Design for Manufacturing, Reliability, & Economics

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

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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, time, and guidance that he has provided Team 1. The added value to the project that he has provided is immeasurable. 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 semi-trucks being used to deliver automotive parts are expected to adhere to a life of 80,000 hours of operation before a rebuild is necessary. [1] If that 80,000 hours target is assumed to be nonstop, that is just over 9 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 type 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. Design For Manufacturing

The goal statement of the overall project is as follows: "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."

To achieve the desired end result, Team 1 strived to adhere to three primary considerations for the overall project design: how to produce an effective seal during operation, how to produce an effective seal during static periods, and how to ensure the seal would remain healthy until the point in which it would be needed in real world operations. Achieving these three points concurrently proved to be much more difficult than originally anticipated, as each tended to affect another inversely as sealing solutions were explored. For example, to produce a viable seal while the motor is static, a secondary contact seal would be appropriate. However, a secondary contact seal will wear as the motor is in operation, and at an increased rate when compared to the OEM contact seals due to the lack of lubrication in the operating environment. This failure inherently means that a secondary contact seal would quickly disappoint the three design considerations required. Similarly, while a noncontact seal may provide better seal longevity, it immediately fails the requirement of an effective seal during static periods, as there will always be a clearance for liquid or vapor oil to escape. With all of this in mind, the design portion of the recapture device (henceforth referred to as the 'super seal') took significantly more iterations and time than was initially allotted for. Ultimately due to time constraints, a decision was made to utilize the design deemed most appropriate to address the root cause of the problem, to prevent and contain the leak. At this point, the direction of the project turned to proof of concept in terms of addressing the leak, with hope that the design held enough merit to elaborate it for better durability by future successors.

As such, the design and assembly of the project can be split into two main categories: the super seal and the test rig.

2.1 Super Seal

The super seal was designed to try and prevent an oil leak rather than simply contain it. The housing for the super seal is made of schedule 40 steel pipe, measuring 200 mm in length by 203.2 mm inner diameter. To achieve the goal of leak prevention, the area within the housing is pressurized to 1 psi by a simple compressor for purposes of experimentation. This induced pressure reduces the gradient between the crankcase and ambient it is exposed to, and as a result increases the oils tendency to remain within the crankcase. To seal this added pressure, a labyrinth seal was incorporating into the design. Due to tolerance constraints and budget, a labyrinth could not be purchased. Creatively, Team 1 was able to fabricate a labyrinth seal out of 29 pieces of 24-gauge aluminum sheet metal. Each sheet was water jetted at the HPMI lab into disks of varying outer diameter: 15 pieces with a 197.58 OD and 14 pieces with 187.58 OD. In addition, each sheet has a 25.4 mm center bore for where it will mount to the test shaft, and four 8mm holes for where they will be fixed to one another. Figure 1 below displays the fabricated labyrinth seal.

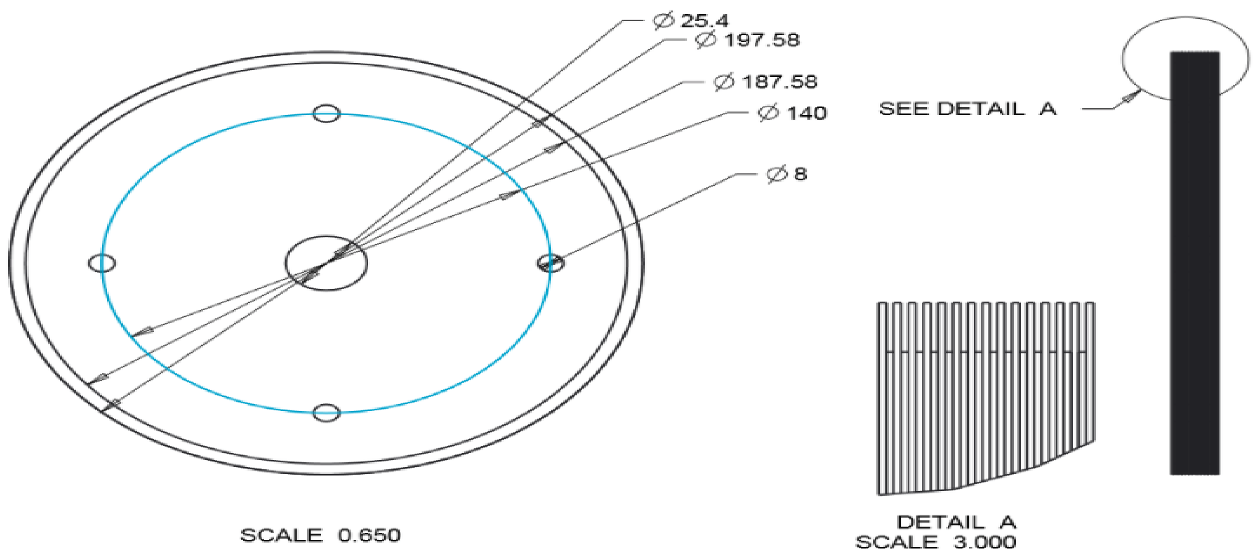

Figure 1: Engineering Drawing of the fabricated labyrinth seal; all dimensions in mm.

Under the notion that an increased number of teeth (tolerance) produces a better seal, the exact number of aluminum sheets was chosen to maximize the sealing effect given the available space constraints.

After consulting, with Cummins liaison engineer, the best practice would be to have this seal incorporated into the machining of the OEM crankshaft. As such, that is why the teeth produce a seal with the inner wall of the housing, rather than with the test shaft like most labyrinth seals.

To assemble the super seal, each of the sheets of the labyrinth seal are securely fastened to one another in an alternating pattern, as depicted above, by the M8 bolts. At which point, the assembled seal is press fit onto the test shaft. The housing for the super seal slides over the labyrinth, and is mounted/dismounted to the crankcase through the incorporation of a welded flange. Lastly, the pressure lines, air regulator, and oil drain lines are connected and the super seal is complete.

2.2 Test Rig

While the amount of time in the machine shop could be considered comparable between the super seal and test rig, the manufacturing of the test rig can be expected to take considerably longer. This is a result of the increased number of components, and need for alignment accuracy during the assembly process. Initially, the motor, pillow block bearings, and cradle are to be mounted to the base plate. Wrapping the band heater around the crankcase for heat introduction follows this. It is important to note that the band heater has been previously wired to both a dimmer switch for heat control and plug for power. From here the OEM seals (used to mimic a mass produced engine) are loosely hung on the test shaft as it is inserted into the pillow block bearings from the rear. This is done to allow for better alignment before pressing the seals onto the welded disks of the test shaft designed to similar crankshaft lobes. To help differentiate the two seals, the front seal has been painted blue, while the rear seal has been painted red. Figure 2 below illustrates this.

Figure 2: Front OEM seal vs. Rear OEM seal.

With the test shaft inserted securely into the bearings, the OEM seals are press fit onto their respective lobes, and alignment within the crankcase should be examined. At this point, the input and output pulleys (76.2 and 228.6 mm, respectively) can be installed using their setscrews followed by the 4LX56 V-belt that connects the two. This will give the 500 RPM operating condition. To switch to the 2000 RPM operating condition during testing, the input and output pulleys are simply switched to the 88.9 and 127 mm (respectively) and the V-belt swapped for the 4LX50. Lastly, safety components like the pressure relief valve for the crankcase and Plexi-glass shielding are installed. When ready for testing, the modular style seal housing can be simply bolted on. Figure 3 depicts an exploded view of the overall assembly.

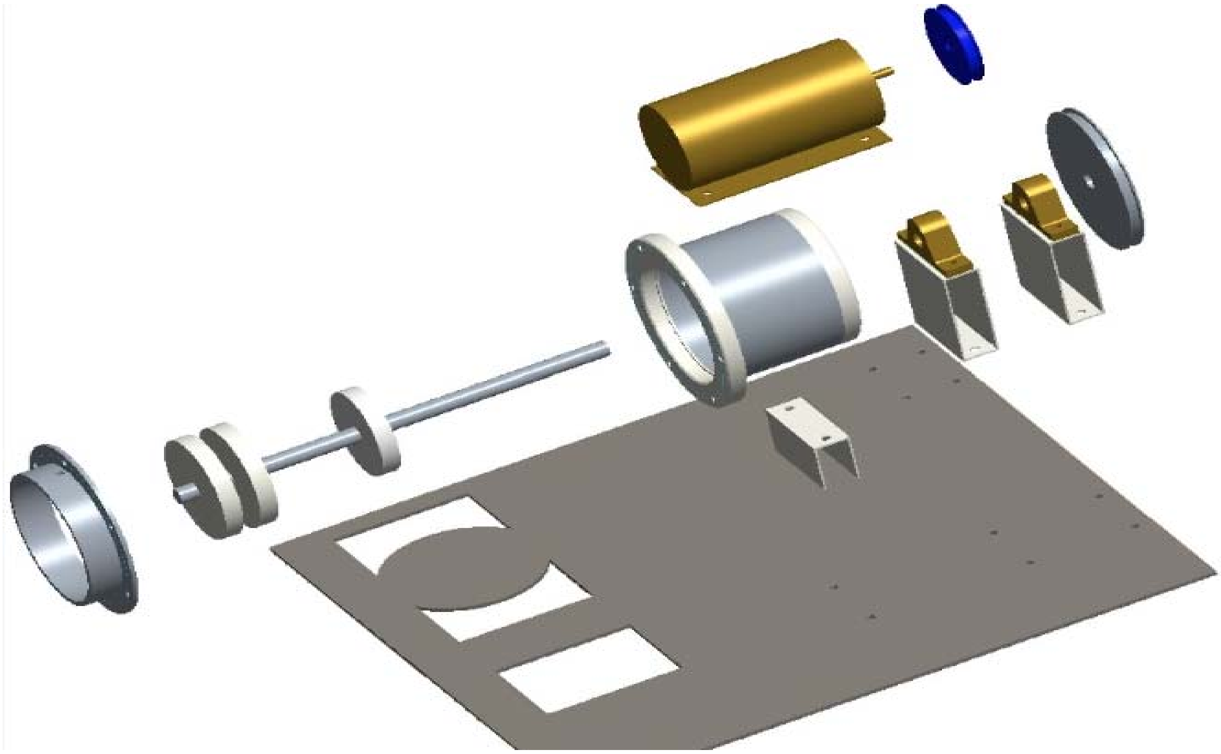

Figure 3: Exploded view of CAD assembly.

2.3 Design Optimization

The overall fabrication time is estimated at 5 hours, while the total assembly time of the completed components is estimated at 2 hours. At this point, the Team is still awaiting parts from the COE machine shop, and will update both those estimates as they are explicitly determined as well as any ways to optimize the assembly process as it is undergone.

Concerning components, a way to optimize the manufacturing and assembly processes would be to incorporate the labyrinth seal into the crankshaft. This reduces the number of parts required for the assembly of the overall system. Additionally, if the housing of the super seal could be machined to include its own grooves that would interlock with the channels on the crankshaft, the sealing effect would be increased. Figure 4 demonstrates this below. Furthermore, an optimization for the super seal would be to provide additional seal types when discovered for increased modularity and testing for each concept.

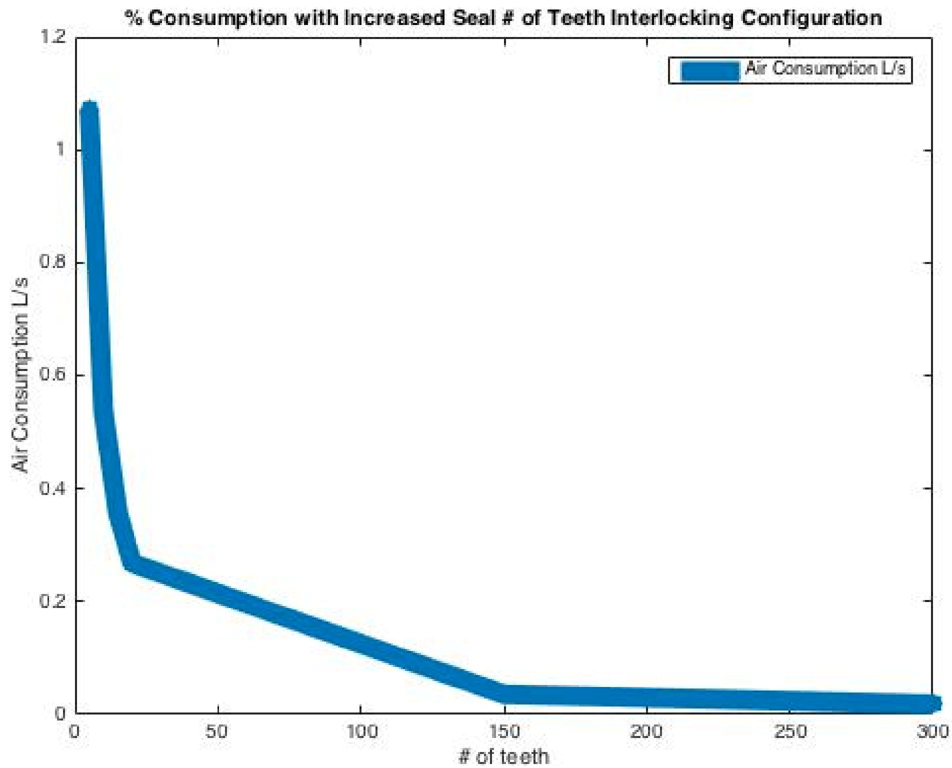

Figure 4: Graph depicting how the air leak rate through the seal decreases with an increase in the number of teeth within the seal.

3. Design For Reliability

Seeing the fact that the Team is anticipating its first test early next week, it's hard to say how its first performance will go or how many successful test cycles the prototype will produce. Reflecting on this, the project scope must be kept in mind; the prototype is designed for proof of concept of sealing solutions, and not designed to demonstrate the proper life cycle capabilities of said sealing solution. As such, there will be components that need to be replaced regularly. Of which, the most prominent would be the OEM seals due to their fragile nature and the fact that they will be press fit onto the lobes. If the test rig were ever disassembled, it would be recommended that these seals be replaced.

In addition, a source of unreliability lies in the need for proper alignment of the test shaft and super seal housing. If either is misaligned during install or damaged in such a manner that would affect proper mounting, the likelihood for a mechanical crash rises significantly. This is dangerous in the sense that a mechanical crash could permanently damage any affected component, and render the entire prototype useless until the parts could be replaced. However, this is a common concern for all mechanisms of this sort.

Considering these potential problem areas, Team 1 attempted to mitigate further reliability issues through the incorporation of critical components where possible. For example, the dimmer switch wired to the band heater ensures proper control of the heat source, and aids in the prevention of improper heat input seeing as how the band heater is capable of 480 degrees Celsius. Likewise, an electric drive motor was chosen over a traditional internal combustion engine of some sort for their enhanced reliability, decrease in required maintenance, and ease of use for the operator. Moreover, the labyrinth seal should prove to be quite reliable, as it will into come into contact with its neighbor components. This enhances its longevity without compromise on its ability to produce a seal (assuming there are no alignment issues as stated previously.

Keeping all this in mind, with the proper assembly of the prototype and routine maintenance performed as prescribed in the Operation Manual, a realistic expectation of life for the overall model is conservatively estimated at around 200 hours of operation.

4. Design For Economics

Cummins set the overall budget for the project at $2,000. This constraint coupled with the tight spatial tolerances hindered the ability to increase the life capabilities of the prototype. As such, the team and liaison engineering opted for a 'proof of concept' approach.

When all was said and done, the total cost for the components of the prototype equaled: $1,181.77. A bill of materials used can be shown below in Table 1.

Part Description	Total Price	Quantity	Cost
motor	$ 147.24	1	$ 147.24
3ft drive shaft	$ 16.62	1	$ 16.62
Rectangular Tube 6"x2" 2 ft long steel for mounting brackets	$ 47.38	1	$ 47.38
Pulley 1: 3" diameter 1/2" bore	$ 30.00	1	$ 30.00
Pulley 2: 3.5" diameter 1" bore	$ 30.00	1	$ 30.00
Pulley3: 5" diameter 1/2" bore	$ 30.00	1	$ 30.00
Pulley 4: 9" diameter 1" bore	$ 30.00	1	$ 30.00
Belt1: 4LX50" V-belt	$ 12.00	1	$ 12.00
Belt2: 4LX56" V-belt	$ 12.00	1	$ 12.00
tubing (pressure lines) 1/4" ID 1/2" OD High Temp silicone rubber	$ 32.55	1	$ 32.55
Bearings (mounted) steel bearings	$ 39.72	2	$ 79.44
Washers	$ 1.05	6	$ 6.30
bolts M10 (pack)	$ 10.45	1	$ 10.45
nuts M10	$ 0.48	30	$ 14.40
Base Plate	$ 59.00	1	$ 59.00
heating element	$ 102.00	1	$ 102.00
rear crankshaft seal	$ -	1	$
front crankshaft seal	$ -	1	$
pressure regulator/ safety relief valve	$ 14.99	2	$ 29.98
primary enclosure (crankcase)	$ 75.67	1	$ 75.67
Secondary enclosure (super seal)		1	$
terciary enclosure	$ 35.00	1	$ 35.00
labyrinth seal	$ 20.00	1	$ 20.00
T's for pressure reg and dial	$ 7.93	2	$ 15.86
Plexi glass shield for system 48" x 96" x 1/8" Clear Acrylic Sheet	$ 99.00	1	$ 99.00
Oil (1 quart?)	$ 10.00	1	$ 10.00
Containers	$ 2.57	2	$ 5.14
Plug for motor 6" 6 gage wire, max amp: 50 125/250 VAC plug co	$ 9.56	2	$ 19.12
Dimmer Switch for heater 1500 watt	$ 63.22	1	$ 63.22
barbed pipe fittings for tee and pressure gauge	$ 3.85	2	$ 7.70
Caps for crankcase ends	$ 132.52	1	$ 132.52
flanges for shaft seals inside dia fit		1	$
flange for crankcase		1	$
2 end threaded pipe nipple for pressure Tee	$ 4.59	2	$ 9.18
		TOTAL COST	$ 1,181.77

Table 1: Bill of materials for the project.

Figure 5 below illustrates a breakdown of each component relative to the total expenditure for the entire prototype.

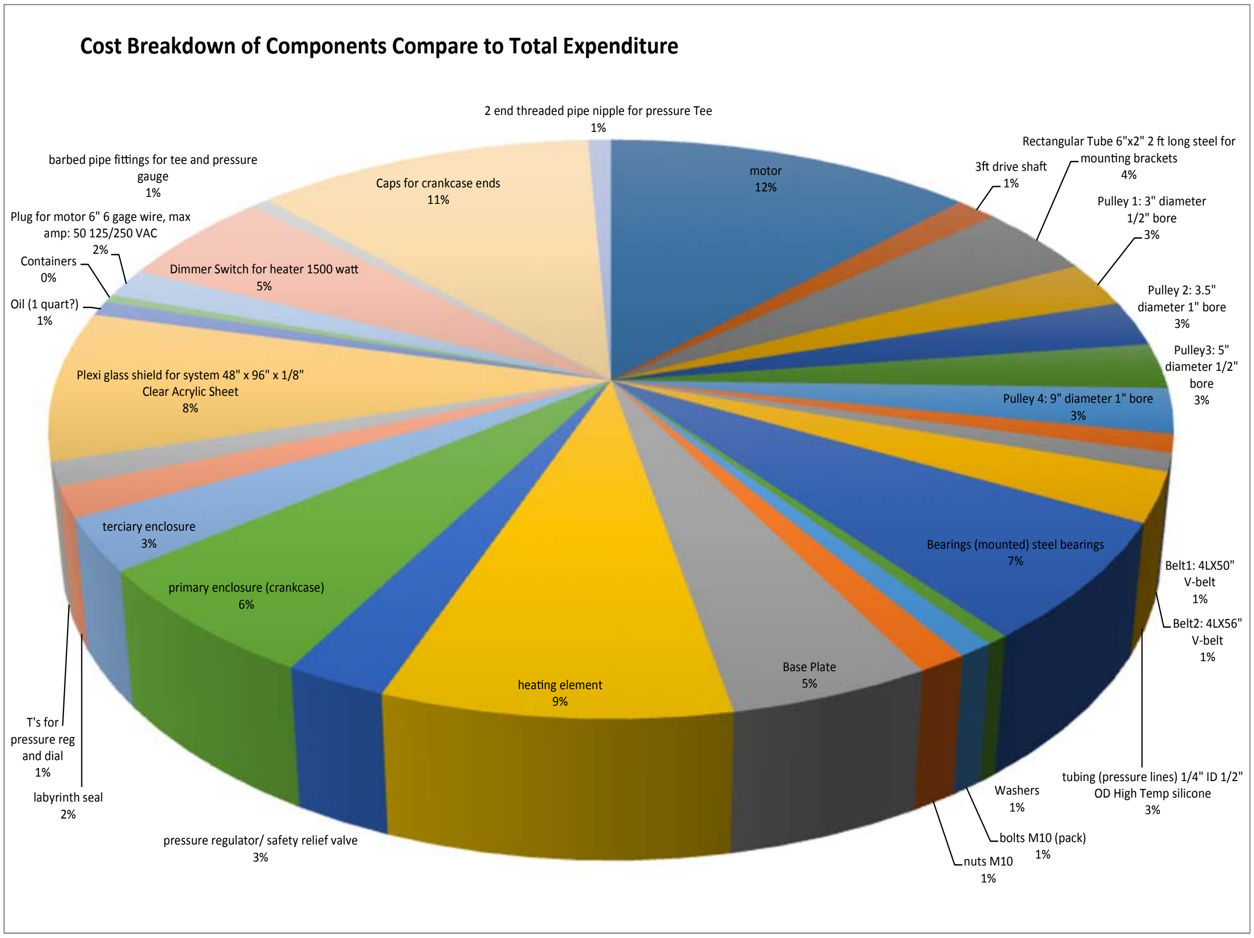

Figure 5: Component breakdown of the project and associated cost.

As can be seen from Figure 5, the major area of budget consumption was the motor, caps for the crankcase ends, and the heating element. From this, if a cost improvement activity were to take place, the opportunity to hold the largest impact would be with those components.

Due to the fact that the project had so many parts, a simplified chart of cost per category compared to the overall budget can be seen in Figure 6.

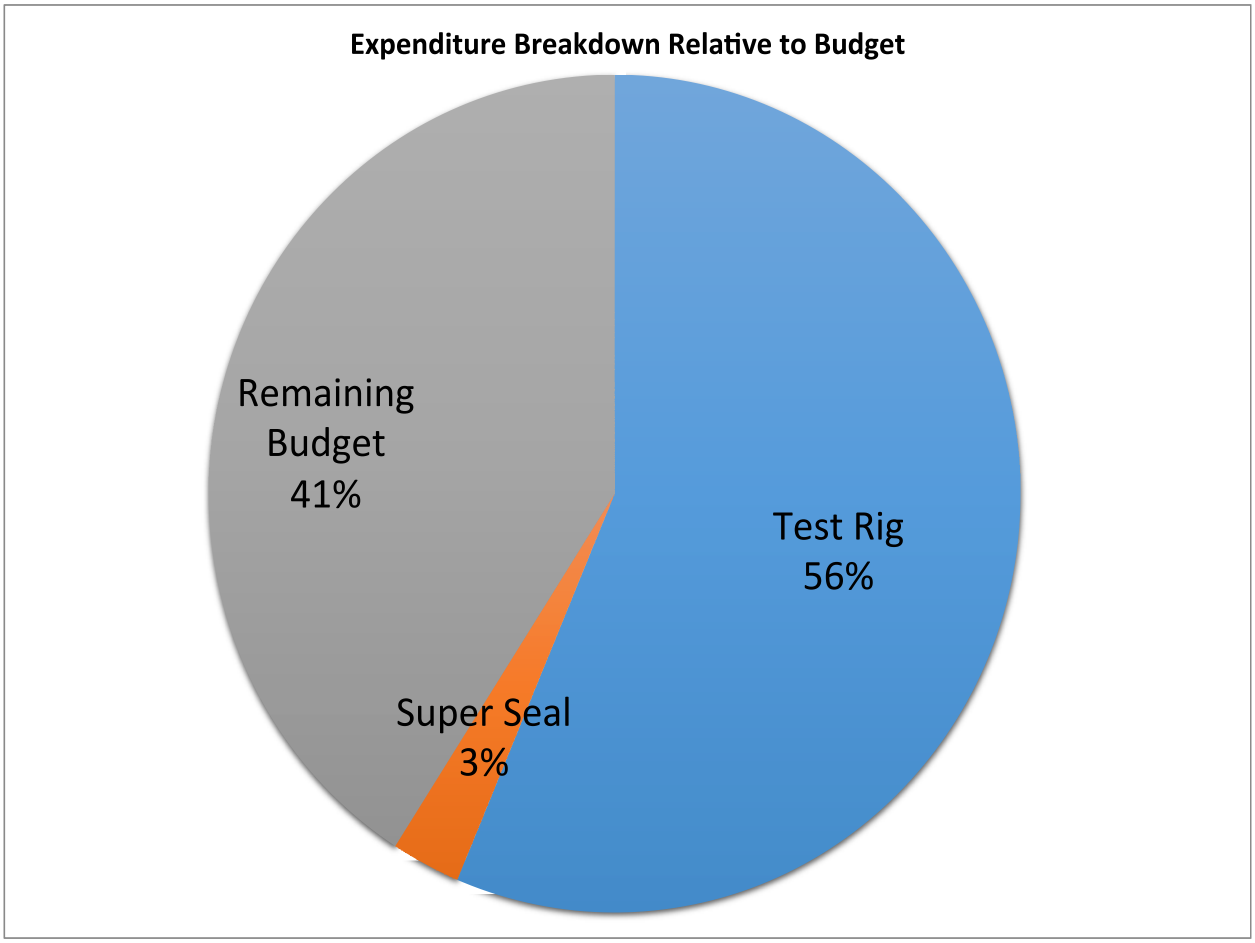

Figure 6: Cost breakdown per category relative to overall budget.

When researching for a comparable product to benchmark industry competition, no results could be found. With this in mind, if the prototype is deemed to be a success, the investment made holds a large amount of added value considering the steps it takes towards solving an industry wide issue. If a group is deemed to succeed the project, the collective impact that could potentially be provided could revolutionize Cummins sealing systems.

5. Conclusion

While Team 1 has yet still to test the prototype, the group feels as though they have brought added value to the problem of sealing rear crankshafts for heavy-duty engines. With the ability to prove the concept designed, future teams/work should be able to continue working with the prototype developed in an effort to: increase seal longevity, improve areas of unreliability, and construct and test alternative sealing options as they see fit. Using only 59% of the provided budget, the roughly $1,182 spent by Team 1 has provided a platform for current and future learning, development, and implementation of two stage sealing systems and their benefit.

References

1. Shaw, Terry. "Sponsor Meeting." Interview.

2. Shaw, Terry. *Project 1*. N.p.: Cummins Inc., n.d. PPT.