Operation Manual

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

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Date Submitted:

April 18, 2017

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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. Through careful consideration and analysis Team 1 has determined that the best solution for the problem is a straight through labyrinth seal with an interlocking teeth configuration. Because of machinability constraints Team 1 will implement a straight through labyrinth seal with a single row of teeth configuration as a proof of concept. The optimal results are to use an interlocking configuration with 10 teeth or a single row with 15 teeth.

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. Team 1 is also grateful for the time taken by Aniket Ingrole at HPMI for his assistance in manufacturing the final product.

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. Functional Analysis

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."

An important note to make is that primary role of this project is a 'proof of concept' for the recapture device. The hope is that the progress generated through Team 1's efforts can be applied by the project successors and one day implemented into mass production.

With this in mind, the function of the project can be split into two main categories: the recapture device and the test rig.

2.1 Recapture Device

A large problem within the transportation industry is the failure of crankshaft sealing solutions. To address this, Team 1 was tasked with designing some sort of device to increase the overall robustness of the current original equipment manufacturer (OEM) rear crankshaft seal that Cummins, Inc. (hereby referred to as Cummins) employs in their mass production. With such tight tolerances determined by the nature of engine operation and available space, numerous design iterations lead to the development and implementation of a labyrinth seal for the added benefit of a 2-stage sealing system. This labyrinth seal is incorporated into a housing that is to be pressurized at 1 psi. The function of the overall device is to induce a pressure gradient between the crankcase and the outside environment designed to reduce the amount of oil that leaks past the rear crankshaft seal, while the labyrinth seal simultaneously produces a non-contact seal around the crankshaft to mitigate oil from escaping the housing. Furthermore, the housing contains a drain so that recaptured oil may be collected into an accessible reservoir.

2.2 Test Rig

The primary function of the test rig is to aid in the proof of concept pertaining to the recapture device (henceforth referred to as the 'super seal'). To accomplish this, Cummins provided a 24-hour trial designed to mimic engine-operating conditions. The trial parameters are as follows: 500 RPM for 2 hours, 2000 RPM for 6 hours, 500 RPM for 2 hours, finishing with 0 RPM for the remaining 14 hours. To enhance the characteristics of the test, the oil within the rig is heated to 125 degrees Celsius.

An overall layout of the project can be seen below in Figure 1.

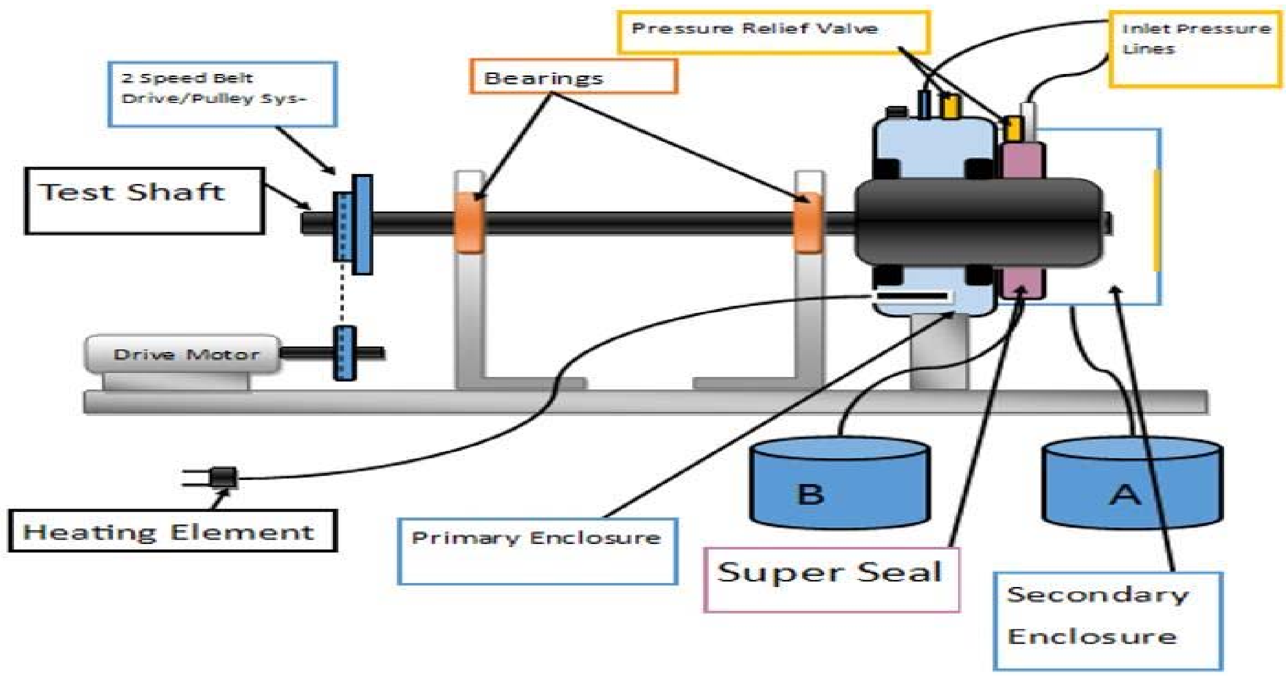

Figure 1: Diagram of the overall project; test rig containing the super seal.

3. Project Specifications

3.1 Super Seal

To achieve an air leak rate through the labyrinth necessary to produce a functioning seal, the required number of teeth was calculated to be 15 for a straight through labyrinth seal with a single row of teeth. [3][4] Alternatively Team 1 suggests that Cummins incorporates a straight through labyrinth seal with interlocking teeth because of increased results with minimal space used. After consulting with our liaison engineer, the ideal implementation method of these teeth would be to have them machined into the crankshaft itself. However, due to the machining abilities capable given the budget, this method was unfeasible. To overcome this obstacle, 29 pieces of 24-gauge aluminum sheet metal (0.6096 mm thickness) were water jetted to alternating outer diameters (15 larger OD, 14 smaller OD), each with a 25.4 mm center bore for the drive shaft, and bolted together. These outer diameters are 197.58 and 187.58 mm, respectively. This pattern of larger and smaller diameters creates 15 'teeth' on the outer edge of the seal. To complete the seal, the constructed labyrinth is press fit on the drive shaft with the teeth producing the seal against the inner diameter of the seal housing. The seal housing measures 20 mm in total length, and is constructed of a schedule 40 steel pipe. Figure 2 below depicts an engineering drawing of the seal assembly.

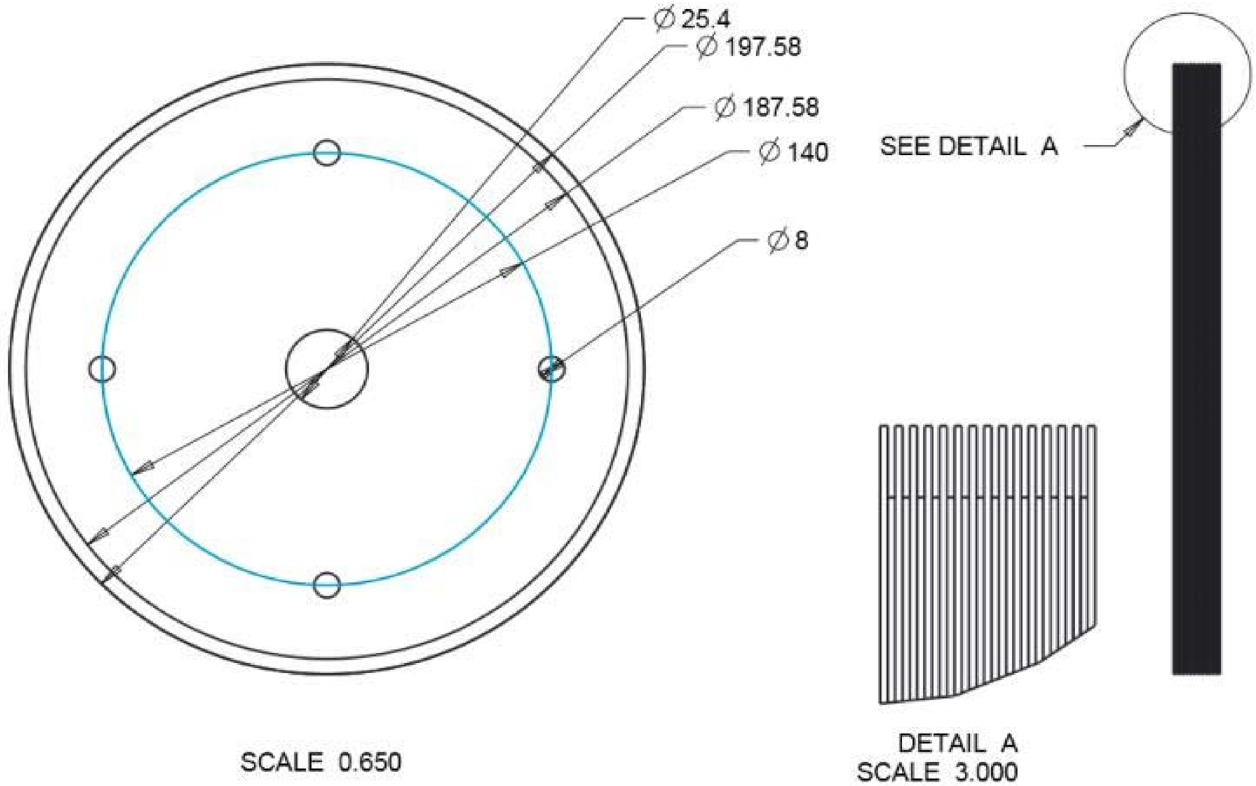

Figure 2: Engineering drawing of the fabricated labyrinth seal; all dimensions in mm.

3.2 Powertrain and Transmission

For ease, a 120-volt Dayton electric plug-in motor was chosen. The motor generates 1/3 horsepower and its part number is: 6K490. The input shaft of the motor mates to a series of V-pulleys measuring 76.2, 88.9, 127, and 228.6 mm, respectively, to achieve the operating RPMs set forth by Cummins for testing. The orientation of each pulley in the series corresponds explicitly to the way they were listed above. The V-belt that connects the set of smaller pulleys is a 4LX50" (1270mm length), whereas the V-belt that connects the set of larger pulleys is a 4LX56" (1422.4mm length).

3.3 Band Heater

A requirement established by Cummins was that the oil temperature during testing needed to be at 125 degrees Celsius. This is considered to be a crucial constraint, and therefore a reliable source of heat is needed. As such, a 1500-Watt band heater capable of reaching 480 degrees Celsius was implemented. This heater has been wired to a dimmer switch so that the temperature can be controlled, and will be monitored with a laser-based sensor and equalized at the required 125 degrees Celsius for testing.

3.4 Test Rig Supports

Supporting the entire structure is a steel base plate. Conveniently, this base plate was also water jetted to provide two circular components for the crankcase, acting as a cradle. To support the test shaft, two pillow block bearings with 25.4 mm bores. The pillow block bearings are supported by 6”x2” rectangular tube cut to the width of the bearings. This allows for the crank case to be shimmed to the correct height to meet the tolerance specifications set forth by the sponsor.

3.5 Crankcase

Similar to the super seal housing, both the primary enclosure (representing the crankcase) and secondary enclosures (control area), a 203 mm length by 200 mm ID schedule 40 steel pipe will be used.

3.6 Drive Shaft

A 25.4 mm hot rolled A-36 steel rod measuring 914.4 mm in length represents the drive shaft for the test rig. To mimic the lobes of the crankshaft that the OEM seals contact, 50.8 mm OD ‘donut’ shaped disks will be welded to the drive shaft. This gives us the lobes needed to mount the seals, without the power requirement needed to then spin a full sized crankshaft.

3.7 Safety

To increase safe operation of the test rig, a digital airflow regulator from Central Pneumatic has been attached to the crankcase. Furthermore, the entire rig has been enclosed with Plexi-glass to separate the operator from the moving components during testing. This exterior Plexi-glass also provides the benefit of oil control if any were to escape, while allowing the operator the ability to visually inspect and monitor the rig during testing.

4. Project Assembly

4.1 Super Seal

The assembly of the super seal is simple, yet important. Each of the 29 sheets of water jetted 24-gauge aluminum must be layered in an alternating pattern between the larger and smaller sets of OD. Once the layering is complete, 4 M8x25mm bolts and corresponding nuts will be used to securely hold them together. Once the seal is aligned and securely fastened, it will be press fit onto the test shaft.

4.2 Test Rig

The assembly of the test rig is outlined below:

1. Mount the motor, pillow block bearings, and cradle to the base plate.
2. Wrap the band heater around the crankcase, and place in the cradle.
3. Loosely hand the OEM seals on the test shaft, and insert the test shaft from the rear of the crankcase, and through the pillow block bearings.
4. Press fit the seals onto the lobes of the drive shaft. Press fit drive shaft into crankcase. Check and adjust alignment as necessary.
5. Initially set the super seal housing onto the rear of the crankcase. Check and adjust alignment as necessary.
6. With alignment ensured, tighten bolts to securely fasten super seal housing to the crankcase.
7. Use the setscrews, mount the pulleys onto their respective shafts, 76.2 mm to the drive shaft, and 228.6 mm to the test shaft.
8. Mount the 4LX56" V-belt onto the pulley setup.
9. Insert pressure lines, air regulator, and oil drain lines.
10. Place Plex-glass over the entire structure when testing.

Figure 3 below displays an exploded CAD view of the entire assembly (without the belts).

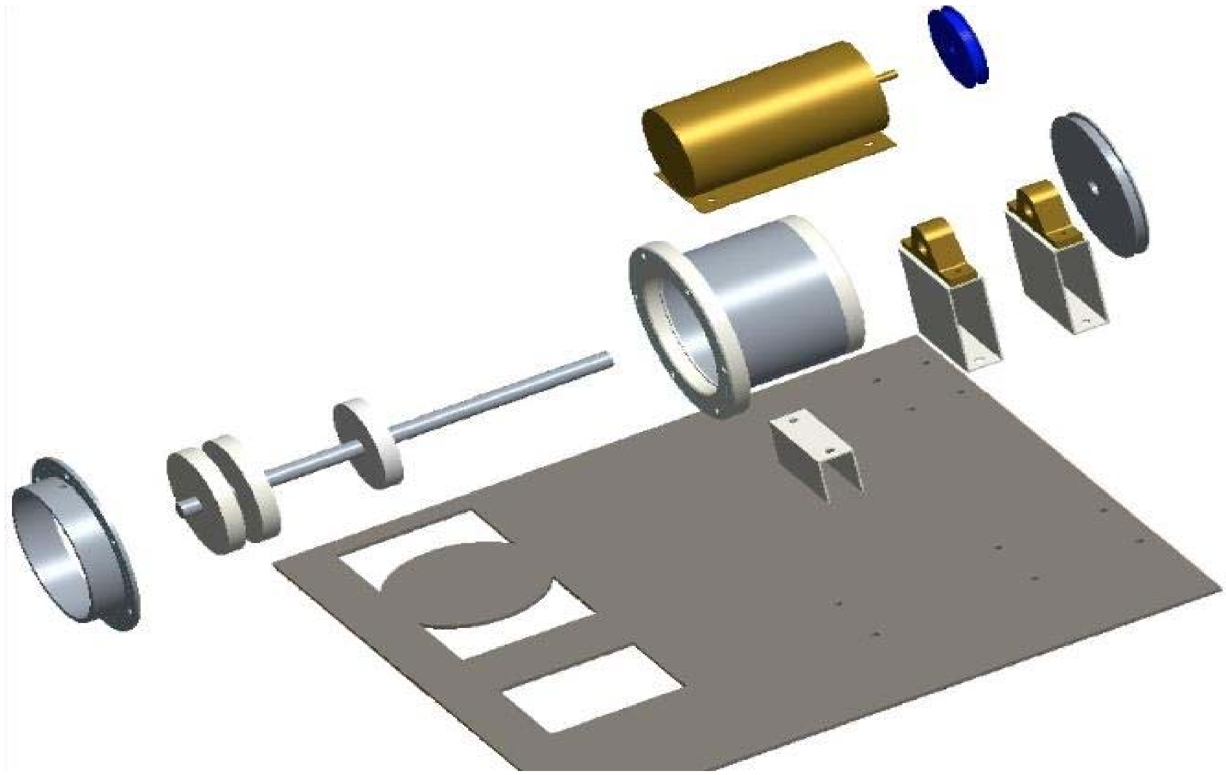

Figure 3: Exploded view of CAD assembly.

5. Operation Instructions

With the seal and test rig assembled, the first step is to insert oil into the crankcase. For purposes of this project, 1 quart of oil will be sufficient. The type of oil for this experiment does not matter, as oils tend to behave the same at elevated temperatures. Next, turn on the band heater and adjust the temperature as needed with the dimmer switch until the desired 125 degrees Celsius is achieved. At this point, the test rig should be ready to run the first segment of its trial. As such, make sure the Plexi-glass enclosure is placed around the structure, plug in the motor, and begin testing at 500 RPM for the first 2 hours.

After two hours has elapsed, unplug the motor and wait for the drive shaft to stop spinning. Remove the safety enclosure and replace the 76.2 and 228.6 mm pulleys with the 88.9 and 127 mm pulleys, respectively. Replace the 4LX56" V-belt with the 4LX50" V-belt. From here, ensure the temperature is set back to the 125 degrees Celsius if it has fallen, replace the safety enclosure, and plug the motor back in. Let this setup run for 6 hours. At the end of which, make sure the test rig has completely stopped, followed by switching the pulley and V-belt setup back to the original orientation. With the 76.2 and 228.6 mm pulleys and 4LX56" V-belt reinstalled, check for the proper temperature, replace the safety enclosure, and run the rig for two hours. At this point, the portion of testing requiring motion has concluded. Let the entire system set for 14 hours, and compare the results of oil in the reservoirs.

6. Troubleshooting

The most anticipated point of failure (if any) is for oil to leak out of the crankcase in areas not pertaining to the drain lines. If this happens, the first thing to check would be the OEM seals are in their proper location and have no slipped off of their lobes. If oil is still leaking, the alignment of the test shaft within the crankcase and tightness of the fastening bolts for the super seal housing should be inspected.

If the band heater is not producing heat, inspect the wiring, and ensure there is no damage, as this could be the potential problem.

During operation, if a grinding or metallic noise can be heard, immediately shut the test rig down, as this warns of a potential system crash. Such a crash could irreversible damage the labyrinth seal, drive shaft, crankcase, or burn out the motor. Any and all of these could result in catastrophic failure of testing, and prevent any further progress until the component is replaced. To address such a noise, the alignment of the test shaft should be confirmed; the test shaft should also be inspected to make sure the welds for the lobe are intact, as any deviation from alignment could produce an orbital motion during operation.

From a safety perspective, always inspect the air regulator, keep the dimmer switch in a location that cannot be accidentally influenced, and ensure the safety enclosure is not damaged in any way. The breach of hot oil can severely burn anyone who may come into contact with it.

7. Routine Maintenance

Before every operation, the safety systems of the test rig should be inspected. If at any point a safety component is deemed broken, replace said component prior to any operation. In addition, routinely verify alignment of the test shaft, proper fitment of the OEM and super seals, and that each of the weld locations does not contain cracks.

With each assembly, verify that surfaces of the labyrinth seal are smooth and do not contain any signs of deformation (scratch marks, cracks, chips, etc.) Also, carefully inspect the OEM seals for any signs of failure; these seals are fragile and will most likely experience some sort of failure during each test. Considering this, frequent replacement of the OEM seals is suggested.

Furthermore, the oil within the test rig should be changed after every 100 hours of operation. Never run the test rig without a quart of oil inside of it, as this can result in a catastrophic breakdown of the test rig.

8. Spare Parts

Bearing in mind the fragility of the OEM seals, it would be wise to hold an appropriate amount in a spare parts inventory consistent with the level of anticipated operation of the test rig. Additionally, a suitable amount of oil should be kept on hand in the event that a leak was to occur. In the event of a system crash, a new test shaft, labyrinth seal, or crankcase may be needed. As a result, if the future budget permits, having a spare of each machined and inventoried may prove to be useful.

9. Conclusion

With this operations manual established, it is critical that the assembly instructions are followed precisely. Specifically of which, the alignment and securing of the test shaft, labyrinth seal, and super seal housing must be strictly enforced and monitored to ensure optimal operation and minimal issues. It is important that any problems encountered are addressed promptly and responsibly, as the super seal and test rig are considered 'one of a kind' currently. Moreover, the operators should perform routine maintenance and inspection of the structure as outlined above. As with everything else, safety is of paramount importance; always ensure the safety components of the test rig are functioning properly and installed correctly, always ensure that any risks within the operating environment have been addressed and action has been taken to mitigate them, and always use caution during operation.

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