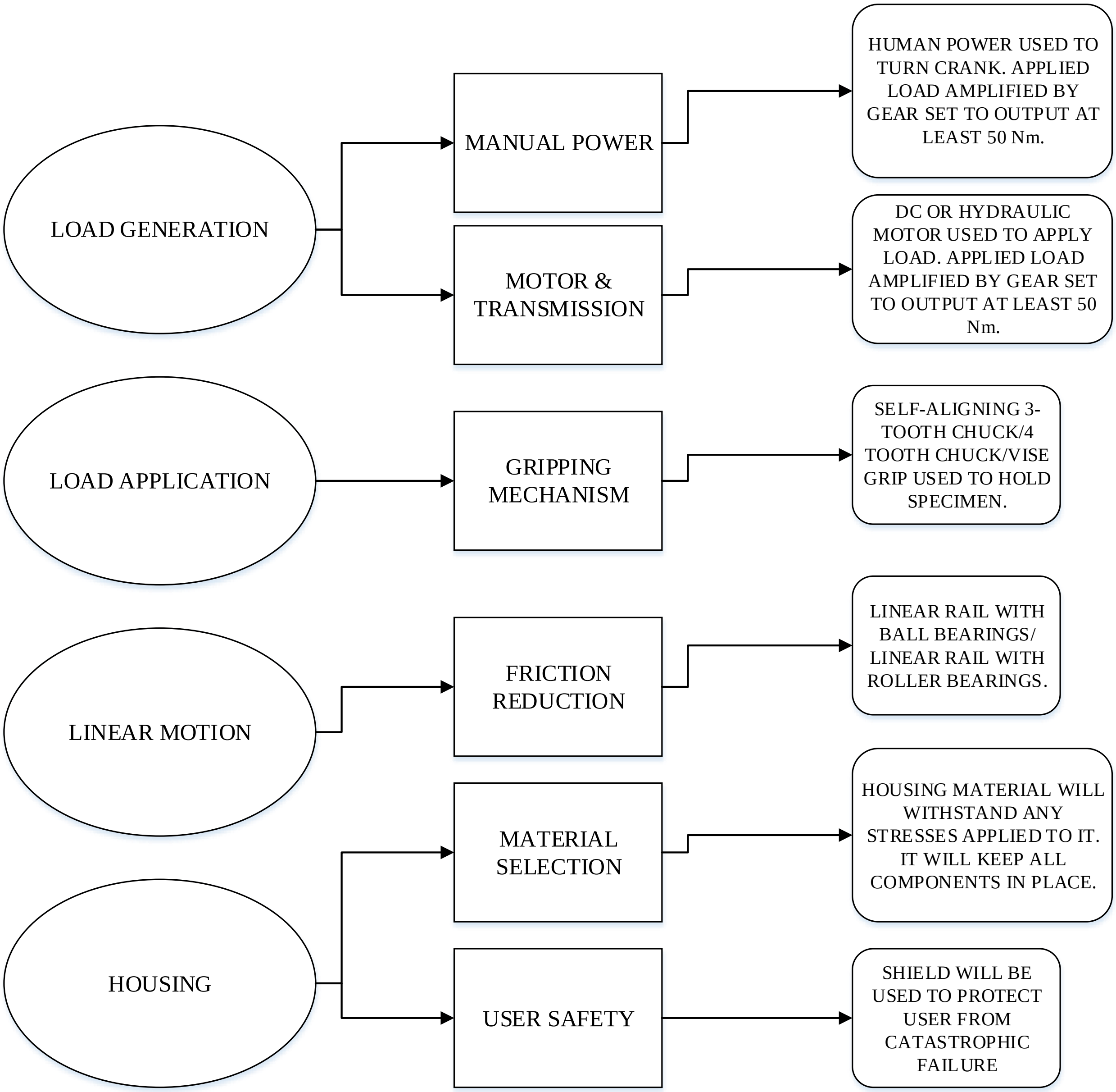

Figure 6 Functional Analysis for Mechanical Components

3.2 Design Concepts

In this section possible designs will be discussed and compared. Instead of comparing 3 total designs, the individual component designs will be compared. This method was chosen since each component of the torsion machine is independent of one another. This will allow for an optimal final design using the best part for each component.

3.2.1 Load Application

A minimum of about 60 N*m is needed to break the titanium specimen. Calculations for the titanium specimen were used since it is the strongest material that will undergo testing. Calculations for this value can be found in the appendix. The equation to find the necessary applied torque (T) is shown below. Three possible designs for the load generation are discussed below.

$$T = \frac{\tau * J}{c} \qquad \text{Eq. 1}$$

Where:

τ = shear stress (Pa)

J = polar moment of inertia (m^4)

c = distance from center to stressed surface of specimen (m)

Manual Crank System

Figure 7 below shows the manual crank system being taken into consideration for the load generation component. The main advantage of this design is its low cost which allows the budget to be used elsewhere in the overall design. Motors cost much more money than a simple shaft and handle. A manual crank system requires almost no maintenance and will never burn out unlike most motors. Additionally, the cost to fix or replace a broken motor is much more than only needing a new shaft or handle. Furthermore, no electrical power supply is needed to apply the load which leads to more financial savings in the long term. The manual crank system is also easy to use and requires no training. The applied force by the user will be multiplied by its perpendicular distance to the shaft and then amplified by a simple gear train. Equations for applied moment and gear torque ratio can be seen below. Finally, building and manufacturing a manual crank system is much simpler than choosing and programming a proper motor.

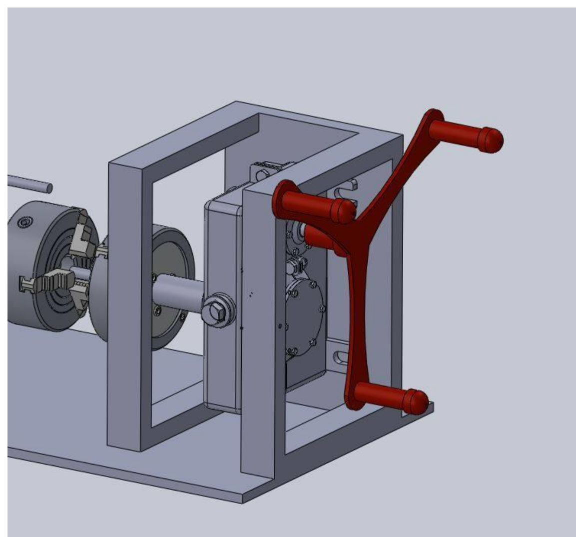

Figure 7 Manual Crank System

$$M = r * F \qquad \text{Eq. 2}$$

$$Torque\ ratio = \frac{N_2}{N_1} \qquad \text{Eq. 3}$$

Where:

M = moment (N*m)

r = perpendicular distance (m)

F = force (N)

N = number of gear teeth

A manual crank system does have some weaknesses. One of the main disadvantages is its inaccuracy. This is because a motor has the capability of being programmed which allows the user to input a desired rate or displacement value. The motor will do exactly what the program tells it unlike the manual system which relies on human power. Also, the user might get tired if the specimen must undergo a lot of cycles or displacement to deform or fail. The crank system is will also weigh more than a motor which effects its portability.

DC Motor with Controller

Another potential option for generating the load for this design is to use a DC motor in conjunction with a microcontroller. One benefit of using a DC motor and microcontroller is that it allows for large variability in the testing. For example, this design must allow for cyclic and monotonic loading. A DC motor and microcontroller has the potential to quickly change from cyclic to monotonic loading and back again with very little effort from the user that is performing the test. Another benefit of a motor and microcontroller is the high level of repeatability. One of the most crucial parts of any laboratory test is to be able to reproduce the data collected. A motor and microcontroller has the ability to repeat the same test many times and apply the exact same conditions each time. A motor and microcontroller system has the potential to be very accurate in the load that is applied and for what period of time that load is applied. For instance, if the test requires that a sample be loaded cyclically to 4.3^0 in each direction, it can be as simply as typing in a few commands on a monitor.

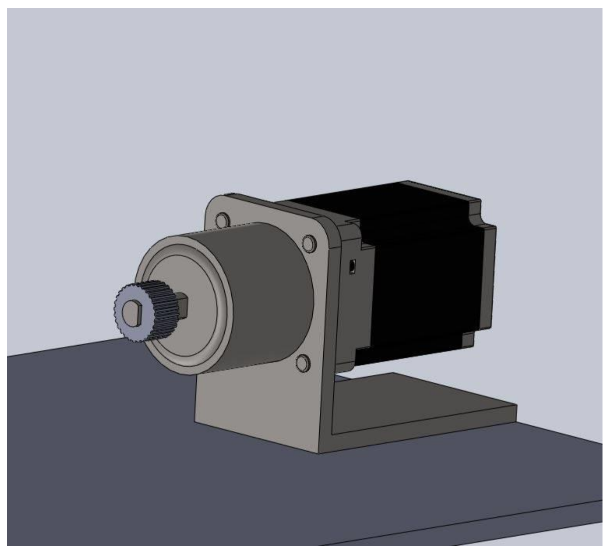

Figure 8 CAD Rendering of DC Motor

One drawback of the motor and microcontroller system is that it must be programmed to operate. With little-to-no prior knowledge in programming, the team will have to dedicate a large amount of design hours to ensure the motor is programmed adequately. Another disadvantage of a motor is that it must be maintained or it may breakdown over time, compared to a manual system that does not require the same upkeep standards. A motor also has the potential to burnout if the load required is too large. The motor and microcontroller can also be expensive when compared to a manually powered design.

Hydraulic Motor with Controller

This form of load application uses a hydraulic system to run a motor that will be the source of the torque applied on the specimen. The design will have at minimum four essential components including the motor, control valve, reservoir, and pump. The fluid in use will either be water or some type of mineral oil; both of which will induce relatively quite a bit of maintenance. This is because flow will be moving through all of the components. Advantages to this type of load application start with its ability to be programmed. This design will have an automated controller connected to the control valve that is compatible with the motor. This allows tests to be repeated over and over with the same outcome. Another perk for hydraulic systems is that these systems are not damaged when it is overloaded. This is why hydraulic motors are the primary choice for jobs that have the need for very high loads. These systems are also preferred in rough terrain situations because dirt and dust do not affect the performance of the system.

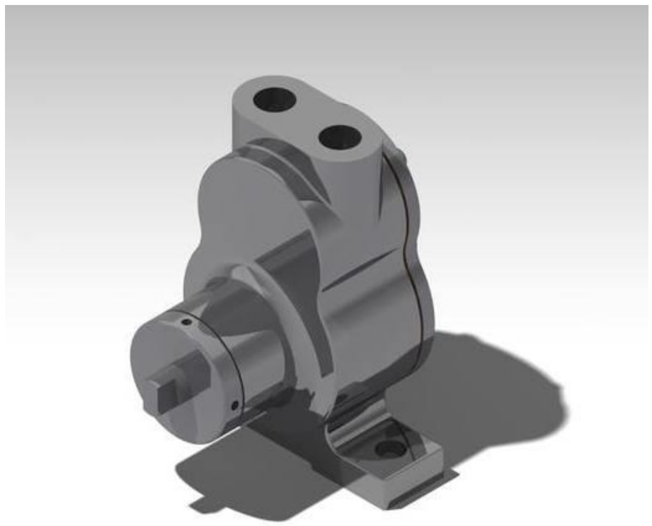

Figure 9 CAD Rendering of Hydraulic Pump

Disadvantages include the extra maintenance, troubleshooting, and cost mostly due to all of the components required to run this system. Preventive maintenance will be required to ensure the efficiency does not vary. This will include changing a filter and a list of checks and balances that will have to be done roughly once a month. Troubleshooting involves pin pointing the problem when the system is not functioning correctly. This process can be quite extensive because it must be performed on all of the components. The cost of the system as a whole will be the highest in relation to other potential design characteristics.

3.2.2 Load Application

Three gripping mechanisms were examined for the torsion machine. These included a 3 tooth chuck, 4 tooth chuck and a vise grip. It is important that a proper gripping mechanism is chosen in order to achieve the highest accuracy possibly. The grip must not allow for any slip or off axis loading.

4 Tooth Self Centering Chuck

Figure 10 shows the 4 tooth chuck design being taken into consideration for the gripping mechanism. The main advantage of the 4 tooth chuck is the load disbursement. This has more teeth than the other designs which allows the gripping force on the specimen to be disbursed evenly over 4 points instead of 3. This leads to a higher allowable gripping force which results in a smaller chance of slip and higher accuracy.

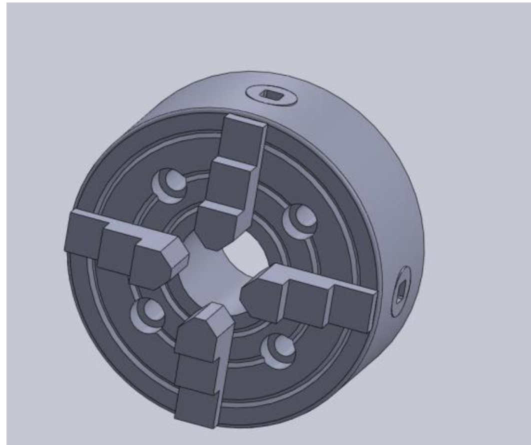

Figure 10 CAD Rendering of 4 Jaw Chuck

The main disadvantage of the 4 tooth chuck is its inability to grip a hex shape specimen. This puts a constraint on the shape of specimens used. The 4 tooth chuck is also slightly more costly than the 3 tooth chuck. Finally, the 4 tooth chuck does not self-align which can lead to off axis loading.

3 Tooth Self Centering Chuck

The primary goal for the gripping mechanism is to efficiently grip the specimen without allowing any slip. This system uses a three toothed chuck to grip the specimen. The chuck has a key in the side of it that can be rotated to optimize the grip for various specimen sizes. The teeth are all dependent on each other within the mechanism. They can be tightened well enough to eliminate any slip on the specimen.

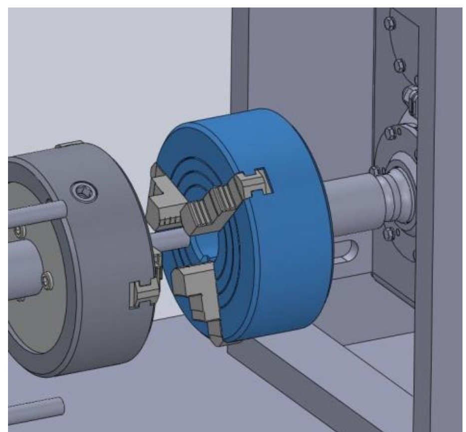

Figure 11 CAD Rendering of 3 Jaw Chuck

A disadvantage to this design is that it only has three contact points. This could make it harder to eliminate the slip. To compensate for that, the grips may have to be tightened even more. This could produce a problem when dealing with thin-walled hollow specimen

Self-Aligning Vise

One of the methods being considered to hold the sample in place is a self-aligning vise. A self-aligning-vise is a tool commonly found in machine shops that is able to hold specimens in place while machining is performed. A benefit of a self-aligning vise is that it is designed relatively simplistically compared to a self-centering chuck. This potentially lowers the chance of the part breaking and reduces the difficulty of repairs. Another benefit of a vise is how easy it is to apply a large holding force to the sample. With the help of the lever arm, a large holding force can produced to secure the sample in place.

One disadvantage of a self-aligning vise is that the typical vises on the market are quite heavy when compared to other holding mechanisms. With most commercially available vises being built to be bolted into the sides of workbenches, these products are quite massive in terms of weight. This large weight leads to another disadvantage, a self-aligning vise would only be able to be used on one end of the sample unless a very large shaft is used on the rotating end to hold the heavy vise while it turns with the sample. On the free (nonrotating) end however, a vise can potentially be used because it will not be rotating.

Figure 12 CAD Rendering of a Self-Aligning Vice

Collet

Another method being discussed as a possible holding mechanism for the torsion tester is a collet. A collet would be used on both ends of the specimen to hold it in place while the torsion is applied. One of the benefits of a collet is that they are very cost effective. Many can be found for much cheaper than other clamping options. Another benefit of using a collet is that it is a not a complex mechanism used to hold specimens. An external sleeve is simply tightened onto the collet and thus applies the holding force.

Figure 13 5C Collet used for Gripping Hex Samples

However, a major drawback to using a collet holding mechanism is that the variability is very low. Collets are made to hold very specific sizes of samples, so multiple collets may be needed in order to hold multiple sizes of samples. Also, if one sample has a hex grip and another has a circular grip, multiple collets would be necessary to hold the variable samples.

3.2.3 Linear Motion

The free end of the specimen must have 1 degree of freedom in the axial direction in case the specimen expands or contracts while experiencing torsion. Three possible designs to achieve this are discussed below. All of the designs make use of some sort of bearings.

Multiple Rods with Ball Bearings

The multiple rod and ball bearing design is shown in figure 14. This design allows the load felt by the free end to be disbursed about the 4 rods. This will ensure that the free end does not move in any way which will result in a higher accuracy for the system. The load felt by each of the bearings will also be less than the other designs which will allow for easier motion. Additionally, the moment felt by the housing is less because the other designs have a longer perpendicular distance. This design also uses less material than the other designs resulting in a lighter machine.

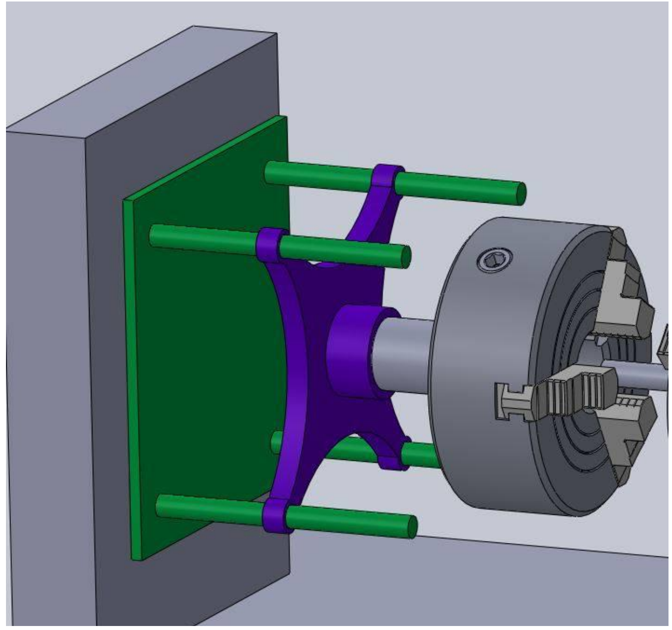

Figure 14 Multiple rod and ball bearings

A disadvantage of this design is the required wall at the end the rods attach to. This will in turn require more material for the housing which leads to a heavier and more costly housing. There is also the chance of the rods deforming due to fatigue or by the user hitting it by accident. Once the rods deform in any way they cannot be used because the bearings won't be able to slide along them. This can lead to inaccuracy if it goes unnoticed as well as higher cost to replace.

Two Rail with Roller Bearings

The reduction of friction is the primary obstacle when approaching the free-end that allows axial motion. A second but related component will be the system's ability to withstand the turning moment it will be experiencing during testing. This Linear Guide System uses linear roller bearings fitted into a housing that will allow motion solely in the axial direction. The advantages of this system is that it will be the best at absorbing the load. The design will either use inclined or lateral rollers. The inclined set can absorb an even greater load. The lateral is more cost efficient than its comparisons.

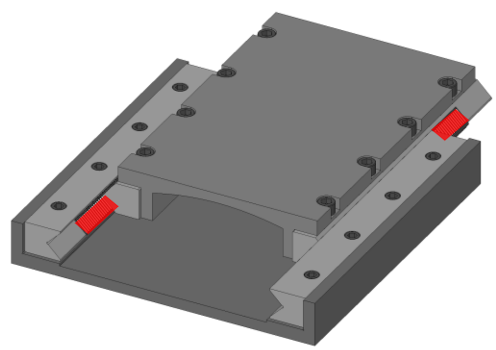

Figure 15 CAD Rendering of Two Rail System with Roller Bearings

Disadvantages of this Linear Guide System includes a relatively higher amount of material needed. More material will raise the weight and overall cost of the system. Although the inclined roller bearings can hold a greater load, it is slightly more costly than the lateral orientation.

Two Rail with Ball Bearings

A method that is being considered for the allowance of the linear motion is a two rail ball bearing guidance system. With this method, the free-end will sit upon a plate that will ride on a two rail track with the assistance of ball bearings. One benefit of this potential method is that using ball bearings are slightly more cost effective than using linear bearings. Another benefit of this design is that this rail system only relies on two rails for guidance, saving on cost and weight.

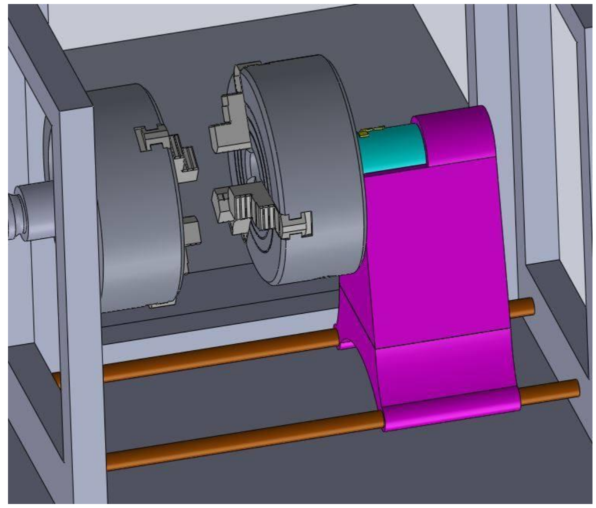

Figure 16 CAD Rendering of 2 Rail System with Ball Bearings

One drawback of this design is the magnitude of the moment that could potentially be applied to the housing due to the radial distance from where the sample is held to where the rails are located. In order to be able to handle this moment, the rails may have to be made out of a stronger material than rails located closer to the sample. Another disadvantage of this potential linear motion design is that if either of the two rails are deformed in any way, the free-end will not be able to move freely down the line.

3.2.4 Sensors

The torsion tester will be used in conjunction with the DIC (Digital Image Correlation) that is provided by the Sponsor in order to determine the strain present in the sample during testing. Using a high speed camera and measuring the particle displacement on the surface of the specimen, the strain experienced can be calculated. Therefore, it is only necessary for our design to determine the stress that the sample undergoes during testing. With this in mind, two potential components are being examined and compared to determine the optimal tool to measure this stress.

The applied load and strain the specimen undergoes must be displayed. Three types of sensors and ways of calculating these values are examined below.

Strain Rosette

The design concept for the use of a strain rosette is shown in figure 17. This design includes placing a strain rosette on the shaft coming off the free end side of the specimen. The shaft will be made out of a highly resilient material that will only undergo elastic deformation which results in a linear relationship between strain (γ) and stress (τ). The slope of this relationship represents the shear modulus (G). This allows a program to easily solve for the applied stress since the properties of the shaft are known. The equation for strain, stress and the shear modulus are shown below. Additionally, strain rosettes are easy to replace and require very little installation time as long as someone has experience with soldering. Due to their geometry, the direction that a strain rosette is placed is not important, making it very easy to implement in to a design. They are also not too expensive and are highly accurate.

$$\gamma = \frac{\Delta l}{l_0} \qquad \text{Eq. 4}$$

$$\tau = \frac{F}{A} \qquad \text{Eq. 5}$$

$$G = \frac{\tau}{\gamma} \qquad \text{Eq. 6}$$

Where:

Δl = change in length (m)
l_0 = original length (m)
F = force (N)
A = area (m^2)
G = shear modulus (Pa)

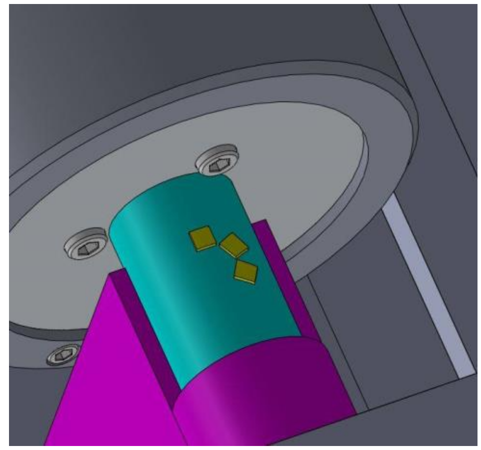

Figure 17 CAD Rendering of Strain Rosette on Free-end Shaft

Strain rosettes also have some weaknesses. One main one being that the user must know how to solder wires. Strain rosettes are also affected by its surroundings, so excessive heat may lead to an erroneous reading. They also have a minimum threshold of strain that they cannot detect under. This can lead to inaccurate measurements. Finally, strain rosettes need a wire running from them to the computer which can get in the way of the user. This also may lead to the user hitting the wire and getting faulty results.

Torsional Spring

A potential way of measuring the applied stress is using a torsional spring at one end of the rotating shaft. Torsional springs use strain gauges that measure strain which in turn can lead to finding stress if the spring properties are known. Torsion springs are relatively easy to install and have a moderate cost. As long as the spring does not plastically deform they are also highly accurate.

The main disadvantage of using a torsional spring is once they are plastically deformed they are not usable and need to be replaced. Springs also tend to change properties after going through many cycles. This can lead to a higher long term cost and more maintenance.

3.3 Evaluation of Designs

3.3.1 Criteria, Method

The following decision matrices were used to select an optimal design. Each component of the torsion machine had several potential design directions, therefore it was deemed necessary to compare each area of the design independently of each other. The design characteristics chosen for each matrix were tailored to each area of the design being examined, Load Generation, Load

Application, and Linear Motion. The weighting factors were determined by team and sponsor collaboration in order to select the design that best fit the needs for the project.

Table 2 Decision Matrix: Load Generation Component

Design	Cost	Weight	Accuracy	Complexity	Maintenance	Variability	Total
Weight Factor	0.25	0.05	0.25	0.1	0.1	0.25	
Crank System	5	3	1	5	5	1	2.9
Hydraulic	1	1	5	1	1	5	3
DC Motor	**3**	**3**	**5**	**3**	**3**	**5**	**4**

From this decision matrix, the DC motor proved to be the optimal component for Load Generation. The main reasons for this selection were the high accuracy and variability that a DC motor system can provide, while being cost and weight effective.

Table 3 Decision Matrix: Load Application Component

Design	Cost	Weight	Reliability	Complexity	Variability	Total
Weight Factor	0.25	0.15	0.3	0.1	0.2	
3 Tooth Chuck	**3**	**5**	**5**	**3**	**5**	**4.3**
4 Tooth Chuck	3	5	5	3	1	3.5
Self-Aligning Vise	3	1	3	5	3	2.9
Collet	5	5	5	5	1	4.2

It was determined that the 3 Tooth Chuck was the best option for Load Application. Although the Collet was close, it was not chosen because it lacks in variability due to the fact that multiple collets would be necessary for different specimen geometries.

Table 4 Decision Matrix: Linear Motion

Design	Cost	Weight	Durability	Complexity	Total
Weight Factor	0.4	0.2	0.2	0.2	
4 Rail Ball Bearing	1	3	1	1	1.4
2 Track Roller Bearing	**3**	**5**	**5**	**5**	**4.2**
2 Rail Ball Bearing	**5**	**5**	**3**	**3**	**4.2**

The decision matrix for Linear Motion determined that the 2 track roller bearing and 2 rail ball bearing design components were equally effective for the design. However, moving forward with the design the 2 rail ball bearing system is more cost effective, and therefore will be used in the optimal design.

3.3.2 Selection of Optimum Design

From using the information in the decision matrices the final optimum design was created and is shown in figure 18. This design uses a DC motor, 2 3-tooth chucks, 2 rails with ball bearings, and a strain rosette. All of these components satisfy the sponsor's needs and constraints. However, there are still come uncertainties and risks associated with this design. Cost will always be an issue due to the set budget of $2000. Some materials used in the final design may not be ideal due to their high cost. Also, it's possible for the motor to burn out or shafts plastically deform if the machine is overused or undergoes a significant amount of cycles. There is the risk of the user not being familiar with the program used set the motor and output the data. Finally, misuse of the strain rosette can lead to inaccurate measurements.

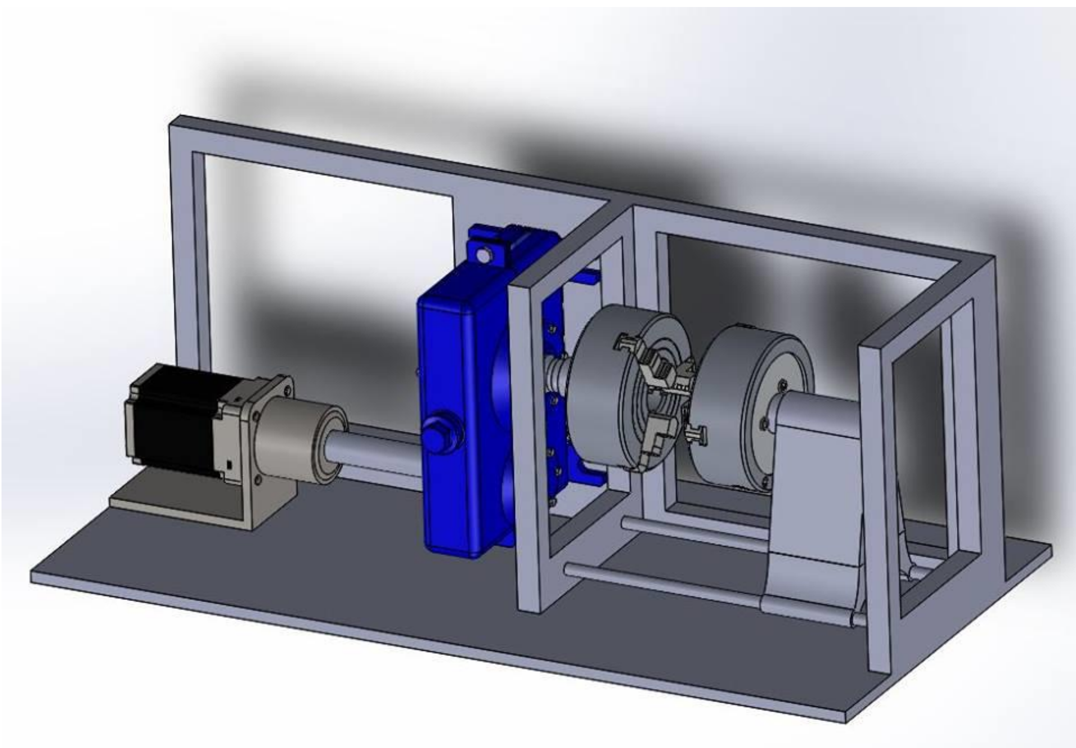

Figure 18 CAD of Optimal Design

4 Methodology

Due to the scope of this project, the task of designing this torsion tester has been broken down into sections and presented in a Gantt chart which will be completed in a systematic manner that will ensure the design is finished by the deadline.

The programming needs for this project include a user interface in order to set desired motor speed and direction as well output of the applied load. Also, the strain rosette must be able to communicate with whichever program being used to deliver the stress data. This interface must be relatively easy to user for the operator of the machine.

4.1 Schedule

The Gantt chart found in the Appendix shows schedule and course of action through the remainder of the semester. As the chart suggests, the first step in the design process has been to do extensive background research on topics relating to our capstone project. There are a few main areas of study that have been inspected before initial designs were produced, these include the torque generation, torque application, torque measurements, linear motion allowance, and housing. These points, as well as others have been researched to assist in the construction of the design. After doing a substantial amount of research, the project moved into the concept generation stage. During this time, initial designs were brainstormed and produced by the team, and calculations were performed to determine the requirements necessary to the design.

Once initial designs were produced, a single optimal design was selected to carry through to the full CAD designing stage. To determine the best pieces for design, a house of quality matrix has been produced and each potential design choice has been compared to a set of standards that are set by the constraints and objectives of the project. This selection process allowed for a single design to be chosen so that CAD modeling could begin. A CAD assembly and drawings will be produced to ensure that the design meets the necessary specifications and so that machining of the parts can be done in the future.

After the CAD designing, a material analysis will be done to select the best material that can be used for the job. Using an FCOFV design approach, the design will be analyzed to be made out of the most cost effective material while still staying within the constraints of the project. Once a material is selected, a budget analysis will be conducted to ensure that all parts necessary can be procured while staying under budget. Vendors will be inspected and quotes will be collected to make sure the price of parts such as the motor or grips are reasonable and fair. Finally, the parts will be selected and ordered and any materials that must be machined will be sent to the machine shop.

4.2 Resource Allocation

Taking a look at the Gantt chart in the Appendix, each task has a specific amount of time allocated for it to ensure that all tasks have enough time to be completed. Table 5 also shows a breakdown of the resource allocation. The background research has been conducted as a team, with each member responsible for being knowledgeable on all subject areas related to the design. It is imperative that all parties associated with the group are all familiar with the background information so that each member understands what is required to complete the design. Concept generation has also been done as a primarily team-oriented activity. Multiple potential designs have be produced by all members of the team and through group discussion the critical design characteristics for the optimal build were determined. The calculations have also been conducted by the team as a whole to ensure accuracy of the results determined.

The design selection has also been be done as a team, with the guidance and feedback of the sponsor to ensure that all avenues are considered. The quality matrices used to determine the optimal design components were developed by the team. Once a design was chosen, a simple CAD model was produced of the design. Logan McCall will take the lead on the CAD production, and will ensure that the drawings are produced within the time frame. Under the direction of Logan, the rest of the group will help to produce any CAD parts and drawings deemed necessary.

Once the CAD design is completed, the budget analysis will be conducted by Reggie Scott. The responsibilities of this analysis are to determine the cost of each part, allocate funding from the budget for each piece, and select vendors from which each part can be obtained. Once vendors are selected, the parts will be ordered and those that need machining will be sent to the machine shop.

Due to the scope of the project and the difficulties that are sure to be encountered with each step, each member of the team will be responsible for helping with all facets of the design procedure. Although Logan and Reggie will be taking the lead in two of the areas specified above, Brendan and Mark will also be assisting with each process as well.

Table 5 Resource Allocation

Task	Lead	Hours/Wk
CAD	Logan	3
Budget Management	Reggie	3
Material Selection	Mark	3
Part Allocation	Brendan	3
Meetings	Team	2
Deliverable Work	Team	3
Miscellaneous	Team	1

5 Conclusion

The Munitions Directorate at Eglin Air Force Base presented us with the task of producing a more effective torsion testing machine. The new torsion testing machine must satisfy geometric constraints as well as functional constraints that were provided by our sponsor. After conducting background research, 5 categories of interest were developed; Load Generation, Load Application, Linear motion, Sensors, and Housing. Multiple concepts were generated for the critical components and they were compared using decision matrices to select the optimal design. The decision matrices were the most important tools used to select the critical components of our optimal design. The sponsor’s needs were taken into account when setting the weight factors for the decision matrices. The optimal design was constructed from the highest ranking components in each category. The next phase is to finalize calculations for motor selection, material selection, and gear/bearing selection. From these calculations, a final CAD assembly will be generated and a budget will be developed to help finalize the components of our device.

6 References

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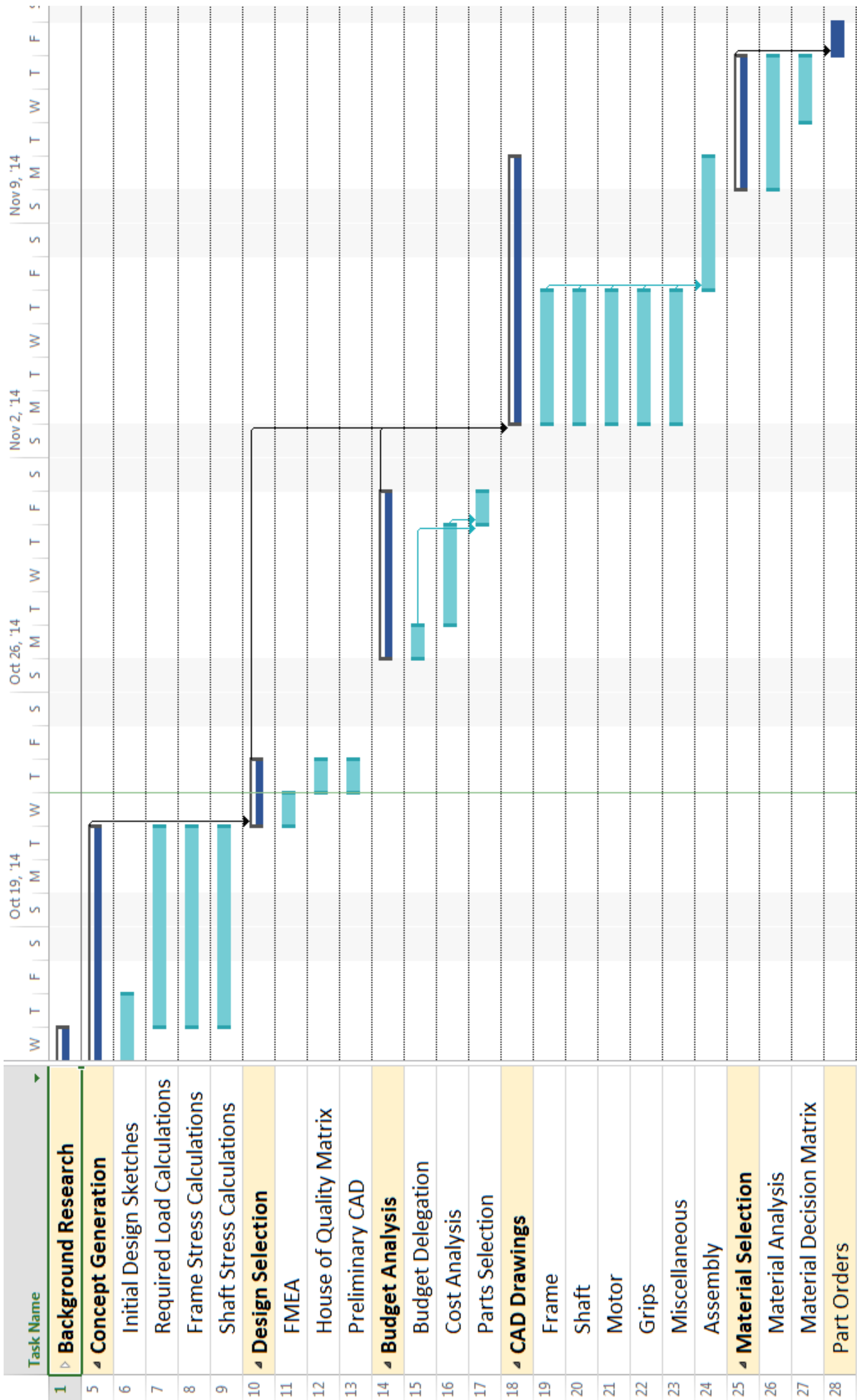
7 Appendix

Gantt Chart



Calculation for necessary applied torque to break Titanium Ti-6Al-4V specimen

$G := 44 \cdot 10^{9} Pa$ Shear Modulus

$D := 10.62 mm$ Outer Diameter

$d := 9.09 mm$ Inner Diameter

$\tau max := 550 \cdot 10^{6} Pa$ Shear Strength of specimen

$c := \frac{D}{2} = 5.31 \times 10^{-3} m$ Distance from center to surface

$J := \frac{\pi \cdot \left(D^{4} - d^{4}\right)}{32} = 5.785 \times 10^{-10} m^{4}$ Polar moment of inertia

$Torque := \frac{\tau max \cdot J}{c} = 59.924 N \cdot m$ Needed applied torque