Material Testing Fixture

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Engineering Analysis

Report 3

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1. Introduction

In this paper we will be discussing the different types of engineering analysis that we performed for our project. As a part of the Engineering Design process, each design must be carefully analyzed to make sure that the materials, dimensions, and overall designs will be successful. In this paper we will discuss the materials chosen for the pushrods, screw, sleeve, and pin. We will perform a compression analysis to ensure that the pushrods meet the compression stresses. We will show the bearing analysis which was performed on the sleeve of our design to ensure that it does not fail. We will show a screw analysis that was performed to evaluate the properties and stresses of the securing screw. Finally, we will cover a cost analysis to help decide the most cost-efficient materials that will still meet the design criteria.

2. Problem Statement

The current pushrods and base connections are causing the specimen to bend due to eccentric loading. This results in premature failure, and crack propagation in the specimen. The goal of our project is to redesign the push rods to conduct compression and tension testing while maintaining axial alignment. In addition to tension testing, the improved pushrod design must also operate within the constraints that are mention below.

3. Constraints

The team identified seven constraints with which the new design must comply. Below is a list of the constraints along with a brief description of each constraint.

1. The specimen size is 20 mm long with a 3 x 3 mm cross sectional area.
2. 6 mm of exposed length in the center of the specimen to allow for a camera to monitor specimen during testing.
3. Each specimen is unique and high in cost therefore grips cannot bite into specimen causing unwanted damage.
4. The magnetic field is crucial to specimen characteristics therefore pushrods cannot interfere with magnetic field.
5. Magnets which induce magnetic field are positioned 10 mm apart.
6. The applied magnetic field operates between 0.5 – 1.0 Tesla.
7. It is critical that the specimen remain axial loaded throughout testing.

4. Updated Design

The updated pushrod design is based off the former design known as the clamp tip. For this design we eliminated the four independent clamping components and elected to use a single screw to secure the specimen during testing. This new design significantly reduced the tip size which ensures that the tip does not interfere with the 10 mm distance between the magnets. This was one of the problems with the previous designs. The new design also ensures easy adjustment feature, utilizing one screw to secure the specimen within the tip of the pushrod. Below in **Figure 1: Updated Design,** a model of the new design is shown.

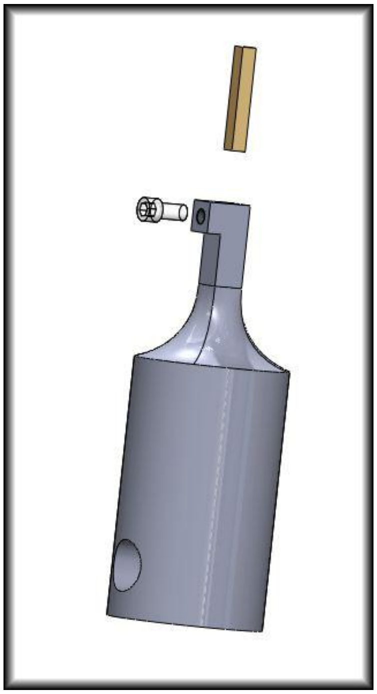


Figure 1: Updated Design

5. Materials Analysis

In our project, all parts of the fixture must be composed of non-magnetic materials since the fixture will be used in a magnetic field environment. After researching, we found several non-magnetic materials. They are:

1. Copper
2. Silver
3. Lead
4. Magnesium
5. Platinum
6. Aluminum Alloy

After comparing each material, we decided to focus on the aluminum alloy because it is inexpensive and readily available. Another reason we chose aluminum was because many of other materials did meet our requirements. Copper has a low yield strength which is not we are looking for as a pushrod. Silver and platinum are too expensive to use. Lead is a toxic material that would not be user friendly or easy to handle. Finally, magnesium is very chemically active, making it unsuitable for this project.

For aluminum alloy, there are many different alloys from which we can choose. They range from 1000 series to 7000 series. Each of these alloys has different properties and is used for different applications.

- 1000 series is basic aluminum without any other addition.
- 2000 series is the aluminum alloyed with copper which is formerly used in aerospace applications.
- 3000 series is the aluminum alloyed with manganese. It is a good rust-proof material which is commonly used for construction.
- 4000 series is the aluminum alloyed with silicon which is a wear resistant material.
- 5000 series is the aluminum alloyed with magnesium which is widely used in ship building because that material can prevent the oxidation.
- **6000** series is the aluminum alloyed with magnesium and silicon which has a good machine property and inexpensive.
- 7000 series is the aluminum alloyed with zinc which is used for aerospace application now.

In this project we have chosen to use aluminum 6061-T6 as the material for pushrod, sleeve, and pin. There are three main reasons why we choose aluminum 6061-T6. First, it is a precipitation hardening aluminum alloy with high yield strength which will be suitable for compression and tension. Second, it has a good mechanical property, and is easy to machine. Finally, because this alloy is one of the most common alloys on the market, it is inexpensive and easy to obtain.

For the screw, which is used for securing the specimen to the pushrod, we decide to look at a few different materials. These materials are nylon type 66, brass, and aluminum. Each of these materials has different characteristics that make them suitable for our project. After comparing the different materials we decided to use nylon type 66 for the screw. The reason we chose nylon is that it is one of the most commonly used polymers which means that it is inexpensive and easy to acquire. The most important reason why we choose this material is because the yield strength of nylon 66 is less than the aluminum which will be used for the pushrods. This will ensure that the screws will not ruin the pushrod or specimen.

6. Compression Analysis

After looking at the different materials for this project, we continue our analysis. A compression analysis was performed in order to analyze the compressive forces on the small area in which the specimen sits. In order to calculate the forces the pushrod will see in a compression test, the area must be calculated. To do this, the length and width, both 3 mm, are multiplied to obtain an area of 9 mm^2, using the following equation:

$$Area = L \times W = 3mm \times 3mm = 9mm^2 \quad \textbf{(1)}$$

Next, in order to keep the units consistent in calculations, the area in mm^2 was converted to square meters, with the following equation:

$$Area = 9mm^2 \times \frac{1m^2}{(1000mm)^2} = 9 \times 10^{-6}\ m^2 \quad \textbf{(2)}$$

After converting the area into the proper units, we then took a varying force of 10 N to 100 N, and divided each force by the area to obtain a compression stress for each force. The following equation is an example calculation:

$$Stress = \sigma = \frac{F}{A} = \frac{60N}{9 \times 10^{-6}\ m^2} = 6.667 \times 10^6\ N/m^2 \quad \textbf{(3)}$$

Below, in **Table 1: Compression Stresses**, the forces ranging from 10N to 100N, with their corresponding stresses are shown.

Table 1: Compression Stresses

Force [N]	Stress [N/m^2]
10	1.111E+06
20	2.222E+06
30	3.333E+06
40	4.444E+06
50	5.556E+06
60	6.667E+06
70	7.778E+06
80	8.889E+06
90	1.000E+07
100	1.111E+07

A compressive force of 60 N is highlighted in the above table. The highlighted cell represents the maximum compressive force that the specimen will see. By compressing it at 60 N, our client can generate accurate test data, yet still allowing for multiple tests to be performed.

7. Bearing Analysis

This analysis focuses connection between the pushrod and the base sleeve of the testing rig. During testing this pin will experience a bearing stress caused by the base component and pushrod being compressed into each other. For this analysis we focused primarily on the compression testing because the forces seen in tension are insignificant when compared to those in compression. The bearing stress was calculated using equation **(3)**.

This analysis was performed for varying wall thicknesses and pin diameters and the resulting stresses are shown in **Table 2: Bearing Stresses**

Table 2: Bearing Stresses

	Pin 10mm	Pin 15mm	Pin 20mm	Pin 25mm
Outer Diameter (mm)	Stress (MPa)	Stress (MPa)	Stress (MPa)	Stress (MPa)
31.0	16.00	10.67	8.00	6.40
32.0	8.00	5.33	4.00	3.20
33.0	5.33	3.56	2.67	2.13
34.0	4.00	2.67	2.00	1.60
35.0	3.20	2.13	1.60	1.28
36.0	2.67	1.78	1.33	1.07
37.0	2.29	1.52	1.14	0.91
38.0	2.00	1.33	1.00	0.80
39.0	1.78	1.19	0.89	0.71
40.0	1.60	1.07	0.80	0.64

As we can see in **Table 2: Bearing Stresses**, as the wall thickness and pin diameter increase the stresses experienced by the sleeve are reduced.

8. Screw Analysis

In this project one of the goals in creating a new testing fixture is to create a rig that is capable of performing tension tests. In order to accomplish this it is necessary to secure the specimen to the pushrod. After looking at some of the design options that were available to us, we decided that to proceed with using a screw to secure the specimen to the pushrod. In tension the max load that would be applied to the specimen would be about 18 N. In order to secure the specimen a few factors have to be considered. On the next page, in **Figure 2: Free Body Diagram**, an image of the forces seen by this type of loading is shown.

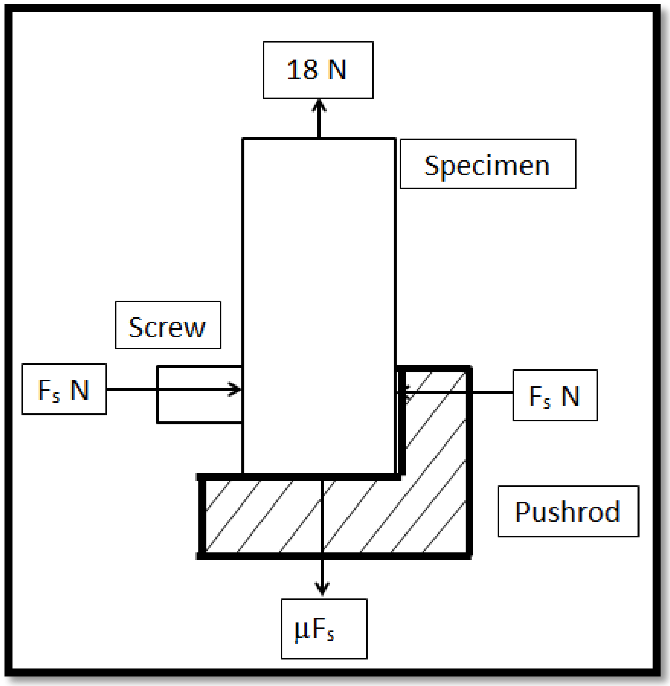


Figure 2: Free Body Diagram

As seen in this diagram, F_s is the normal force applied by the screw to the specimen. Taking into account the frictional component, we find that the following equations are useful in helping to determine the required forces.

$$\sum F_y = 18\text{N} - \mu F_s = 0 \quad \textbf{(4)}$$

$$F_s = \frac{18}{\mu}\text{N} \quad \textbf{(5)}$$

After looking finding the coefficients of friction for the different types of material we were able to calculate the different forces that will be seen. Below in **Table 3: Screw Forces**, a table of forces and their corresponding coefficients of friction are shown.

Table 3: Screw Forces

F_s [N]	Friction
120.0	0.15
36.0	0.50
21.2	0.85
15.0	1.20

As can be seen in this table, the max force than any type of screw needs to apply to secure the specimen was found to be 120 N. For the rest of the calculations, we assume the max force to be 120 N.

To continue the analysis of the screw, it is necessary to ensure that the threads will not strip the push rod when subjected to this force. After looking at the different screw types that are available, we decided that the best screw type for this application would be an M3 x 0.5 x 6mm screw. This is a standard metric screw size that has a major thread diameter of 3mm and a pitch of 0.5mm. In order to calculate the stresses seen by the pushrod and the screw the following equations were used.

Internal Pushrod Shear Area

$$A_s = \pi \cdot n \cdot l_e \cdot D\left(\frac{1}{2n} + 0.57735(D - dp)\right) \quad \textbf{(6)}$$

External Screw Shear Area

$$A_n = \pi \cdot n \cdot l_e \cdot dr\left(\frac{1}{2n} + 0.57735(dp - dr)\right) \quad \textbf{(7)}$$

The variables in these equations are defined below
$p =$ Pitch
$n = \frac{1}{p}$ = Number of threads per inch
l_e = Fastener thread engagement
$D =$ Major diameter of internal thread
$dr =$ Minor diameter
$dp =$ Pitch diameter

Using equations **(6)** and **(7)**, along with the dimensions of a M3 x 0.5 x 6 mm screw, the results for the shear area were calculated and are shown below in **Table 4: Shear Results**.

Table 4: Shear Results.

D [mm]	dr [mm]	Le [mm]	dp [mm]	p [mm]	External Area [mm^2]	Internal Area [mm^2]
3.000	2.385	3.500	2.567	0.500	**18.623**	**32.986**

We then performed an analysis of the different types of materials that we could use for the screws. We chose to analyze two of the screws with the lowest coefficients of friction. In this analysis we chose to look at brass and nylon screws. Below in **Table 5: Stresses**, the results of the calculation for each screw are shown.

Table 5: Stresses

	Nylon Type 66			**Brass**		
	Yield Str. [MPa]	**Force [N]**	**Coeff. Friction**	**Yield Str. [MPa]**	**Force [N]**	**Coeff. Friction**
	45	120	0.15	130	51.43	0.35
External Thread Force to Fail [N]	838.1			2421.0		
Internal Thread Shear to Fail [N]	8081.6			8081.6		

As we can see in this table, the force required to strip the internal threads is about 8 kN. This result means that both of the screws will strip before stripping the pushrod threading. This is exactly what is desired as we do not want to damage the pushrod itself.

Next we look at the cross-sectional area on which the screw will apply force. Below in **Figure 3: Sectional View**, and **Figure 4: Tip**, a cross-sectional view of the area where the force is applied, and a model view of the tip, are shown.

Figure 3: Sectional View

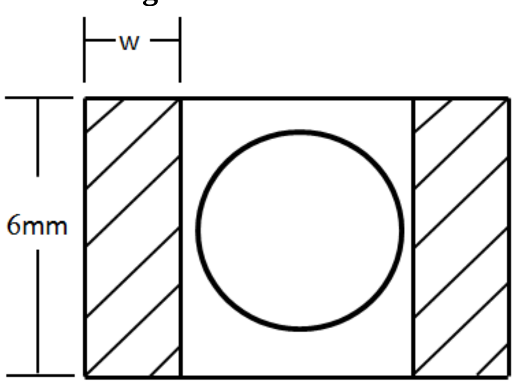
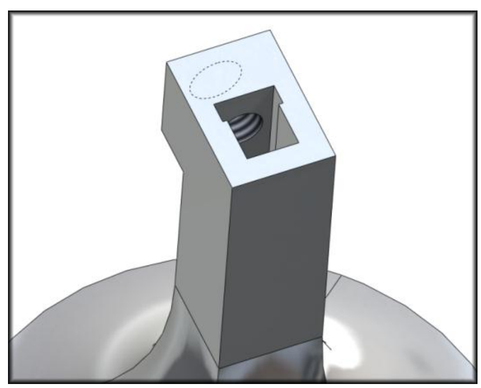


Figure 4: Tip



In these views, we show the smallest area over which the force is applied. The wall thickness *w* can be varied from 0.5mm to 1.25mm. On the next page, in **Table 6: Wall Stresses**, we see the results of calculating the stress over these two areas.

Table 6: Wall Stresses

M3 x 0.5 x 6mm	Break Fixture	
Wall 'w'	**Stress MPa**	**FS**
0.50	20.00	12.1
0.55	18.18	13.3
0.60	16.67	14.5
0.65	15.38	15.7
0.70	14.29	16.9
0.75	13.33	18.1
0.80	12.50	19.3
0.85	11.76	20.5
0.90	11.11	21.7
0.95	10.53	22.9
1.00	10.00	24.1
1.05	9.52	25.3
1.10	9.09	26.5
1.15	8.70	27.7
1.20	8.33	28.9
1.25	8.00	30.1

As seen in **Table 6: Wall Stresses**, the stresses seen over this area range from 8–20MPa. Although initially surprising, the factors of safety that correspond to these stresses, range from 12–30. These values match our expectations given the magnitude of the forces that are seen and the strength of the aluminum.

9. Cost Analysis

After we looked at different references, we were able to create a table of the cost of the different materials. There are six types of metals that are listed in the table along with the associated costs. They are Copper, Silver, Lead, Magnesium, Aluminum Alloy and Platinum. We created a scale to describe the price, ranging from 1 – 9, where 9 is the lowest cost. Below in **Table 7: Material Cost**, we show the different materials and costs.

Table 7: Material Cost

Material	$/lb	Description	Scale
Copper	3-3.5	A little Expensive	4
Silver	30-32	Too expensive	2
Lead	2.3-3.0	A little Expensive	5
Magnesium	2-2.6	A little Expensive	6
Aluminum Alloy	**0.6-0.9**	**Inexpensive**	9
Platinum	50-60	Too Expensive	1

As can be seen from this table, Aluminum alloy is the most inexpensive material.

Next, we analyze the different types of aluminum alloy, 1000 series to 7000 series. After comparing the costs of the different materials, we found little variation in the cost, about $3 - $3.5 per kilogram. Because of similar pricing, it is important to look at the different material composition. For instances, the aluminum 1000 series is 99% pure aluminum while the 7000 series is made from zinc. The material that best suits our needs was Aluminum 6061-T6 for the main components of our design. Below in **Table 8: Alloy Pricing**, the costs and compositions of the different aluminum alloys are shown.

Table 8: Alloy Pricing

Aluminum Alloy	Alloyed Component	Price: $/kg
1000 Series	Pure 99%	2.6-4
2000 Series	Copper	2.5-4.2
3000 Series	Manganese	3.5-3.6
4000 Series	Silicon	3.0-5
5000 Series	Magnesium	2.5-3.5
6000 Series	Magnesium Silicon	2.5-3.5
7000 Series	Zinc	2.5-5.5

After looking around for different types of screws, there were two main types of screws. The two types of screws we will focus on will be brass and nylon. By comparing the costs, we find that the brass is much more expensive than the nylon. Below in **Table 9: Screw Pricing**, the cost of each screw is shown.

Table 9: Screw Pricing

Screw	Price / piece [$/piece]
Brass	0.1-1
Nylon	**0.005-0.006**

10. Conclusion

In conclusion, we have performed material analysis, compression analysis, bearing analysis, screw analysis and cost analysis. We compared different materials and found that our best option for the pushrod, sleeve and pin is the aluminum 6061-T6. It is nonmagnetic material and common used. It is also easy to machine. To secure the specimen we have opted to choose nylon 66. Nylon 66 has lower yield strength than Aluminum 6061, and it is inexpensive.

11. Gantt Chart

The timeline has been slightly updated since our second report. One major change is that we have extended the time allotted for Engineering Analysis to end simultaneously with our Final Design Review and Project Proposal. The reason for this substantial extension was due to our client's needs. With so many critical constraints needing to be met, each design we propose may require modifications. With each design update, our client may suggest modifications, which then require us to perform further analysis. We are currently on schedule with updating the website, which includes uploading presentations, and reports. The updated Gantt Chart can be found in **Appendix 1: Updated Timeline**.

References

1. http://www.engineershandbook.com/Tables/frictioncoefficients.htm
2. http://www.engineersedge.com
3. http://www.alibaba.com
4. Shigley’s Mechanical Engineering Design, 9th Edition.
5. http://www.tcdcinc.com
6. http://www.engineeringtoolbox.com/friction-coefficients-d_778.html

Appendix 1: Updated Timeline