O-ring Testing & Characterization:

Midterm 1 Report

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Abstract

The purpose of this Midterm 1 report is to define the project's progress thus far. Team 1 was asked to develop a method in which to analyze elastomeric gaskets based upon property values. The report includes background information, an overview of the remaining steps that will be taken to complete the assignment, designs with analysis, and methodology. The design and analysis of the project explains the functional analysis, design concepts, and concept evaluation. The background information, needs statement, project goal, objectives, and constraints have previously been identified. A plan has also been devised and updated on how the project will be completed. The next steps for the team will be to secure required testing supplies and equipment, commence sample testing, and analyze the resulting data.

1.0 Introduction

The purpose of this report is to breakdown the plans on how the project will be completed, explain its requirements, as well as, explain the design and analysis executed so far. This project is being developed by Team #1, and it encompasses elastomeric seal-ring testing and characterization. Upon completion, this project will help eliminate variability in the selection of elastomeric gaskets by creating performance requirements through this project's results. This project is being sponsored by Cummins, Inc. and funded by the Aero-Propulsion, Mechatronics, and Energy Research Building, as well as Cummins, Inc. Our sponsor is a manufacturing company that bases most of its efforts on service diesel and natural gas engines. Cummins was founded in 1919, and currently has branches located in 190 different countries, making the need for standardizing the selection process of seal-rings even more crucial. Seal-rings and/or gaskets are used to create a seal between two or more parts, and their performance can affect the quality of a large range of products and systems.

In this report, the design and analysis of the project is broken down in order to display the details of the design progress and prototype analysis. The functional analysis, conceptual designs, and design evaluations, are covered by the design and analysis. Following is the methodology in which we outline the updated project schedule and allocation of resources. The Gantt chart created earlier has been updated to correlate with the methodology and can be found in the Appendix. A conclusion summarizes the crucial details of the report.

2.0 Project Definition

2.1 Background Research

Each and every Cummins (and non-Cummins) engine currently being produced contains a variety of O-rings also called elastomeric seal-rings because they are not always circular in cross section. These rings are implemented in order to create leak free joints between engine parts that may contain a range fluids from coolant and lube oil to compressed air. Many of these fluids are subjected to high pressures with internal parts reaching relatively high temperatures when operational. These high temperature and high pressure environments require the joint to be designed with the best quality elastomeric seal-rings available. Depending on the working environment, the rings must also have the capability to function while exposed to the elements and harsh chemicals. In response to these conditions, seal-rings are made from various materials; such as silicon rubber, which is resistant to weathering[1], and fluorocarbon, which can be used in the presence of petroleum based chemicals[2]. In order to produce longer lasting, low maintenance engines, the need for better designed joints containing elastomeric seal-rings is increasing.

A typical elastomeric seal-ring is circular in cross section and is referred to as an “O-ring”, seen in Figure 1. Although these will work for most joints, Cummins has found that using an elastomeric ring with a non-circular cross section, like the ones shown in Figure 2, can increase sealing pressure while using less material. However, the current procedure for determining the best type of seal-ring for a specific joint is costly because the process of testing samples requires extensive finite element analysis, which can be lengthy. Due to its simplistic shape, the circular seal-ring can be quickly and cost effectively designed by using the amount of crush to estimate the sealing pressure created by the mating parts. If a similar process can be applied to rings of different cross sections, the time and cost of designing parts can be greatly reduced.

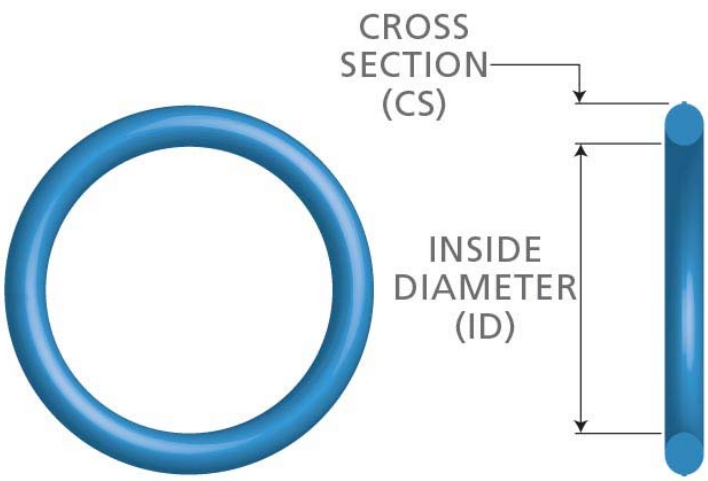

Figure 1: General O-ring Profile[3]

During the design process of elastomeric seal-rings, it is important to consider variables such as percent crush and sealing pressure. Percent crush (or crush value) is defined as the percentage of differential between the original sealing component height (or radial dimension) and the compressed height (or radial dimension) as installed. Sealing pressure is defined as the pressure generated between the elastomeric sealing component and the mating parts by the crush of the sealing component[2].

Figure 2: Elastomeric seal-ring of non-circular cross section[5]

Another area of testing that will need to be addressed in the future is the effect of fatigue and creep on these oddly shaped rings. Currently there are standards for testing elastomeric seal-rings' performance capabilities, such as the ASTM D1414-19[4], which can be conducted on rings with contrasting cyclic loads and working temperatures in order to give insight into how the different properties of an O-ring will be affected by age. Although standards for testing sealing-rings with a general cross section already exist, standards specific to different cross sections do not exist. This is important due to the fact that a sealing-ring with a unique cross section will perform differently than a ring with a typical cross section.

2.2 Need Statement

The development of a quick method to test and characterize sealing rings is needed in order to standardize the selection process of the part in this growing industry. The creation of this scientific method will give engineers the ability to accurately predict the performance of the selected part cross-section within a certain tolerance. This method will involve parameters such as shape factor, crush value, and sealing pressure in order to best apply the data to practical use. This is a crucial step for the project sponsor, Cummins, Inc., in that costs will be reduced in the form of time saved during the design process and less material being used in the finished parts. This new process could also potentially be used for quality assurance when used with the supplier's products.

The current design process for sealing-rings requires numerous iterations of finite element analysis which is lengthy and therefore costly.

2.3 Goal Statement & Objectives

A new sealing-ring characterization process needs to be defined that will aid in the design process to more quickly select a suitable seal-ring cross section for a specific joint. We will devise a method that will reduce the cost, time, and effort needed to determine the proper cross-sectional profile to use. A single method will be developed that will take into account properties and characteristics to provide a suggestion as to what type of cross-section or ring would work best for the desired sealing pressure of the condition.

The team is expected to have developed a method to characterize seal-rings based upon properties such as sealing pressure, crush value, and will also devise a shape factor to be used in the characterization of the components. The procedure will be capable of receiving the shape factor or other specification of any geometrically shaped seal and accurately predict the sealing pressure. The three previously mentioned properties of sealing pressure, crush value, and shape factor would also be portrayed on a 3-D contour plot for visual representation and analysis. The devised method will involve cost effective and material preserving techniques. This process will reduce the amount of man-hours required and therefore money and resources spent on acquiring a customized solution.

2.4 Constraints

This project could have been applied to just about any elastomeric sealing component currently in production, but in order to produce results within the time frame given, the scope of the project needed to be defined in a way that produced useful results while being efficient with the time frame given. The first and most restrictive constraint of a project is the budget. For this project, $2000 was set for the budget from Cummins, Inc. and the Aero-Propulsion, Mechatronics, and Energy Research Building. The budget will be used for acquiring samples to be tested and machining a custom test fixture to receive the various samples. Beyond the budget, the constraints consist of parameters set by Cummins that confined the project scope in order to create reachable results. These parameters include limiting the project to testing elastomeric seal-rings made from FKM, which is a name given to the fluoroelastomer category of materials by the ASTM standards. This is the material most used by Cummins in critical applications, and limits the range of durometers to be tested to 70 – 80 Shore A[6].

Other factors that will consume time and resources include the availability of test equipment, distance between the team and the sponsor, as well as the confidential nature of certain information that would otherwise aid the team. A MTS machine capable of applying a load of up to 1 kilo-newton has been located and will be available for use by the team. If a sample requires a load greater than the 1 kilo-newton available, that sample may have to be excluded from the experiment. The distance between the team and the sponsor will serve as a constraint on time due to shipping of samples sent from Cummins, which will need to be factored into the timeline. Although the team was able to acquire the Cummins standards on designing elastomeric gaskets, other documents such as engineering prints will not be available to use in designing the test rig. Time will therefore be spent on learning the correct process to design and machine the grooves for the mating flange on the test rig.

3.0 Design and Analysis

3.1 Functional Analysis

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3.2 Design Concepts

Design 1:

The first design was conceived with the concept of simplicity in mind. It consists of static grooves of varying widths and depths machined into a plate. The groove dimensions are calculated using equations based on information found in CES 98010. The standard contains a table of common seal sizes, which gives groove height and width based on each seal size. This data was graphed to check for linearity between sizes and because there is a linear correlation, this graph can be used to determine groove dimensions for seal sizes not listed in the table. The groove dimension calculating method, displayed in the Appendix, can be applied to all designs.

The model of this design, which consists of a groove plate and base, is shown in Figure 3. In this preliminary design, nine grooves are machined into a plate so multiple plates will be necessary in order to accommodate the number of grooves needed which at the moment is more than 18 grooves.

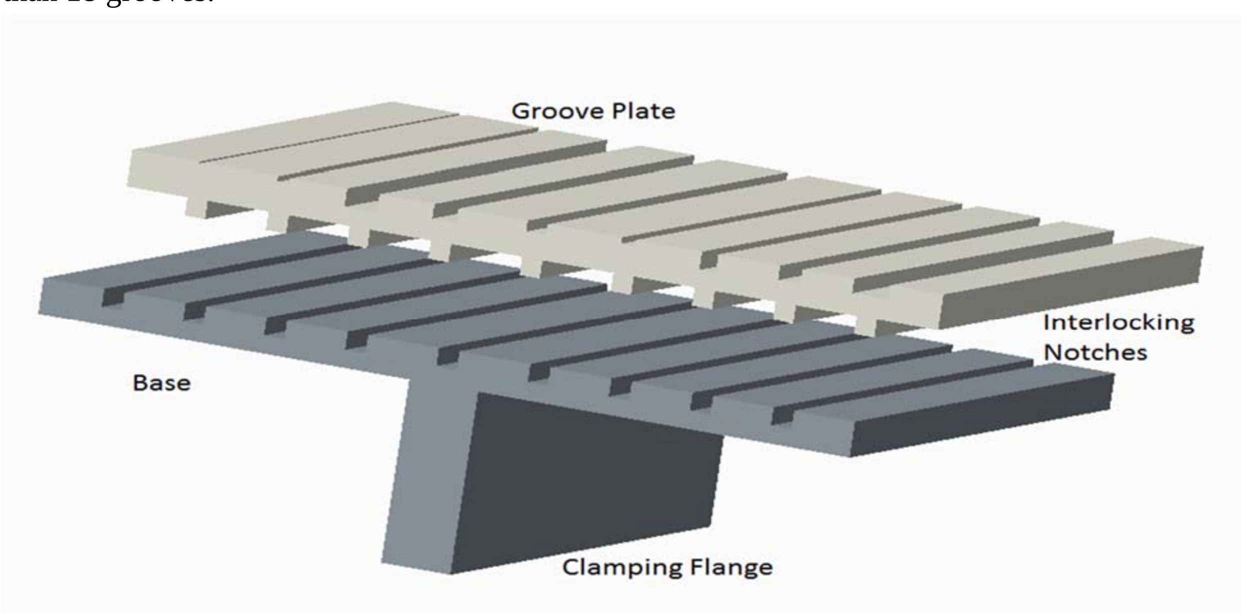

Figure 3: Design 1 - centered testing position

On the bottom of the groove plate there is rectangular protrusions of equal dimensions centered under each groove. These protrusions will fit into corresponding notches on the base which will help hold the groove plate in place. With the protrusions being centered under each groove and a notch in the base centered directly under the load cell, a groove loaded with a sample can be centered under the load cell simply by placing it's corresponding protrusion in the center notch. A clamp can be applied to the edge of the plate to ensure the groove plate does not move during testing. Having the base plate the same length as the groove plate will allow the groove plate to be supported under at least half of its length at all positions. Figure 4 shows this design in an arrangement where a groove off center is to be tested.

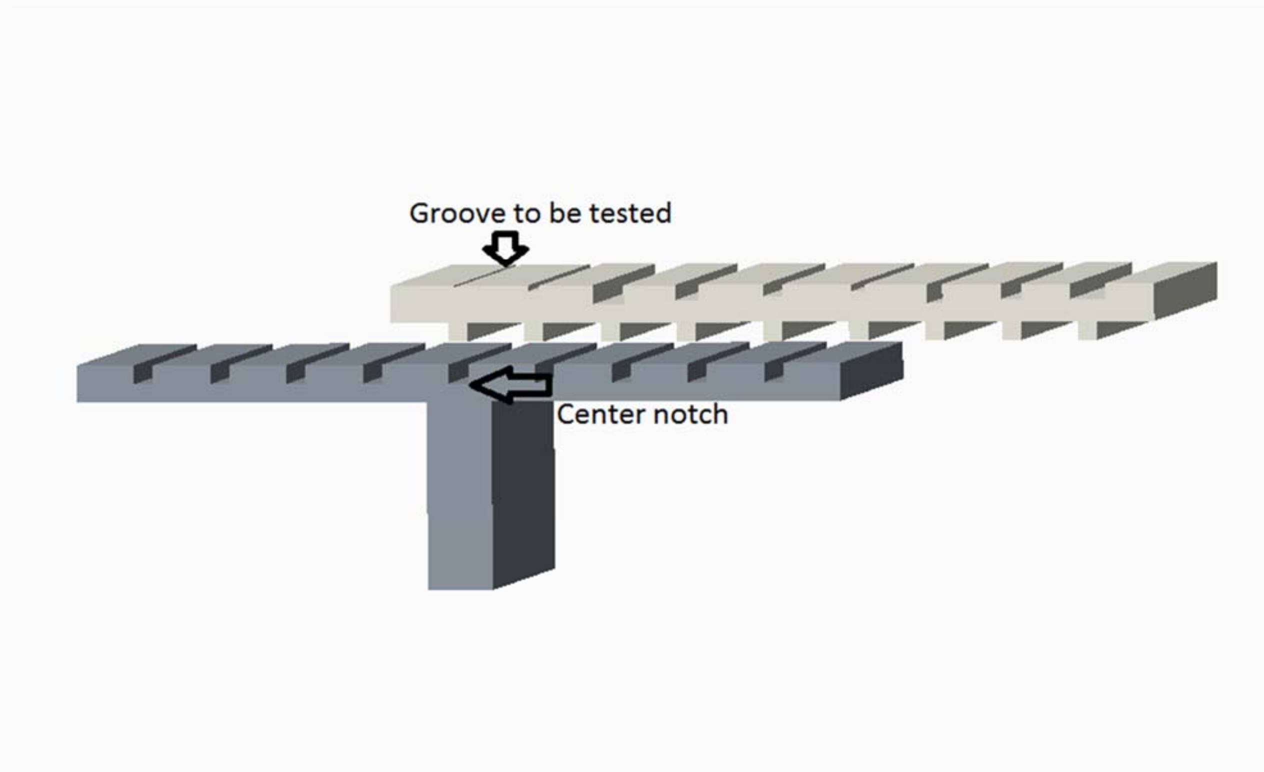

Figure 4: Design 1 - offset testing position

The clamping flange is designed to be used with the MTS machine's vice which is adjustable side to side so the base will be able to be centered under the load cell easily. Also, the top of the vice's jaws are flat and already parallel to the load cell so when the base is loaded it will sit on this surface thus making the base and ultimately the groove plate parallel to the load cell which is a paramount feature.

Design 2:

This second design was created in order to tackle a large bulk of different cross sections. It consists of three grooves on the base plate that serve as a guiding track for two plates (or adjustable groove walls) that translate from opposite sides and come together as seen in Figure 5 below. The base has the same clamping flange as design 1, except for the geometry of the grooves and their direction. In design 2, the grooves are trapezoidal shaped in order to not only limit movement to the y-direction, but to also negate the moment created from an overhang of the adjustable plate over the base. Since we want to test in the same direction as design 1 in order to keep come consistency in the designs, we need to create these trapezoidal grooves in a direction perpendicular to the ones in the previous design in order to allow translation.

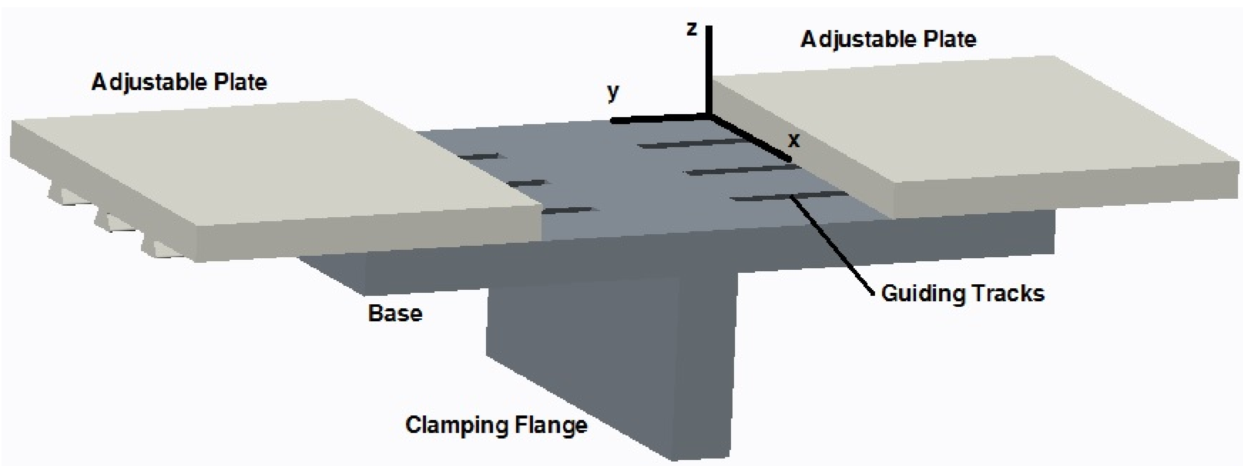

Figure 5: Design 2 - adjustable grooves

The adjustable plates resting on the base plate will be machined in pairs and will vary in height, to accommodate for the various groove heights. As mentioned earlier, depending on the height of the seal, there is a standard groove height. In order for this design to be effective, the cross sections, although varying in geometry, need to have a small variation in heights. This will make this design feasible, by only having to adjust the width of the groove with the translation of the two upper plates along the track. The bottom of these adjustable plates have a protrusion that matches the base plate in order to guide the plates along the y-direction. During testing the seals will expand in the lateral direction, creating a force that could translate the adjustable plate. Therefore, in order to limit that, a set of clamps must be used during testing to limit the effects of seal expansion. The adjustable plates can accommodate unlimited width dimensions under ___ mm, but can vary in force application location since there is no groove mechanism to ensure the centering of the material. The drawings of the parts and assembly can be seen in the Appendix.

Design 3:

Design 3 will feature a single base plate, with smaller, individual plates containing one groove per plate. The base plate will have a rectangular depression on the top surface that will receive the smaller individual groove plates. This will allow for smaller, thinner groove plates because these smaller plates will be supported from below by the larger base plate. This design will feature an individual plate for every cross-section. These individual plates will lie in the depression of the base plate and will be easily exchanged between testing of different cross-sections. The grooved plates will sit slightly above the surface of the base plate to allow for an easier extraction when changing from one cross-section to another. There will be a retaining lip on the front and back of the baseplate to help hold the groove plate in place during testing. The retaining lips will be recessed below the surface to further ease the testing setup and tear-down times. As shown below in Figure 6, the baseplate will be much smaller than those of the other design concepts, however the clamping flange will have the same dimensions as other design concepts. The vice on the MTS machine will ensure the base plate is perpendicular to the compression direction. The individual plates will be machined with the specified groove dimensions. A small clamp will be used to reduce the noise that may arise from minor slippage between plates due to the tolerance limits of both the baseplate and the groove plates. The groove plates will be machined from a thinner block which will reduce the financial burden of machining individual plates with a single groove. This design was created with simplicity in mind. The testing procedure using this design will be easier than designs 1 and 2 and allow fewer opportunities for human error to affect testing results.

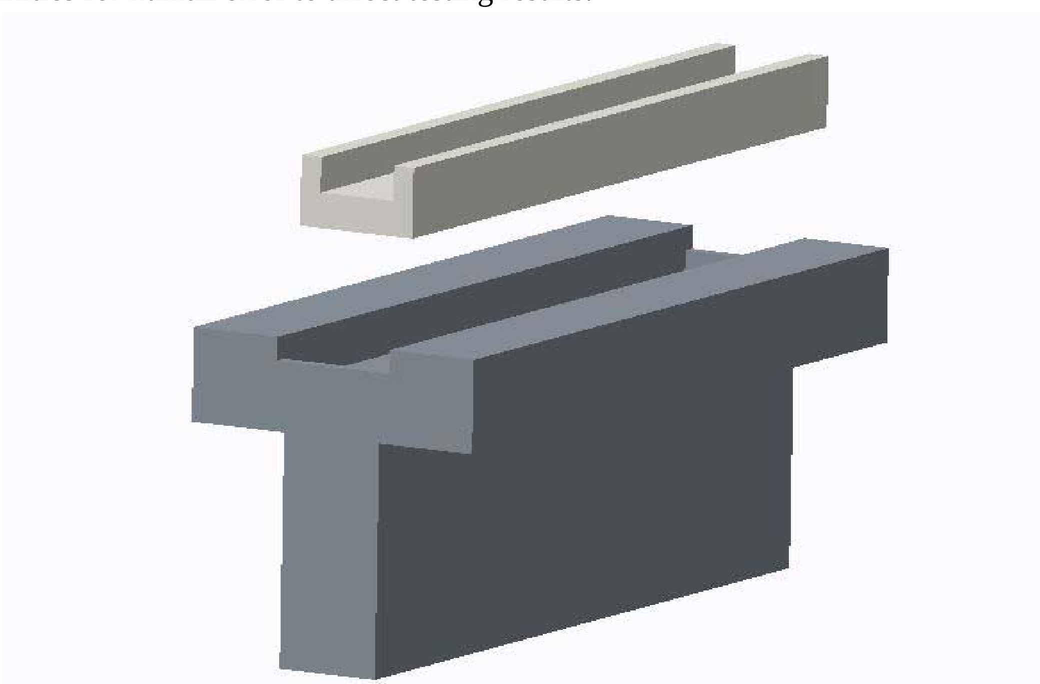

Figure 6: Design 3- individual groove plates

3.3 Evaluation of Designs

After brainstorming multiple design concepts, the time came to decide whether the designs had the right criteria or not. To do this, the Team decided the best method with which to decide the optimum design was to use a decision matrix. The decision matrix assigns desired criteria a weight, which is then multiplied against the strength of that design's ability to meet that criterion. The design with the highest total compared to the others is the design best fit for the job.

3.3.1 Criteria, Method

The criteria for the designs were derived from several places like the design specifications, performance specifications, and industry standards. These criteria or design parameters were then weighted upon importance by percentage. The heaviest parameter was "cost", with "rigidity", "setup time", and "stability under load", which all weighed the second most. "Cost" weighed the most because of the budget constraint, but also because one of the main goals of this project was to produce a method that would reduce cost. "Ease of use" was weighed the least important parameter due to the necessity of the method. It was concluded that even if the design was not easy to use, the Team was willing to trade ease for data security and accuracy. Also, the Team would be capable of writing a proper procedure to simplify use and minimize error as much as possible when using the design.

Table 1: Design Concept Decision Matrix

		Types of Design		
Design Parameters	**Weight (%)**	**Design 1: Static Notched Plate**	Design 2: Adjustable Plates	Design 3: Single Notched Plate
Rigid	15	9	3	6
Ease of Use	5	9	3	6
Machineability	10	9	6	3
Cost	20	6	6	6
Setup Time	15	9	3	6
Durability	10	6	3	9
Stability under load	15	3	6	9
Safety	10	6	3	9
	Total	**690**	**435**	**675**

3.3.2 Optimum Design Selection

Based upon the results of the design matrix and the deep consideration of each design, Team 1 has chosen design concept one, the Static Notched Plate design. The Static Notched Plate design had the highest total out of the three designs, which shows that it displayed the most promise for meeting many criteria well. Design concept three also showed possibility, but did not meet the same criteria with the same strength as design concept one. Design concept two was a good idea in that it would have provided flexibility in the testing process. However, it did not meet other criteria as strongly as the other two concepts and was therefore abandoned. The design concept chosen by Team 1 is Design 1, the Static Notched Plate.

4.0 Methodology

4.1 Schedule

From this point on, as always, the schedule is one of the most important factors of the entire project. Since the vast majority of progress thus far has been documented, the schedule contains future items and items still awaiting completion. Tasks currently underway are finalizing the selected prototype testing fixture design for the MTS machine and researching methods of data reduction and manipulation. We have decided to make the fixture out of Aluminum due to availability, cost, strength, and machinability. We will order the material and begin construction as soon as it arrives. However, we are still awaiting cross-section ranges and samples from the sponsor and are consequently unable to prototype fixture designs to the level of detail that we could with those ranges. In the meantime, we will research and test ways to manipulate the data we are going to collect. The Team will involve advisors in this latter development, since their experience in theory, research, and handling pure experimental data will most likely prove invaluable in guiding our efforts.

Once the range of seal cross sections to be tested is solidified, samples will be ordered and obtained. The Team will then attempt to predict what sort of results will come from testing the samples individually, in a way evaluating raw data. Then testing will commence, followed by test validation where it is secured that the test was conducted successfully and the data is useable and not corrupted or bad. This step is checked in the data compilation stage, where data from an individual sample is compiled and examined with data from other samples. If the data is determined to be faulty, then testing is done again until data can be used. Once data is checked to be dependable and compiled, it is manipulated and analyzed in order to uncover relations between properties of the samples. The results of this manipulation are finally analyzed, and if possible, displayed in the form of a contour plot. This plan is all displayed visually as block diagram in the appendix.

4.2 Resource Allocation

To move forward, the Team needed to be organized and aware of which tasks were going being handled by which team members. Table 2 below represents the distribution of team resources to future tasks that need to be completed, as well as a rough estimate of time it should take to complete said task. Some tasks are more difficult or more time consuming than others, so more than one member has been assigned to tackle those particular tasks.

Table 2: Resource Allocation

Task	Team Member	Time Allotted
Acquire materials for design components	Kenneth McCloud	1 week
Research machine shop capabilities/tolerances	Emilio Kenny	1 week
Research standards for irregular seal-ring cross-sections	Tawakalt Akintola Erin Flagler	1 week
Make contact with MTS overseer, and schedule a weekly lab time	Erin Flagler Richard Edgerton	1 week
Keep website updated	Kenneth McCloud	continuous
Acquire Fuji paper	Richard Edgerton	2 weeks
Work on midterm presentation slides	Emilio Kenny	1 week

5.0 Conclusion

Since the last report, the testing method, machine, and equipment supplier have all been identified. Team 1 will be using an MTS machine and FujiFilm paper to test a range of different seal ring cross-sections in compression tests. Three different design possibilities were conceptualized, virtually prototyped, and weighed against the project requirements. The design determined to be most applicable was Design Concept 1: Static Notched Plate. This determination was arrived at with the used of a decision matrix and project criteria taken from design and performance specifications along with industrial standards. This design should theoretically perform the strongest for the testing that is required. The Team will move forward with the construction of the physical design prototype and connect with faculty to begin early experimentation with possible methods of data manipulation.

6.0 References

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(3) *Typical O-Ring Model*. n.d. Webpage. 10 October 2014. <http://fs23.formsite.com/parcoinc/images/O-ring_Cross_Section_V2.jpg>.

(4) "ASTM Elastomeric Gasket Standard." Technical Standard. n.d. Online. 10 October 2014. <http://www.astm.org/Standards/D1414.htm>.

(5) *Elastomeric Static Seal*. n.d. Webpage. 10 October 2014. <http://articles.sae.org/12886/>.

(6) Cummins, Inc. "Seals, Molded Elastomeric." Technical Standard. n.d. 10 October 2014.

7.0 Appendix

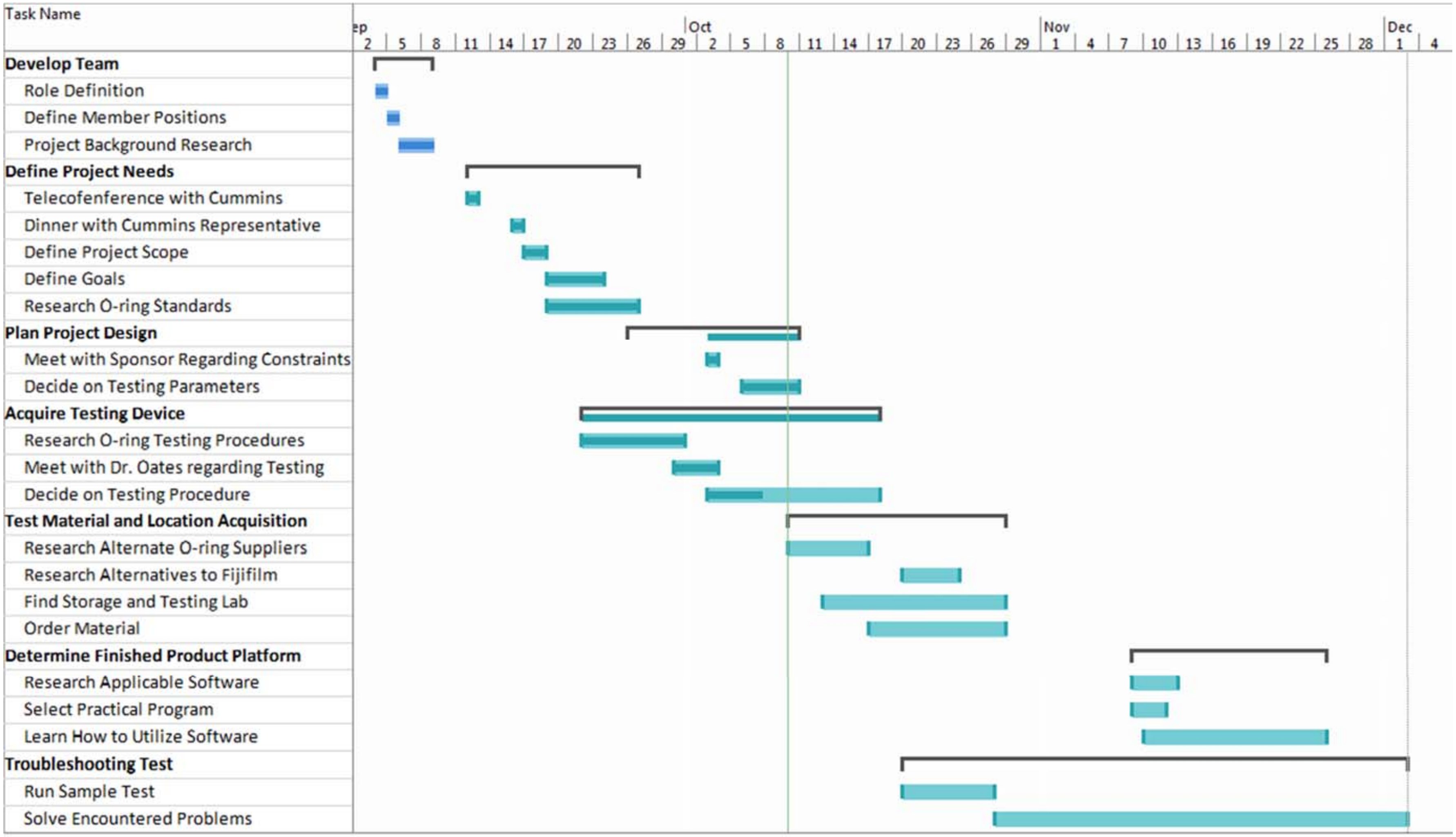

Figure 7: Gantt chart