Midterm 2 Report

Super Seal: Adding a 2nd Stage Sealing Device To Recapture Oil From Seal Leaks

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Table of Contents

Table of Figures iv
ABSTRACT .... v.
ACKNOWLEDGEMENTS vi
1. Introduction 1
2. Background 3
  2.1 The Role Of Engine Oil 3
    2.1.1 Why Is Engine Oil Especially Important Today........ 3
  2.2 Oil Leaks 4
  2.3 Current Recapture Methods 4
3. Project Scope ....6.
  3.1 Need Statement 6
  3.2 Goal Statement 6
  3.3 Objectives 6
  3.4 Constraints 6
  3.5 House of Quality 7
4. Methodology 8
  4.1 Tentative Project Schedule 9
5. Conceptual Design 9
  5.1 Current Assembly 10
    5.1.1 ISX15 Component Material........13
  5.2 Macroscopic Ideation 13
  5.3 Preliminary Design Work 16
    5.3.1 Investigation Into Various Seal........17

5.3.1.1 Labryinth Non-Contact Seal 20
5.3.1.2 Hybrid Labryinth Non-Contact Seals 21
5.3.1.3 Centrifugal Pressure Seal 22
5.3.1.4 Standard Contact Seal 22
6. Future Work 26
7. Conclusion 28

References 29

Table of Figures

Figure 1……………………………………………………………………………………4

Figure 2……………………………………………………………………………………7

Figure 3……………………………………………………………………………………9

Figure 4…………………………………………………………………………………..10

Figure 5…………………………………………………………………………………..11

Figure 6…………………………………………………………………………………..12

Figure 7…………………………………………………………………………………..14

Figure 8…………………………………………………………………………………..16

Figure 9…………………………………………………………………………………..17

Figure 10………………………………………………………………………………...18

Figure 11…………………………………………………………………………………19

Figure 12……………………………………………………………………………..…..20

Figure 13……………………………………………………………………………..…..21

Figure 14……………………………………………………………………………..…..22

Figure 15………………………………………………………………………………...23

Figure 16…………………………………………………………………………………25

ABSTRACT

The goal of the Cummins Inc. sponsored project is to design a device that will capture oil that leaks out of a crankshaft seal. The collected oil is to be transferred to a holding reservoir enabling future reinsertion into the crankcase. This objective will be obtained through the application of various engineering design methods, coupled with collaboration between the college and industry appointed sponsors. The overall effectiveness of this device will be assessed through a 24-hour simulation across various operating regimes proposed by Cummins, and carried out through a custom test rig for which the group must also design and fabricate. Team 1 has done preliminary research into the problem to better understand the gap between the current and ideal situation, as well as the concept of the product needed to achieve success with the objective.

ACKNOWLEDGEMENTS

The group would like to make a point to thank Dr. Shih for his hard work in gathering the available projects for the entire semester. In addition, an acknowledgement must be made for the course instructor, Dr. Gupta, seeing as how he has been (and will continue to be) the main source of information pertinent to the course. Furthermore, a note of gratitude would like to be made for the sponsor engineer, Terry Shaw, for his time and effort spent with the team thus far.

1. Introduction

Due to the ever-increasing demand of goods and services, modern powertrain systems used for their conveyance are being repeatedly held to higher and higher operational standards. As such, the schedule for routine engine overhauls are being delayed to the point where the industry is beginning to push the boundaries of what is currently possible. To illustrate this, current diesel powered semi-trucks being used to deliver automotive parts are expected to adhere to a life of 30,000 hours of operation before a rebuild is necessary. [1] If that 30,000 hours target is assumed to be nonstop, that is just under 3.5 years of continuous function. It is important to note that performance for that duration without any stopping is highly unrealistic in this application, but rather was used as to help gauge just how high the target for modern machinery is. To meet these inflating targets, innovations in design and manufacturing are, and will continue to be, necessary.

As with everything, the primary driving factor is cost. Engine overhauls across the wide range of models in current production yield extremely high numbers when it comes to repairs. For example, the replacement of a rear crank seal for the Cummins 95 liter locomotive engine is $21,000. [2] This is due to the extreme amount of labor involved; these types of engines have such little clearance between parts, that to access anything that is not located directly on the exterior requires a large amount of component disassembly merely to access what needs replacing. If this repair cost is then coupled with the opportunity cost of lost productivity, the expenses for this seal failure begin to accumulate rapidly. This notion can be extrapolated to most large-scale power generation systems in use today. Ultimately, fixing issues as they fail is not an option for the companies that operate them.

With this in mind, the prevention of premature component failure is highly important. Not to mention, the concept of what is considered to be a “failure” has evolved over the years. In modern times, customers are becoming more sensitive to what is perceived as a failure. A large segment of this sensitivity increase concerns leaks. Historically, leaks were tracked through dripping, spraying, or fluid actively running from whichever aspect of the motor it was contained in.

However, current customers perceive a leak as an instance when a component is not “dusty dry”. [2] Interestingly enough, the customer is technically correct with this assertion.

Therefore, to continue to align themselves with increasing customer expectations for both engine performance and evolving classifications of failure, Cummins Inc. (Cummins) is looking for a method to recapture oil that has managed to work its way past the rear seal of a crankshaft. This oil is to be collected as thoroughly as possible and deposited into an accessible reservoir where it will remain until a powertrain technician can reinsert the oil back into the crankcase.

2. Background

2.1 The Role Of Engine Oil

Simply put, engine oil is the lifeblood of a motor. Most notably, engine oil serves the main function of providing lubrication between components of the motor as it performs under high pressures and temperatures. By reducing friction, and therefore wear, motor oil aids in prolonging the life of vital parts.

However, advances in technology have provided the opportunity for oil to do more than just lubricate parts through their additives. Modern motor oil removes dirt and debris buildup within the engine and suspends it within the fluid until it can be removed during the next oil change; effectively working to clean your engine. Furthermore, todays oil supports increased fuel economy, protects the vehicles emissions system, works to assist with hydraulic operations for variable valve timing (VVT), and maintains components at cooler temperatures, all while possessing the ability to perform these task across a extensive range of temperature spectrums.
[3]

2.1.1 Why is Engine Oil Especially Important Today?

Consider the trend of engine design in today’s market. To meet rising demand for better fuel economy, original equipment manufacturers (OEM) are transitioning into motors with smaller and smaller volumetric output. However, this typically comes with the sacrifice of power. To offset that sacrifice, turbochargers are commonly installed. The shaft inside of said turbocharger can rotate at speeds of up to 200,000 revolutions per minute. As a result, it is imperative that oil can reach these components quickly, while providing an effective form of lubrication and cleaning. Otherwise, the entire system fails, producing an inability to reach OEM targets and leaving the customer with costly repairs. [4] Figure 1 displays a photograph of a turbocharger during operation.

Figure 1: Depiction of a turbocharger during operation. The intense heat generated can be seen by the color change.

2.2 Oil Leaks

The "go to" cause of an oil leak is the result of a failed gasket or seal, most commonly being an issue with the crankshaft seal. [5] Depending upon the operating conditions of the vehicle, the seal can dry rot, crack, break, tear, or some combination of them all. However, there are also instances in which oil can escape past seal that is in perfect working condition. For instance, during normal operation the oil within the crankcase becomes heated. While heated, not only can the oil convert into a mist, but the increased temperatures cause thermal expansion within the seal. After operation, the subsequent cooling process allows oil mist to discharge past the crankshaft seal as a result of differences in cooling rates between the two, often collecting along the underside of the vehicle. In either case (faulty or non-faulty seal), this is still considered to be a component failure due to the fact that the oil is no longer completely contained within the crankcase.

2.3 Current Recapture Methods

Preliminary research conducted indicates there is no widespread device with the sole purpose of recapturing oil that has leaked out of a vehicle. This statement (and research) applies to any mechanical device or piece of hardware that is fitted to a vehicle, either in the OEM or aftermarket segments. Rather, the main option is to use a drip pan to catch large oil leaks while the vehicle is stagnant for large periods of time (where possible).

Instead, the aim of current line of products is to prevent the oil from continuing to leak through the use of a "stop leak" additive/sealant. These products are design to be mixed with your engine oil and circulate throughout the motor. During their circulation, these additives seep into seals to try and recondition them back to their original characteristics: softer, more flexible and proper shape. [6]

Ultimately, this means that there is a gap in the current market. If successful, this project could have a large impact to the current design, manufacturing, assembly, and repair processes. Additionally, it could save customers and technicians both time and money.

3. Project Scope

3.1 Need Statement

A current industry setback is that engine oil commonly leaks past the rear crankshaft seal. This particular failure is becoming more paramount in the eyes of the customer.

3.2 Goal Statement

"Design a device to capture leaking oil from a rotating test crankshaft and deposit it in a reservoir so that it can later be reintroduced to the crankcase. Additionally, a test rig for the device must also be fabricated in order to assess the functionality of the design."

3.3 Objectives

- Design a capturing device to collect oil that has leaked from a rear crankshaft seal.
- Design a rig that can be used to test the recapture device in order to determine its overall effectiveness.
- Determine feasibility of each design with technical proof (calculations, drawings, etc.).
- Order, obtain, or manufacture components for each design.
- Construct the oil recapture device.
- Construct the test rig; ensuring it can adhere to the operating regimes given by Cummins.
- Perform the 24-hour trial, and assess overall project success.

3.4 Constraints

The project must adhere to multiple constraints. They include, but are not limited to:

- A budget of $2,000 is not to be exceeded.
- The oil recapture device must work with a Cummins OEM 165mm rear crank seal.
- The oil recapture device must be able to hold oil that has been heated to 125°C.
- The oil collected must be deposited in a reservoir that can be emptied by a technician.
- The oil recapture device must fit in the space between the rear crank seal and flywheel housing.

In addition to the constraints of the recapture device, the rig with which it will be tested be designed around some constraints. These include but are not limited to:

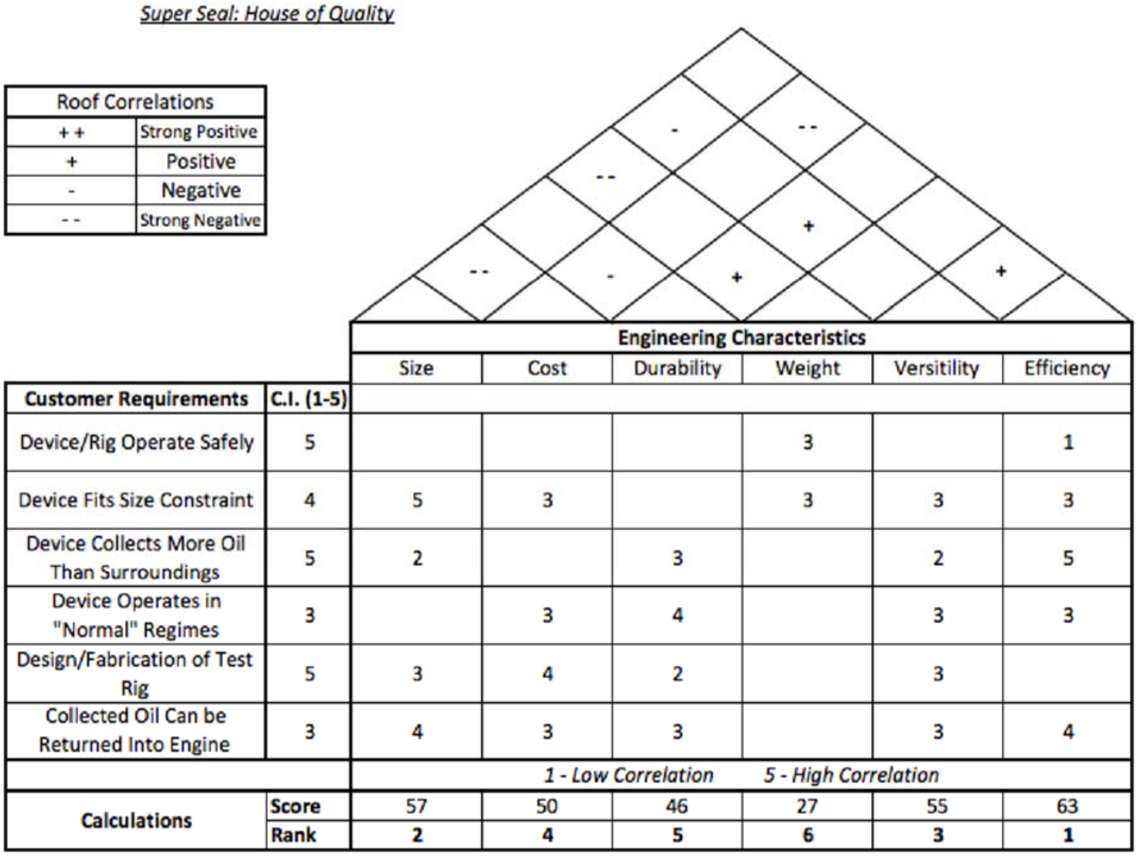
- Rig must be able to operate continuously at variable speeds between 500 and 2000 RPM.
- Rig must rotate the appropriate size "crankshaft" across the provided operating regimes.

- Test fixture must be enclosed and properly grounded to ensure safe operation.
- Rig must be able to shutdown from full operation without any issues.

3.5 House of Quality

To help address the need statement, and fulfill the goals and objectives set forth by the team, a house of quality was constructed as a basic tool to help guide the team towards important engineering characteristics that will be vital to the design of a solution.

Please reference Figure 2 below for the House of Quality that has been generated for this project.



Super Seal: House of Quality

Roof Correlations	
+ +	Strong Positive
+	Positive
-	Negative
- -	Strong Negative

		Engineering Characteristics					
		Size	Cost	Durability	Weight	Versitility	Efficiency
Customer Requirements	**C.I. (1-5)**						
Device/Rig Operate Safely	5				3		1
Device Fits Size Constraint	4	5	3		3	3	3
Device Collects More Oil Than Surroundings	5	2		3		2	5
Device Operates in "Normal" Regimes	3		3	4		3	3
Design/Fabrication of Test Rig	5	3	4	2		3	
Collected Oil Can be Returned Into Engine	3	4	3	3		3	4
		1 - Low Correlation			*5 - High Correlation*		
Calculations	**Score**	57	50	46	27	55	63
	Rank	**2**	**4**	**5**	**6**	**3**	**1**

Figure 2: House of Quality for the project.

4. Methodology

For this project, there are a few different distinct phases. Each stage serves its own purpose in order to develop a quality product that will meet all of Cummins requirements. The first stage of this project will require continued research into the problem to gain a better understanding of how the gap between the current and ideal condition arises. In this stage it is important to work directly with the sponsor engineer, Terry Shaw, to learn from his experience and expertise regarding this system that the group is being asked to address. Furthermore, benchmarking will prove to be a key element in order to ensure that Team 1 is measuring up well to other competitors, as well as to ensure that no time is lost on a portion of the project that someone else has already solved. Once sufficient knowledge has been gained on the problem and system/components, the secondary phase is to then begin designing the two vital components to this entire project: the oil recapture device that is to be the solution of the problem, as well as a rig that will be used to test the solutions ability to perform across a range of operating regimes provided by Cummins. It is important to keep a keen eye on time management for both aspects of the project in order to deliver a quality product in a timely manner. In addition, with the project sponsor being located so far away, effective information sharing and various communication between the group and sponsor will be vital, and must be performed as efficiently as possible. This will help the project flow more efficiently throughout the year. The design phase of the project should prove to be the most challenging, yet rewarding portion of the project. This is where the background research and knowledge gained from the sponsor are put into motion. An important note to make is that the design of our solution and test rig should be developed using concurrent engineering, in an effort to minimize any lack of correlation between the two. Once viable designs have been selected, the necessary parts must be ordered as soon as possible to give the supplier a reasonable amount of time to process the request (and make any adjustments if need be). A close watch will be kept during this phase in order to ensure that the budget of $2,000 is not exceeded. Once all parts have been ordered or machined, the actual construction of the project will begin. It will be extremely important that this stage not be taken lightly, as any shortcoming or overlooked detail could result in a failure of the entire system. Once the construction phase is complete, the final stage of the project is to test the device under operating conditions to which Cummins has provided so that the overall effectiveness of the design can be analyzed. By using this methodology, the group hopes to exceed the expectations set forth by the project sponsor, Cummins.

4.1 Updated Tentative Project Schedule

Figure 3 below represents the tentative schedule for the fall semester.

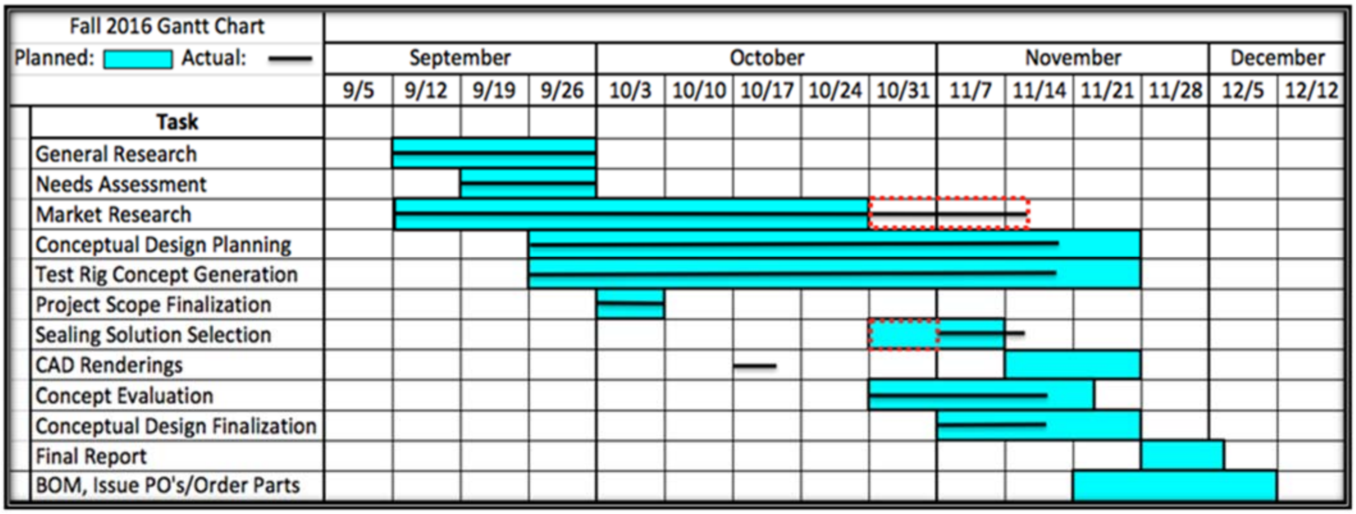


Figure 3: Gantt chart to be tentatively used for the fall semester.

Note: Even though significant time has been spent with various research and meetings with industry professionals, the team does not have enough confidence in any particular idea to aggressively pursue it. Further research is being performed in the hopes that over the coming weeks a finalized concept can be attained and followed.

5. Conceptual Design

With an overall idea of the problem at hand, as well as the established goal and objectives to address it, initial brainstorming activity commenced. The objective of this session was to begin to piece together potential solutions through the use of the engineering characteristics dictated to be the most crucial through the house of quality: efficiency, size, and durability.

5.1 Current Assembly

The motor to which the design will be initially applied is the Cummins ISX 15; a 15-liter inline 6-cylinder diesel combustion engine capable of producing up to 600 horsepower. With the aid of the liaison engineer from Cummins, technical drawings of this particular power plant were acquired to provide a visual for reference due to the lack of physical motor observe. Please reference Figure 4 and 5 below for these drawings. [1]

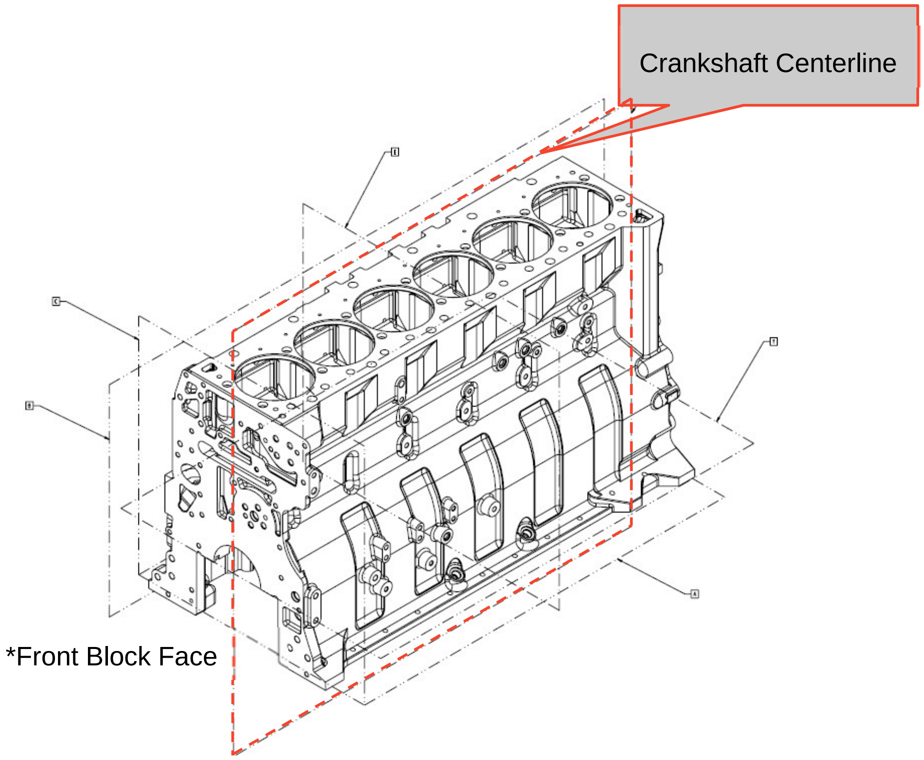


Figure 4: Cummins, Inc. ISX 15 engine block. [1]

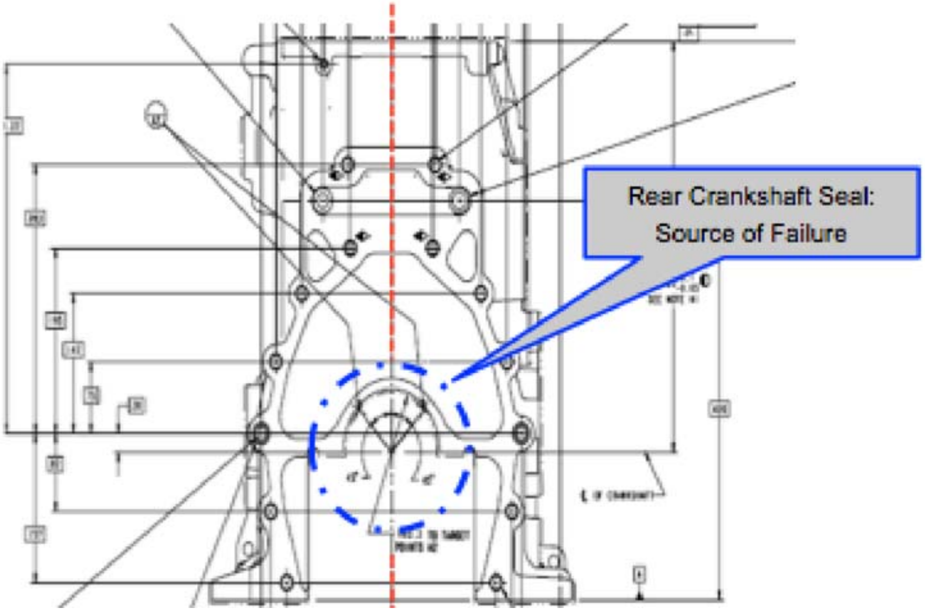


Figure 5: Cummins, Inc. ISX 15 engine block. Rear face showing where the crankshaft exist the engine block. [1]

Here, Figure 5 represents an orientation of the block showing the rear face where the crankshaft exits the block and bolts to the flywheel. The blue circle and callout represent the location of the current rear crankshaft seal (primary seal). This area also represents the area in which the secondary sealing device to be designed will reside. Diving deeper into the current assembly, a cross-section view of the primary seal assembly was also provided. This can be seen in Figure 6 below.

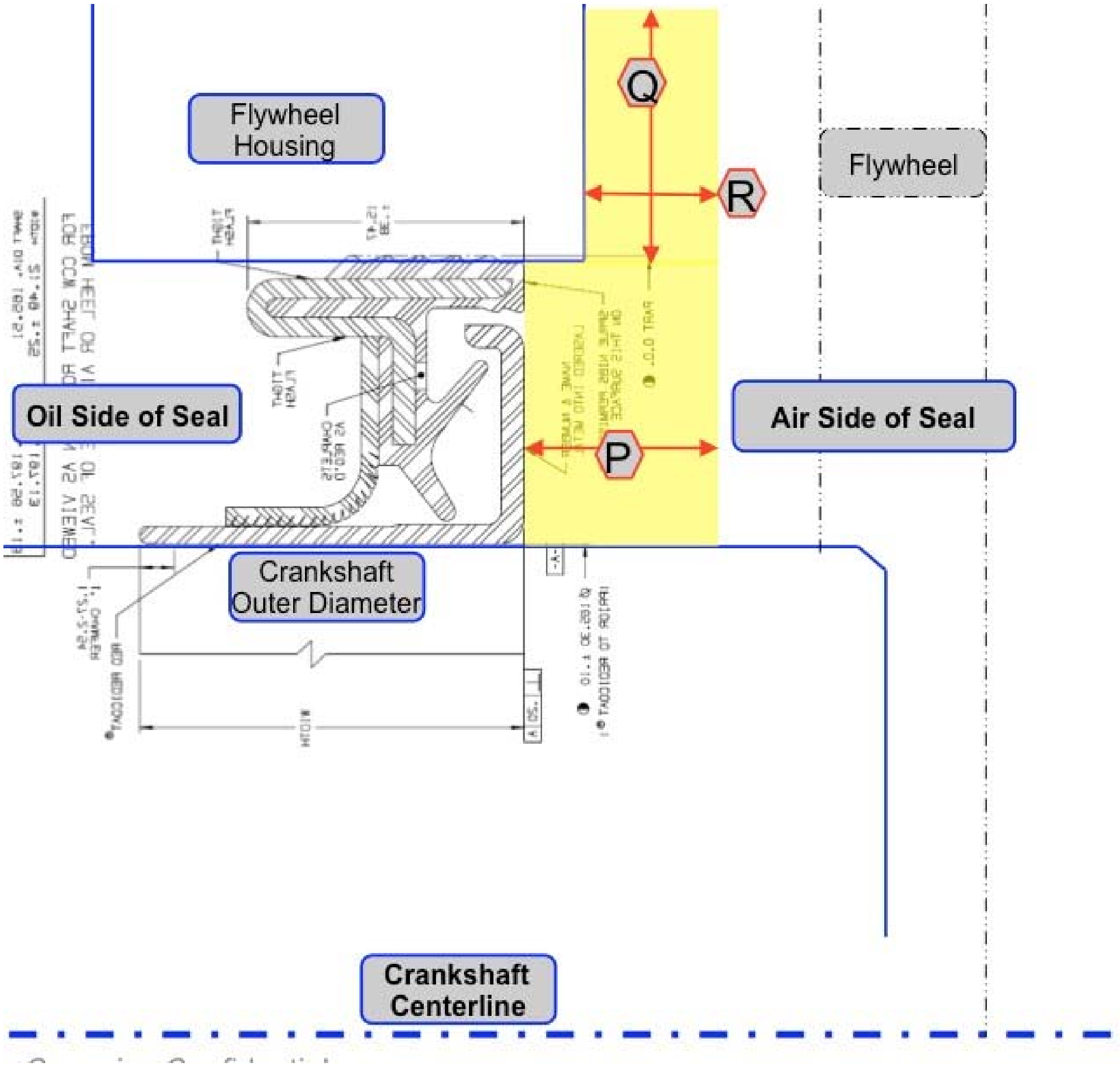


Figure 6: Schematic of rear crankshaft seal and its adjacent components. [2]

Figure 6 is especially helpful, not only for the visual it provides of the seal assembly, but particularly in the fact that it references the available dimensions between the crankshaft, seal, flywheel, and flywheel housing. Ultimately, this area is the vacant space discussed within the constraints in which the concept generated through this project will have to reside, and operate in. To assist in the understanding of these tight spatial constraints, the ‘Q’, ‘P’, and ‘R’ axes have a maximum dimension of 25mm, 25mm, and 15mm, respectively. To further challenge things, the project sponsor has requested that these parameters be minimized closer to that of 10mm, 15mm, and 10mm, respectively.

5.1.1 ISX 15 Component Materials

The materials used here are important in the sense that they will either need to be mimicked through the final project assembly, or improved upon if deemed beneficial to the overall goal. According to our liaison engineer, Cummins uses a gray cast iron for the engine block of the ISX 15, a crankshaft made of 4140 steel with an unhardened surface, and finally a seal composed of Teflon that is bonded to rubber surrounding the mild steel inner body. This seal also has ribs imbedded into it to aid in its sealing abilities. [1] The components of our hybrid labyrinth seal will be the same as the primary crankshaft seal. The Teflon gives a low coefficient of friction but also is rigid enough to last the life of the device.

5.2 Macroscopic Ideation

Keeping in mind that the secondary sealing device generated must be proven through the fabrication of a test rig, the notion of concurrent engineering plays a large factor. If the two are developed hand-in-hand, the risks of future issues brought upon by any gaps between the two can be mitigated. From a macroscopic point of view, an idea of what the overall project will look like can be seen on the following page in Figure 7. The test device will be stationary and should be compact enough that 2 people can maneuver it. The rig will be fixed to a baseplate using bolts and welds if needed. The shaft will rotate via a two speed pulley system such as that on a drill press. This method will give the most efficient transformation of speeds from 500 to 2,000 rpm while also reducing the cost instead of using a true variable speed motor. A conceptual depiction of the test rig is shown on page 14 yielding color coordination so different components can be easily seen.

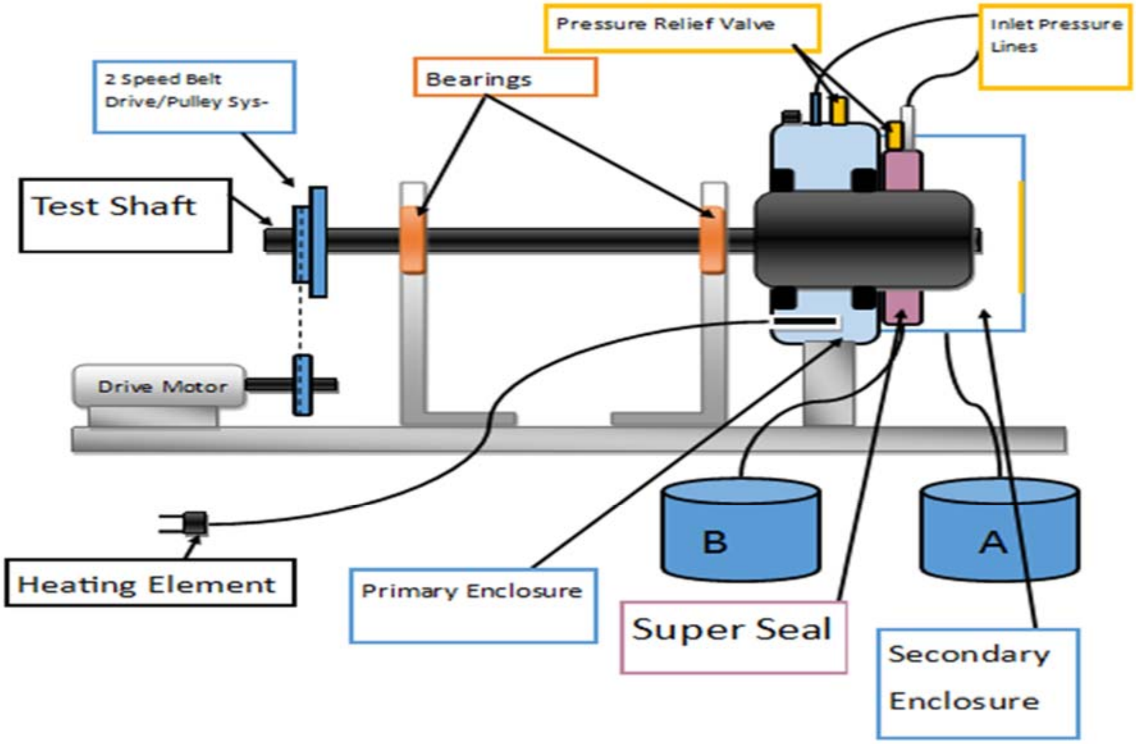


Figure 7: Pictorial representation of the overall project at this time. [2]

Initially, the drive motor was proposed as a small internal combustion engine. However, due to the challenge of determining exact revolutions per minute (rpm) required for testing purposes, a plug in electric motor was proposed. This provides the opportunity to adjust rpm more accurately and easily through the use of a potentiometer. [7] The bearing types have been chosen to be a roller bearing and a thrust bearing. The thrust bearing will account for the axial force of the shaft while the roller bearing will provide the stability as the shaft rotates. Technically, components such as the bearings will need to be theoretically calculated for their properties relative to cost, to ensure that the materials selected are both sufficiently strong and cost effective. In this instance, the primary enclosure represents the engine block for where the testing oil will be placed, this is represented by the light blue region in Figure 10. The test shaft selected will be of the same material as the current production crankshaft in the ISX 15, 4140 steel with an unhardened surface. For the purpose of the test rig, the shaft will be necked down where the bearings and pulley system is incorporated. This is to reduce the overall cost and power required to rotate a shaft of larger size. The test shaft will be the same diameter as the current production crankshaft at 165mm at the end of the primary enclosure and the “super seal” region. Both of these parameters have been chosen to try and mimic the current production assembly as much as possible, effectively closing the gap between our design prototype and the current production assembly. If promising results are attained, this should make the transition from prototype to production component smoother. As such, the idea moving forward is that any opportunity within the project where reverse engineering is present to be taken advantage of to aid this transition.

Within Figure 7, the pink shaded region is representative of the device that will be designed and fabricated. Per customer requirements, this device will be attached to some sort of drain line feeding into measurement container ‘B’ (the reservoir). This component is the actual “super seal” device. This region will be pressurized to create a pressure difference between the device and the primary oil enclosure. This pressure difference in theory, will force the oil that is trying to escape back into the primary enclosure, thus preventing oil leaks to begin with. Using a pressurized chamber will also yield more options for a sealing solution. This is because the seal in fact does not need to be totally “air tight”. This means that some pressure will escape but, the incoming pressure will compensate for this loss of pressure from the seal. Using a pressurized chamber will also aid in the recollection of the oil, helping to force the oil into the reservoir.

Moving farther right in the Figure, the blue outlined segment pertains to the secondary enclosure required to have an empirical control within the testing stages. This secondary enclosure will not only seal the device from the surrounding environment, but also provide a benchmark for the impact that the implemented secondary seal has on the system by capturing any oil that manages to leak past both the primary and secondary sealing methods. This escaped oil will also be drained into its own reservoir, measurement container ‘A’, for measure.

Ideally, the volume of measurement container ‘B’ is to be greater than the volume of measurement container ‘A’, with the ultimate goal of maximizing the amount of oil in container ‘B’ to as close to 100 percent as possible.

The design of the test rig has took a slight turn in the aspect of its functionality. We feel that in addition of the ability to test the effectiveness of our device, the idea of producing a test rig to test multiple types of seals could also hinder a quality result of the project. By implementing this system onto the test rig, Cummins Inc. would be able to test the effectiveness of different types of seals that can be used for crankshafts.

5.3 Preliminary Design Work

After some discussion and brainstorming, initial countermeasure designs began to take shape, each compounding off of one another through an evolutionary pattern to address concerns with the previous concept. For example, the initial concept generated can be seen below in Figure 8. This design is a 'bare bones' concept, providing the most basic platform to build off of and facilitate progress. It consists of a simple plate of extruded material, such as gray iron to match the material of the block (or aluminum for weight) that can be bolted to the rear face of the crankcase containing a secondary seal represented in red.

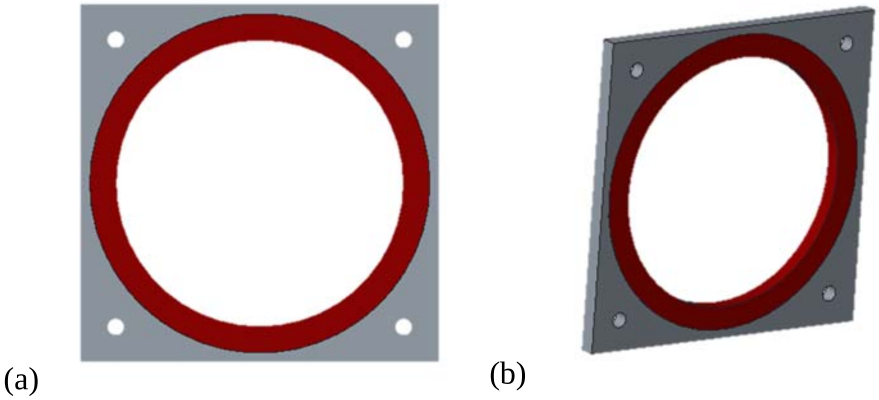


Figure 8: Computer aided drawing of the preliminary design of a secondary sealing device showing (a) the front face and (b) a rotated orientation for 3D view.

This preliminary design is inherently flawed however, in the sense that any oil that may leak past the primary seal and into this cavity has the opportunity to accumulate in the corners, preventing recollection into the reservoir. To address this issue, the next design was created exploring a circular geometry in an effort to provide a single point of recollection. Figure 9 demonstrates this next stage of the concept generation.

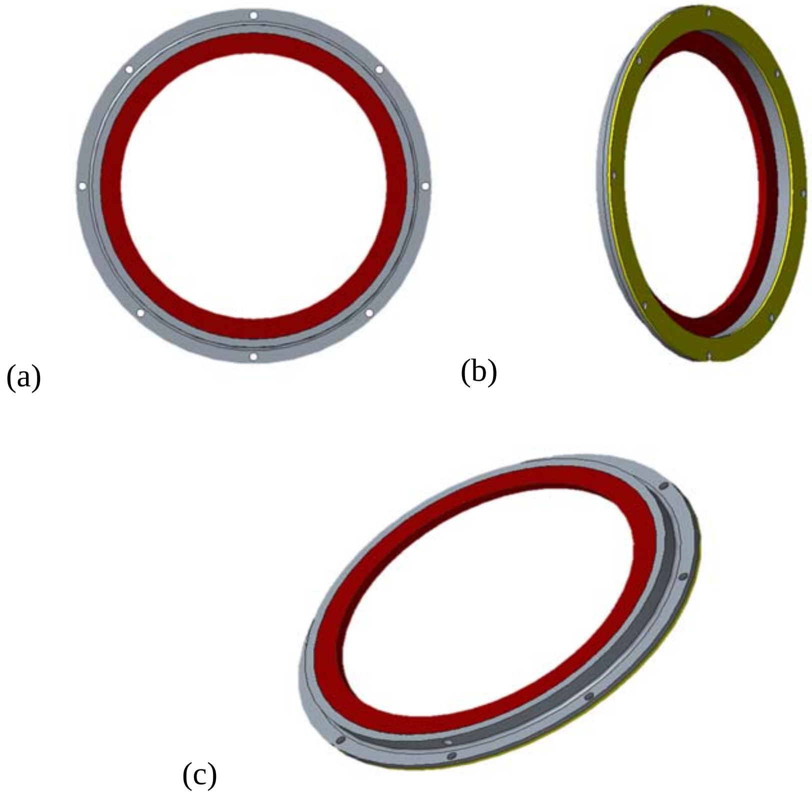


Figure 9: Computer aided drawing of the next concept of a secondary sealing device showing (a) the front face and (b) the rear face, and (c) a rotated orientation showing the drain hole at the base of the frame.

Not only does the circular geometry provide an increased opportunity for recollection, but through the addition of a drain hole at the very bottom a hose may now be attached that will provide the transportation medium between the seal and the reservoir. An interesting note to make about this design is that it will also need a gasket of some sort to prevent oil leaking from in between the two surfaces (block and secondary sealing bracket). Keeping oil from bypassing this gasket may not be as difficult an obstacle as the secondary seal concept, but must be considered moving forward.

5.3.1 Investigation Into Various Seals

Given the unique and extensive requirements that the 2^{nd} Stage seal must adhere to; it is imperative that the correct seal is chosen in order to optimize the robustness of the overall design.

In order to do this, it is important to first know the functionality of seals, more importantly rotary shaft seals and how they operate. Once this knowledge foundation is set, the concepts can then be transferred into a viable solution for the second stage seal.

A shaft seal is used in components with rotating shafts, generally kept in lubrication with oil or grease contained in the system, while also keeping external debris such as dust and water out. The importance of these seals is crucial to the operation of the system. When a seal fails, oil leaks from the engine causing friction within the internal moving components. This increase in friction causes wear on the internal parts that can lead to premature engine failure. To accommodate this, the materials are carefully chosen with the coefficient of friction in mind, and specifically how to mitigate it with the aid of oil as a lubricant, to extend the overall life of the seal in use. Rotary or "shaft" seals are generally categorized in two types; contact seals and noncontact seals. Contact seals, as the name dictates are in contact with the rotating shaft at all times. These types of seals are your standard V or O-ring shaped seals that fit snugly around the shaft, causing a reduction in the life of these types of seals due to the extensive amount of friction and wear over time. These seals do work extremely well when a shaft rotates at low speeds or when the shaft is not rotating at all. An example of a contact seal is illustrated in Figure 10 below.

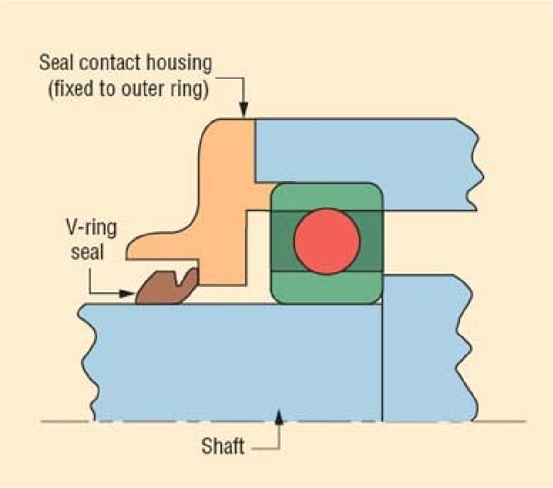


Figure 10: V-Ring contact seal illustration. [8]

Non-contact seals however, are not always in constant contact with the rotating shaft. These seals are more advanced and are typically used in long life situation. This is because the amount of friction and wear are significantly reduced as the shaft rotates. These seals can be used to seal shafts at that rotate at higher speeds. Though these are great attribute of non-contact seals, there are also some drawbacks. Being that the seal is not in constant contact with the rotating shaft, there are some instance where the oil can leak past the seal or where debris from the surrounding environment can enter in the controlled fluid cavity. The three main types of non-contact seals are Labyrinth, Hybrid Labyrinth, and Centrifugal Pressure seals. Although these seals are alike in the fact that they are non-contact, there are many differences in their actual functionality. An example of a Non-Contact Centrifugal Pressure Seal can be seen below in Figure 11.

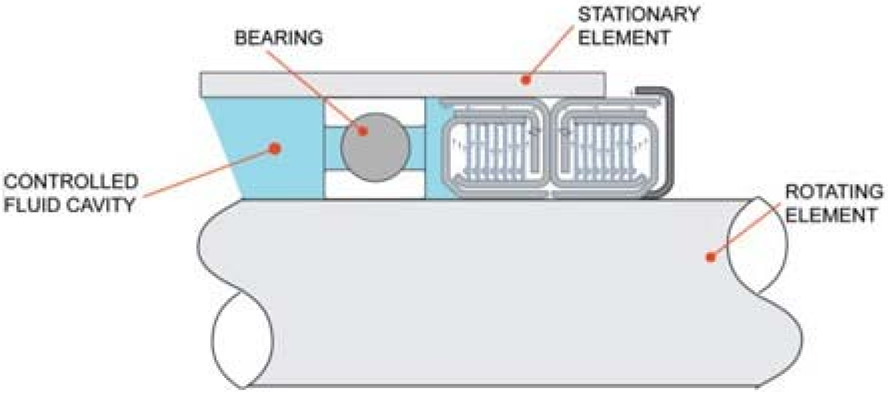


Figure 11: Non-contact centrifugal pressure Seal. [8]

The non-contact region is given by the series of channels that connect the controlled fluid cavity to the open environment. As the shaft rotates, a pressure difference within the channels of the seal produces the actual sealing effect. With this pressure difference, the controlled fluid is pushed back into the controlled fluid cavity while environment is also forced back in on its self. This makes this type of seal viable for certain situations.

In choosing a seal for the purpose of this project, it is important to realize that this seal will be dry for the majority of its life. This is due to the fact that this seal is placed behind the rear crankshaft seal, meaning the only time oil will be in this region is after the crankshaft seal has failed. If we are anticipating that the crankshaft seal will not fail until engine over hall is needed at 30,000 hours, the seal chosen must be either of a self-lubricating type or have the capability to run dry and withstand the overall wear and friction from the crankshaft. With this in mind, careful consideration and selection of the seal is of paramount importance.

5.3.1.1 Labyrinth Non-Contact Seal

A labyrinth seal is a type of non-contact seal that separates a controlled fluid cavity from its environment without closing off this passage way entirely. These types of seals use the fluids resistance to flow through a given passage of width and length; this is done by using a series of “mazes” or channels that the fluid can potentially flow through, but stops due to the long path of travel and the pressure drop across this path. This type of seal works extremely well when a shaft is rotating. However, when the shaft is stationary, the fluid is able to “weep” past this seal and into the environment. Also, given the unique nature of this device, an adequate seal is only generated at high rotational speeds. To further understand these types of non-contact seals, research was done at how they perform in the three stages of operation. These stages are nonrotating, constant speed, and accelerating/decelerating. In the constant speed stage, as long as the stationary and rotational elements stay axially aligned, the seal will hold and no fluid will leak into the environment. This also goes the same way when the shaft is accelerating or decelerating. As long as the shaft is rotating within the desired limits for the corresponding seal, there will be no failure. The failure with these types of seals comes during the last stage of operation: non-rotating. During this stage there is not a pressure difference between the seal and the fluid. This means that in this stage the fluid can potentially leak out or external environment can come into the controlled fluid cavity. Given this mode of failure, this type of seal may not be the best choice for our device. An example of a Labyrinth seal is shown below in Figure 12.

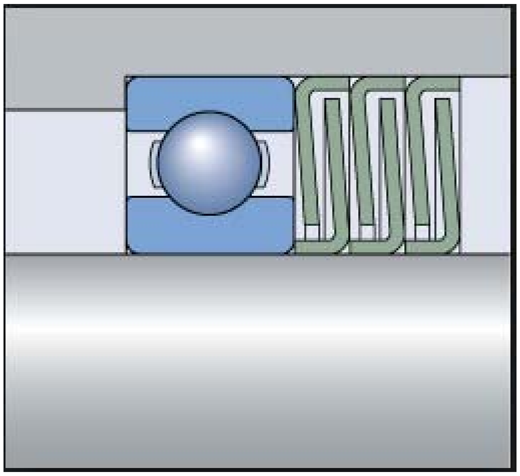


Figure 12: Labyrinth seal shown to the right of bearing. [9]

In Figure 12 above, the series of channels can be easily seen within the seal. These channels increase the fluids resistance to flow when the shaft is rotating. This is also the reason these types of seals fail with a non-rotating shaft.

5.3.1.2 Hybrid Labyrinth Non-Contact Seal

A hybrid labyrinth seal was chosen as a second option for a long life seal. These seals are much like a standard labyrinth seal in the fact that they use channels or “mazes” within the seal and use the fluids resistance to flow. However, the difference with these seals is they also incorporate aspects of a contact seal to help with the drawbacks of a standard labyrinth seal. These seals solve the problem of containments entering the controlled fluid cavity when the shaft is not rotating, but leakage may still occur, though this leakage is dependent on the amount of time the seal is stationary. These seals are closed to the external environment and therefore are a slightly more desirable design than a standard labyrinth seal. When the shaft is in its operating mode, the fluid surrounding the seal must stay within laminar flow. This restricts operation speeds with these types of seals. Also, when mounting these types of seals, alignment is crucial. If the seal is shifted in the axial direction at all, the seal will fail to perform as desired and with cause definite failure of leakage. An example of this type of seal is shown below in figure 13.

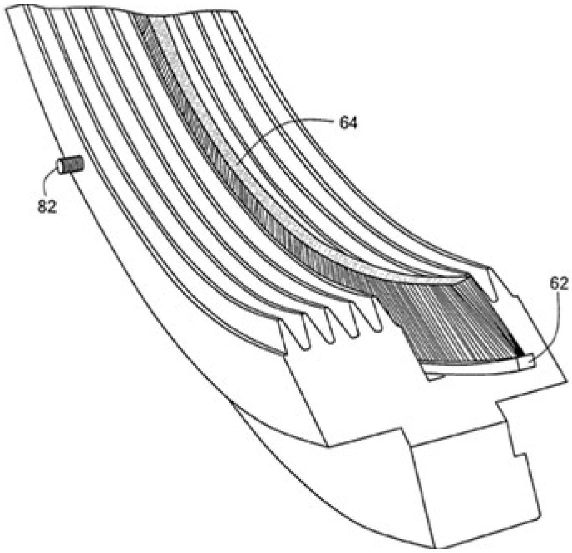


Figure 13: Illustration of a Hybrid Labyrinth Seal. [10]

5.3.1.3 Centrifugal Pressure Seal

The next type of non-contact seal explored was a centrifugal pressure seal. This seals have an extremely long lifespan and can actually operate under more circumstances than the labyrinth type seals. This type of seal, as discussed early on creates a pressure difference within an open rotating cavity of the seal itself in order to pump the controlled fluid back into the controlled fluid cavity. Though this seal is partially open to the external environment when the shaft is not rotating. But when rotation occurs, the containments that have entered the seal are pumped out away from the controlled fluid cavity and back to the environment. This means this type of noncontact seal does not leak when the shaft is not rotating. This type of seal also corrects the alignment issue that comes with most standard non-contact seals. Centrifugal pressure seals can actual tolerate some vibration and misalignment and still perform up to the desired expectations. This in turn, makes for a viable option to our problem. An illustration of this type of seal is shown previously in this section.

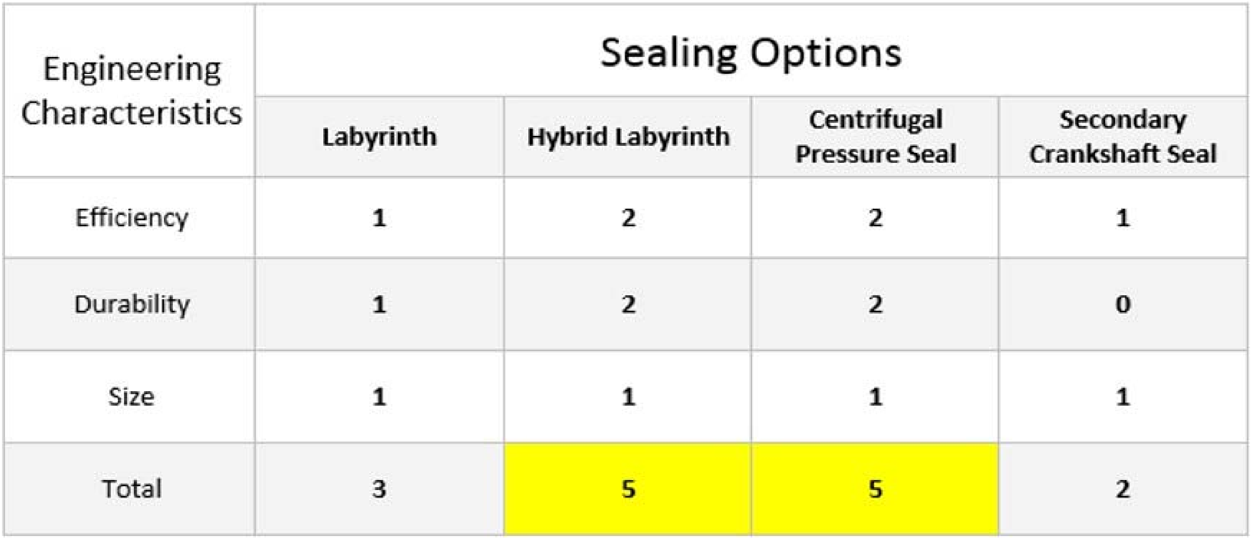
5.3.1.4 Secondary Contact Seal

Another concept that was brought to attention was the implantation of a secondary crankshaft seal. This is a type contact seal that would in turn need lubrication throughout its life or suffer failure long before that of the primary crankshaft seal. Due to this situation, any progress with this concept further was deterred.

Figure 14: Standard Cummins Crankshaft Seal. [11]

As shown above, this seal is held in place by 12 screws that evenly place the seal around the crankshaft. The crankshaft slides through the middle of the seal and is in constant contact when either rotating or stationary. Consequently, this seal would wear overtime if not properly lubricated.

When looking for a solution to the seal problem, comparisons between the different options must be made. A Pugh matrix was constructed in order to help achieve this task. The different types of seals being compared were labyrinth, hybrid labyrinth, centrifugal pressure seal, and a secondary crankshaft seal. This options were compared again the essential engineering characteristics obtained from the House of Quality. The weighted scale for this Pugh matrix is from 0-2, 0 being there is not improvement and helps the system none, and 2 being there is much improvement to the design.



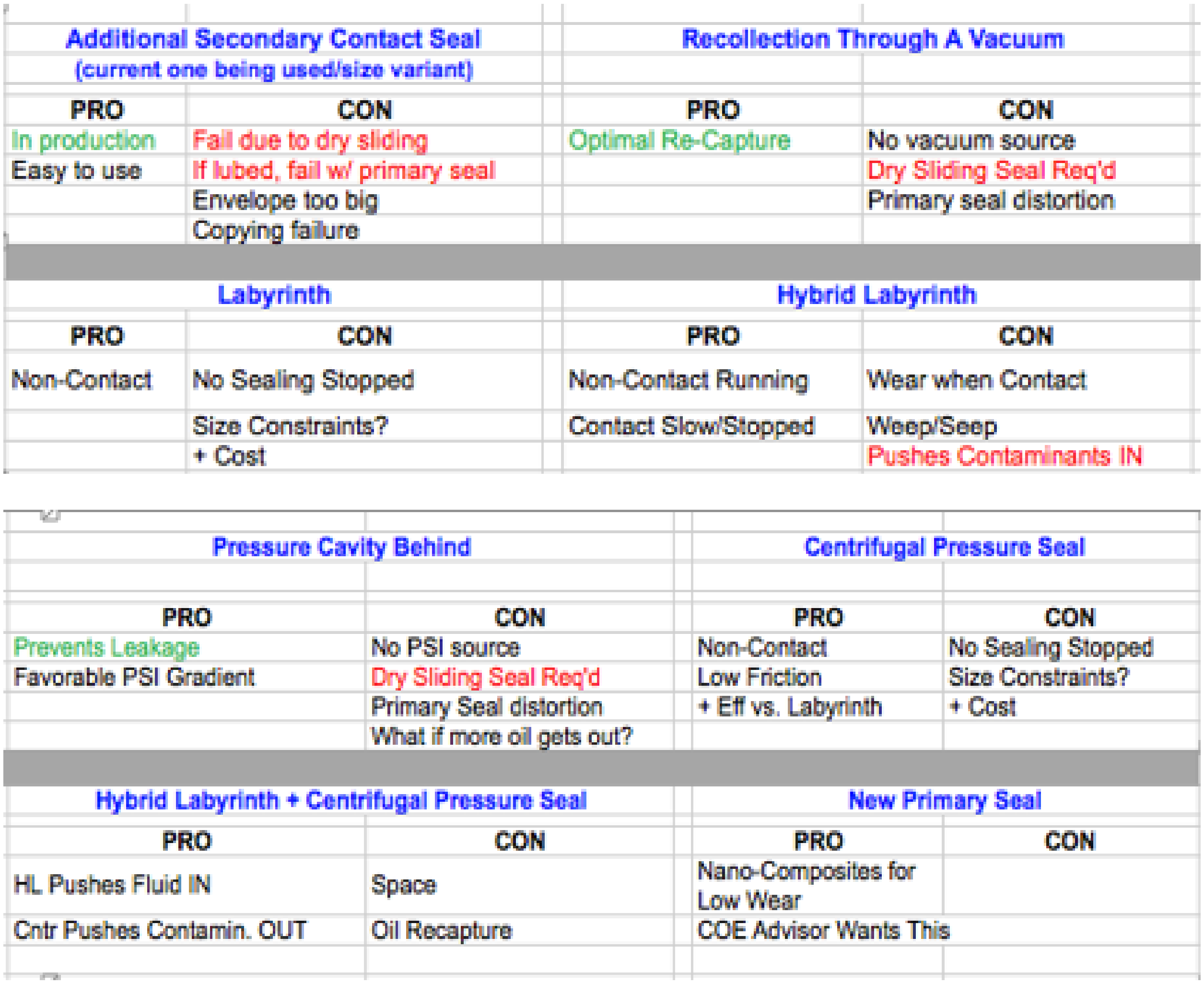
Engineering Characteristics	Sealing Options			
	Labyrinth	**Hybrid Labyrinth**	**Centrifugal Pressure Seal**	**Secondary Crankshaft Seal**
Efficiency	**1**	**2**	**2**	**1**
Durability	**1**	**2**	**2**	**0**
Size	**1**	**1**	**1**	**1**
Total	**3**	**5**	**5**	**2**

Figure 15: Pugh matrix comparison of seal types.

From the Pugh matrix, it was concluded that the hybrid labyrinth seal and a centrifugal pressure seal are the most viable option that will adhere to the extensive customer requirements. Although we feel that these are good sealing options, each type still theoretically fails some sort of customer requirement at some operation stages. For us, this means that the conceptual design phase may run longer than anticipated, until we feel we have a viable solution to this problem. Although the anticipated results have not been obtained yet, extensive knowledge on sealing applications thus far have gotten us closer to our goal of developing a long life seal with the ability to run dry.

5.4 Seal Selection

Choosing a viable sealing solution is arguably the most important aspect of the project. Without choosing the proper seal, the oil will escape freely and the design will be flawed. In order to help with this selection, the team constructed a decision matrix with pros and cons of different ideas throughout the past semester. This matrix is shown on the following page in Figure 16. Using this matrix, Team 1 decided on the most reasonable sealing option to be a hybrid labyrinth seal and also using a pressure cavity behind the rear main crankshaft seal. The hybrid labyrinth was chosen for its non-contact characteristics when rotating at high speeds and also for its contact characteristics when the shaft is rotating slowly or stopped. This will yield the best solution for the actual seal because of its increase in life and wear resistance. Aside from the hybrid-labyrinth seal, a secondary seal implementation will be used to increase the overall robustness of the design. This will be the implementation of a pressurized chamber behind the rear main crankshaft seal. The main functionality of this pressure cavity will be to prevent the initial leaks. By increasing the pressure in the cavity behind the primary crankshaft seal, the oil that tries to escape past the primary crankshaft seal will be forced back into the primary enclosure thus preventing potential leaks from the start. We feel that this method is the best scenario because the seal will provide the function for the oil recapturing while the pressurized chamber helps in the prevention aspects of leaks. By using this option, team 1 has took the problem a step further from a ‘patch’ method to a true prevention method yielding in a more robust design.



Additional Secondary Contact Seal (current one being used/size variant)		Recollection Through A Vacuum	
PRO	**CON**	**PRO**	**CON**
In production	Fail due to dry sliding	Optimal Re-Capture	No vacuum source
Easy to use	If lubed, fail w/ primary seal		Dry Sliding Seal Req'd
	Envelope too big		Primary seal distortion
	Copying failure		
Labyrinth		**Hybrid Labyrinth**	
PRO	**CON**	**PRO**	**CON**
Non-Contact	No Sealing Stopped	Non-Contact Running	Wear when Contact
	Size Constraints?	Contact Slow/Stopped	Weep/Seep
	+ Cost		Pushes Contaminants IN

Pressure Cavity Behind		Centrifugal Pressure Seal	
PRO	**CON**	**PRO**	**CON**
Prevents Leakage	No PSI source	Non-Contact	No Sealing Stopped
Favorable PSI Gradient	Dry Sliding Seal Req'd	Low Friction	Size Constraints?
	Primary Seal distortion	+ Eff vs. Labyrinth	+ Cost
	What if more oil gets out?		
Hybrid Labyrinth + Centrifugal Pressure Seal		**New Primary Seal**	
PRO	**CON**	**PRO**	**CON**
HL Pushes Fluid IN	Space	Nano-Composites for Low Wear	
Cntr Pushes Contamin. OUT	Oil Recapture	COE Advisor Wants This	

Figure 16: Decision matrix for sealing option.

By using a pressure gradient system, determining the amount of air needed while also determining the leak rate of the air will be crucial step in the design process. Since we know that air will leak out of the chamber at a slow rate, it is important to calculate leak rate in order to not over pressurize the system. The leak rate is found from the idea gas law and the amount of time the system is ran. Mathematically, the air leak rate of the from the above test rig can be calculated from the ideal gas law formula;

$$P * V = n * R * T \qquad Eq.[1]$$

If $n, R, and\ T$ are constants,

$$P_1 * V_1 = P_2 * V_2 \qquad Eq. [2]$$

Where, P is absolute pressure, and V is absolute Volume.

Therefore, $leak\ rate = \frac{\Delta V}{T}$

Where, ΔV is change in volume, and T is the time.

Volume of chamber is calculated to be, $V \approx 753.6\ cm^3$

Also, the pressurized air flow rate, Q is calculated by multiplying the Area, A of the chamber by the Velocity of flow, V. i.e.

$$Q = A * V \qquad Eq. [3]$$

The Power supply needed for our source of pressure, P is calculated by the formula below;

$$Power = \frac{\gamma * Q * P_1}{\gamma - 1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \qquad Eq. [4]$$

By using these equations, the leak rate and the power required for a desired pressure can be constructed. It is important to note that at this stage in the design process, although these equations are needed, there are multiple parameters that are still to be fully determined such as the volume of the chamber. This is unknown because this approximate volume now is calculated with a standard crankshaft seal instead of a hybrid labyrinth seal.

6. Future Work

Having finalized the conceptual design for the secondary oil entrapment device, several gaps have yet to be spanned. In the coming weeks senior design team 1 will explore the few remaining uncertainties in the conceptual design. Creating a pressure within the super seal enclosure greater than the pressure within the crankcase will generate a pressure gradient that will force the oil back into the crankcase. An existing difficulty that must be overcome by the team is locating a viable source of this adverse pressure. The enclosure will require a 0.325 psi raise in pressure to generate the desired adverse pressure gradient within the super seal enclosure. Due to clearances along the perimeter of the enclosure that air will escape, there is a potential pressure drain greater than 0.325 psi to the source of the pressure. The team will analyze the turbochargers as a potential source of pressure for the super seal enclosure. The impact of a pressure reduction within the turbocharger will be further studied. Further research into this matter will be necessary. Another known challenge will be the acquisition of a hybrid labyrinth seal with the correct size and tolerances. Other difficulties the team will endure will also include machining the parts for the test rig. The cad renderings for the components within the test rig must be completed and sent to the machine shop as early as possible to ensure that parts are obtained in a timely manner. Many components of the test rig will yield some challenges in the machining such as the test shaft and the primary enclosure. The irregular geometry of the test shaft will increase the difficulty of this task. Selecting, ordering and assembling the remaining components for the test rig are also a difficulty team 1 will encounter. After the test rig has been assembled, the super sealing hardware configuration will be mounted and tested at the given sponsor parameters.

7. Conclusion

The purpose of this project is to design a device that captures oil that has leaked from a rear crank seal for a Cummins diesel motor. This leakage is considered to be a failure in the eyes of customers. In addition, Team 1 is tasked with the challenge of also designing and building a test rig to determine the effectiveness of the oil capturing system. This custom test rig must be able to rotate a replicated crankshaft continuously at a steady speed of 500 RPM and 2000 RPM in order to gain the most knowledge on how the system works. The test is to last a total of 24 hours, afterwards the oil in the capturing device will then be measured. The results of the measurement will then yield the effectiveness of the device. The conceptual design has been finalized. The greatest remaining challenges include component selection, machining, assembly as well as seeking a viable external source of pressure. Further research into these subjects must be done. Team 1 will continue to hold weekly meetings with our sponsor Terry Shaw and also weekly team meetings in order to give updates on the project and its progress. Component selection, machining and assembly will be team 1's primary focus.

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