Super Seal:
Development of a Robust 2nd Stage Oil Sealing Device for Heavy Duty Engines.

Final Presentation

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Cummins' Heavy Duty Truck engine, the ISX 15 @ 15 Liters, 600 HP

Presentation Overview

- **Project Review**
  - Background Information
  - Project Description
- **Concept Design**
  - Test Rig Design
  - Seal Design
- **Testing**
- **Project Schedule**
- **Conclusion**

Project Background

What's The Problem?

- Motor oil is repeatedly leaking past the rear crankshaft seal.
  - Failed seal
  - Material fluctuations due to thermal transients

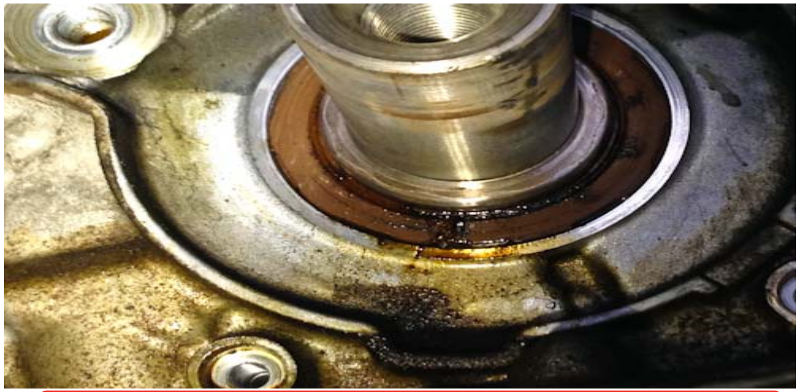


Figure 1: Depiction of rear crank seal leaking oil.[2]

Motivation

- Cost
- Evolution of Customer Perceptions

Figure 2: Cummins' newest engine, the Hedgehog @ 95 Liters, 4500 HP
Cost for crank seal replacement: $21,000.[3]

Project Background

Goal Statement

- Design a device to capture leaking oil from a rotating test crankshaft and deposit it into a reservoir so that is can be reintroduced to the crankcase.
  - *Primarily demonstrate functionality/performance of additional seal design.*
  - *NOT to demonstrate life capabilities of design solution.*

Objectives

- Design a capturing device to collect oil.
- Design a rig that can be used to test the recapture device.
- Determine feasibility of each design with technical proof.
- Construct the oil recapture device and test rig.
- Perform the 24-hour trial, and assess overall project success.

Concept Generation

Technical Drawings – ISX 15

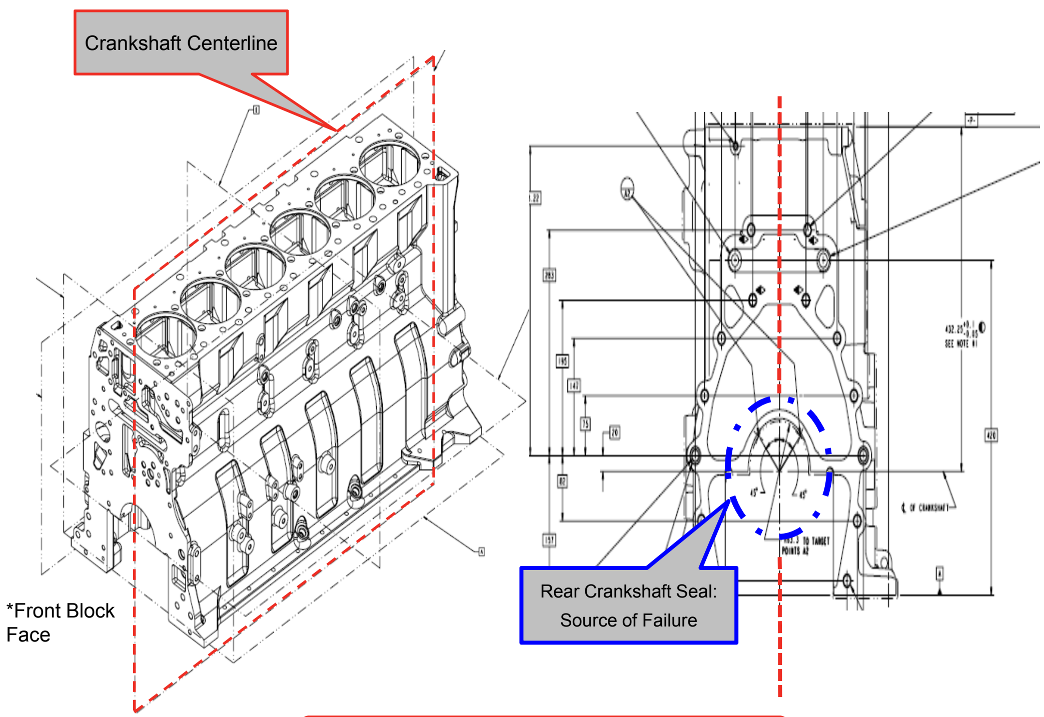


Figure 3: CAD drawing of the ISX 15 engine block.[4]

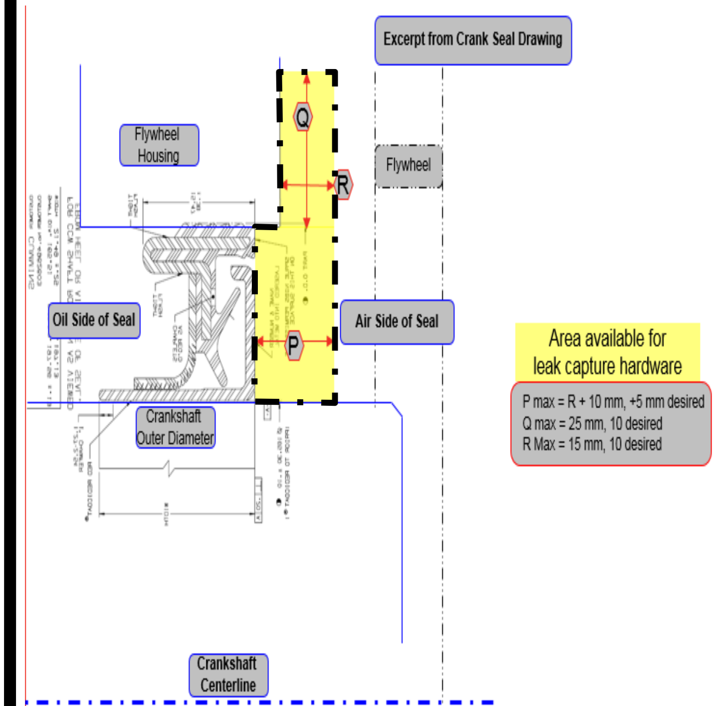


Figure 4: Visualization of available space for design.[4]

Test Rig Concept Generation

Macroscopic Ideation

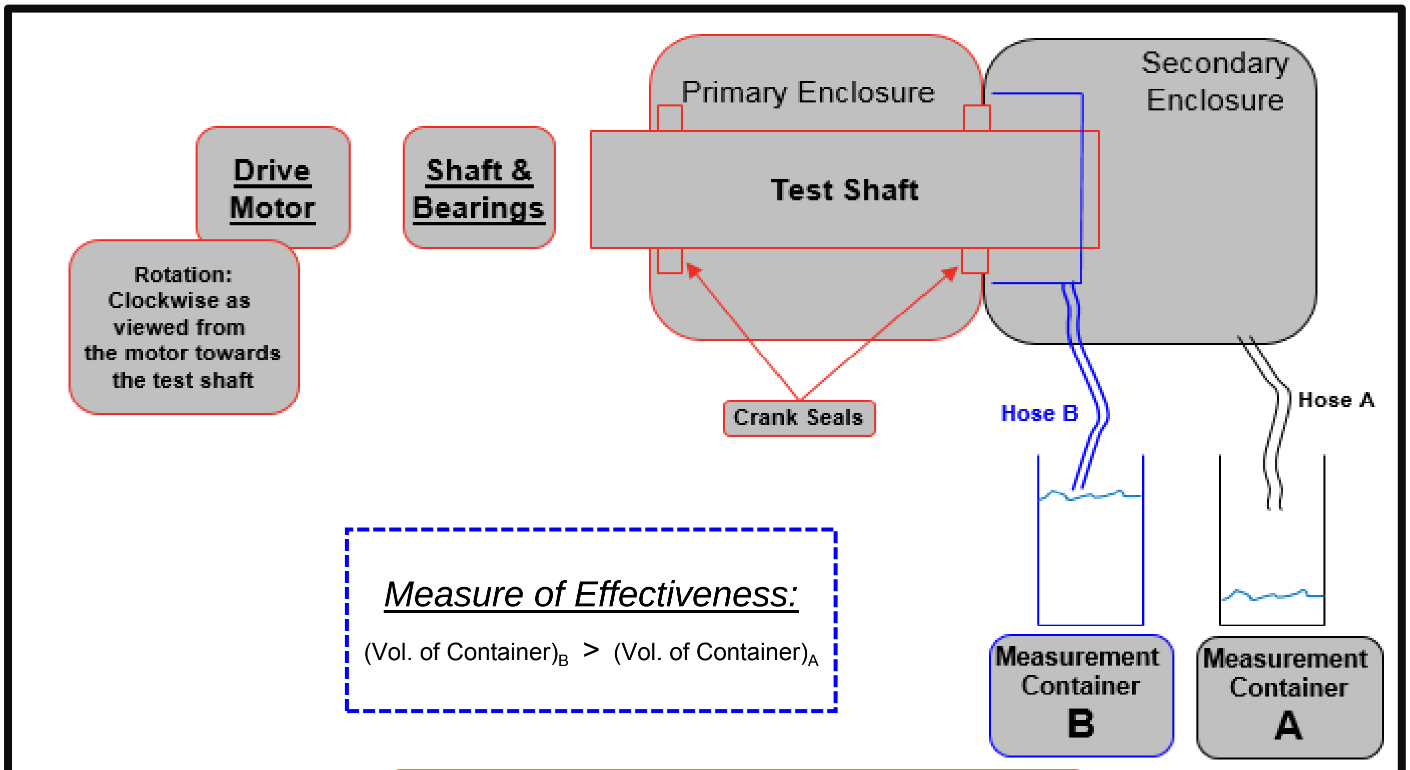


Figure 5: Concept of entire product; Basic Visualization of overall system.[3]

Sorting Test Cycle

Initial Test Cycle	
Duration (hrs)	Speed (RPM)
2	500
6	2000
2	500
14	0

Requirements

- Shell must be oil tight.
- Shell will be filled with oil to 55 mm above the bottom of the 165 mm crankshaft seal.
- Oil must be heated to 125°C.

If the sorting cycle yields positive results, additional steps and durations can be added to increase complexity.

Macroscopic Design

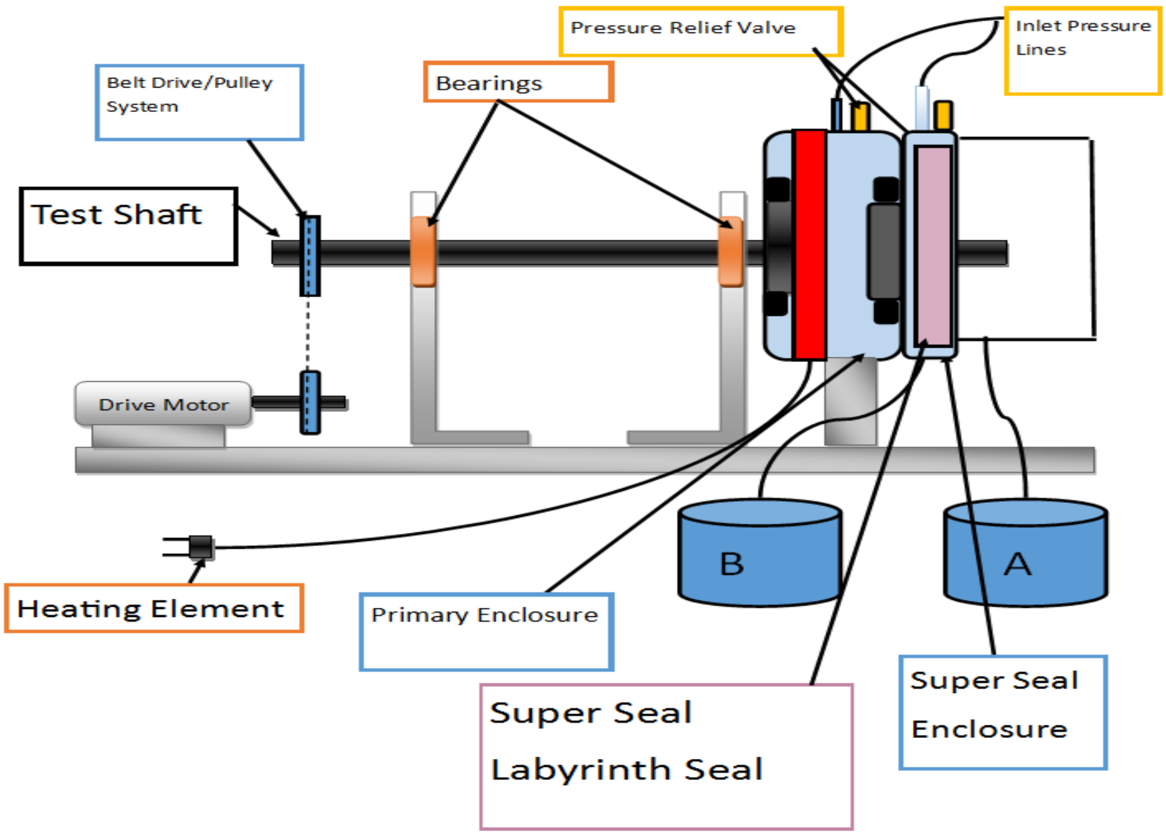


Figure 6: Concept of entire product; capture device couples to test rig.[3]

Major 'OTC' Components

- 1500W Band Heater
  - 900° F at 120 Volts.
  - Dimmer Switch to alter voltage input to heat crankcase to 125° C.
- 1/3 HP Belt Drive Dayton Motor
  - 1475 RPM at 120 Volts.
  - V-belt pulley system utilized to achieve desired shaft speeds for test.
- Mounted Bearings
  - Pillow Block Bearings with 1" bore to support custom shaft.
- Air Compressor
  - Craftsman 4 gallon air compressor.

Figure 7: Pictures of components purchased for the test rig.

Major Custom Components

- Custom Test Shaft
  - Custom flanges: (1) with 165 mm and (1) with 140 mm OD and the labyrinth seal
    - 4140 Steel – Mimic OEM crankshaft
      - Seals press fit over flanges.
  - Flanges press fit on shaft and welded in place

- Crankcase
  - Made from 8” (203 mm) schedule 40 steel pipe.
  - Caps welded on either side for seals to be press fit inside.

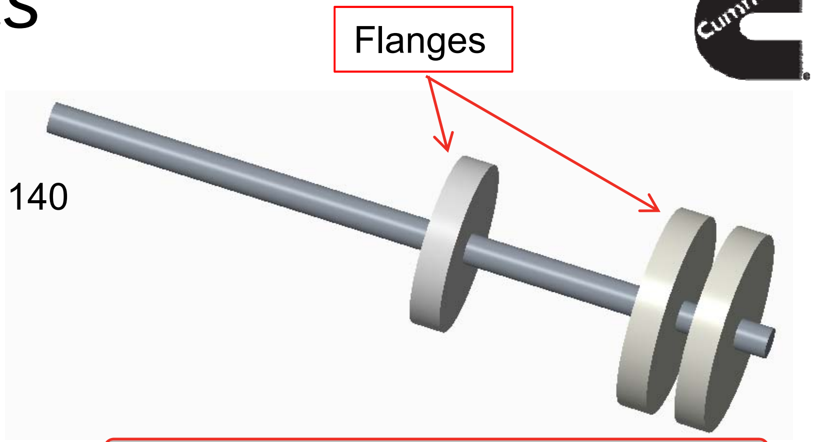


Figure 8: CAD rendering of the custom test shaft employed in the test rig.

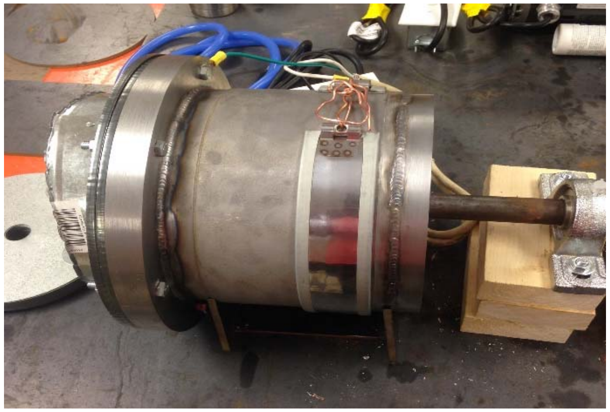


Figure 9: Picture of the custom crankcase employed in the test rig.

CAD Assembly

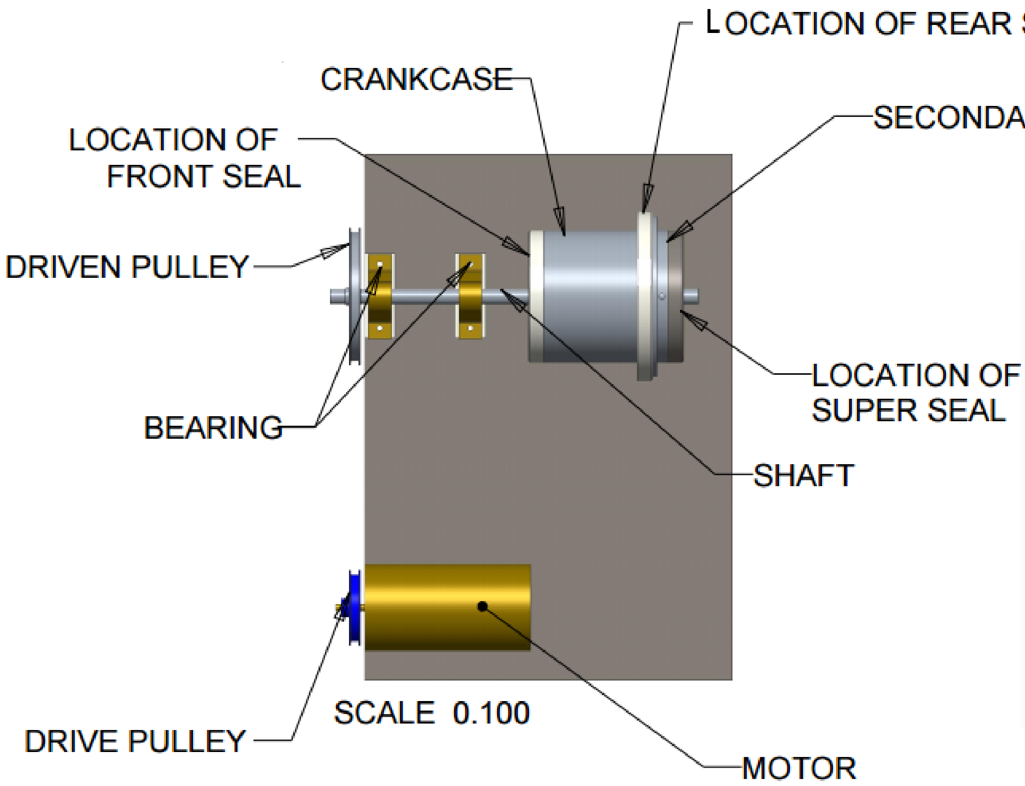


Figure 10: CAD assembly of the overall test rig.

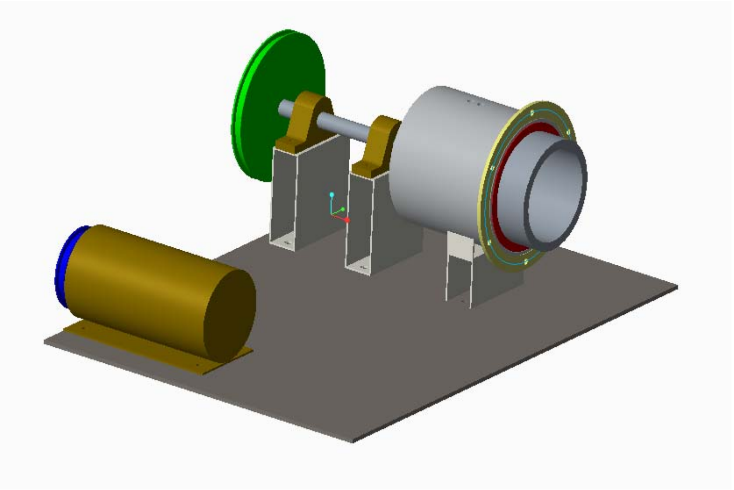


Figure 11: CAD assembly of the overall test rig; alternative view.

Seal Concept Generation

Inherent Challenges

- **Sealing**
  - Each sealing method explored theoretically fails some customer requirement.
  - No “1” solution.
    - Solution = Idea(A) + Idea(B) + …
- **Innovation**
  - Use of innovative design techniques/materials.
  - “Exciters” in addition to “expected”
- **Space**
  - Tight tolerances on spatial availability for device.
    - Keep in mind the customer’s customer.

Seal Concept Generation

Macroscopic Ideation – Seal Solution

EC's from H.O.Q.:

1. Efficiency
2. Size
3. Durability

Additional Secondary Contact Seal (current one being used/size variant)		Recollection Through A Vacuum		Pressure Cavity Behind		Centrifugal Pressure Seal	
PRO	CON	PRO	CON	PRO	CON	PRO	CON
In production	Fail due to dry sliding	Optimal Re-Capture	No vacuum source	Prevents Leakage	No PSI source	Non-Contact	No Sealing Stopped
Easy to use	If lubed, fail w/ primary seal		Dry Sliding Seal Req'd	Favorable PSI Gradient	Dry Sliding Seal Req'd	Low Friction	Size Constraints?
	Envelope too big		Primary seal distortion		Primary Seal distortion	+ Eff vs. Labyrinth	+ Cost
	Copying failure				What if more oil gets out?		
Labyrinth		Hybrid Labyrinth		Hybrid Labyrinth + Centrifugal Pressure Seal		New Primary Seal	
PRO	CON	PRO	CON	PRO	CON	PRO	CON
Non-Contact	No Sealing Stopped	Non-Contact Running	Wear when Contact	HL Pushes Fluid IN	Space	Nano-Composites for Low Wear	
	Size Constraints?	Contact Slow/Stopped	Weep/Seep	Cntr Pushes Contamin. OUT	Oil Recapture	COE Advisor Wants This	
	+ Cost		Pushes Contaminants IN				

Figure 12: Decision making matrix to facilitate design.

Concept Selection

Foundation of Design

- Pressurize cavity behind rear main seal
  - Aids in a solution to the root cause of the problem = **Best** place to start

Drawbacks	Considerations
No Source of Pressure	All Cummins Engines Are Turbocharged
Potential Primary Seal Distortion	Regulate Air Pressure to Mitigate
Control Of Oil That Does Leak	Careful Placement of Pressure Introduction Point
Air Seal Needed To Maintain Pressure Gradient	***Do Not Need An Absolute Seal (e.g. House Heater)***

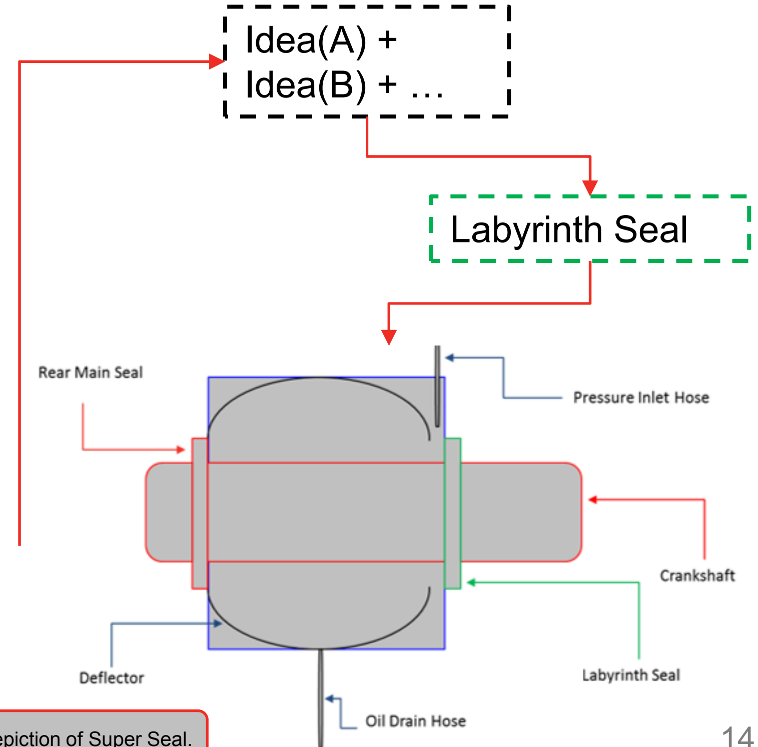


Figure 13: Simple cross section depiction of Super Seal.

Seal Design

Labyrinth Seal

- Mechanical Seal
  - Designed to make the path of fluid tortuous through the implementation of numerous channels.
  - Produces a seal when the shaft is rotating due to centrifugal motion.
  - Non-Contact Seal – Increased longevity.
- Alterable Parameters
  - Number of teeth
  - Tooth Geometry
  - Material of Seal
- Constraints
  - Target air consumption 2.25 L/s ≈ 1% of engine air intake
  - Static TIR = 0.5 mm
  - Dynamic TIR 0.35 mm

Figure 14: Labyrinth seal visualization.

Types of Labyrinth Seals

- Straight Through
  - Basic annular shape.
  - Different patterns of teeth.
  - Easier to machine.
- Stepped
  - Conical in shape.
  - More difficult to machine.
  - Not much more efficient for greater cost to produce.

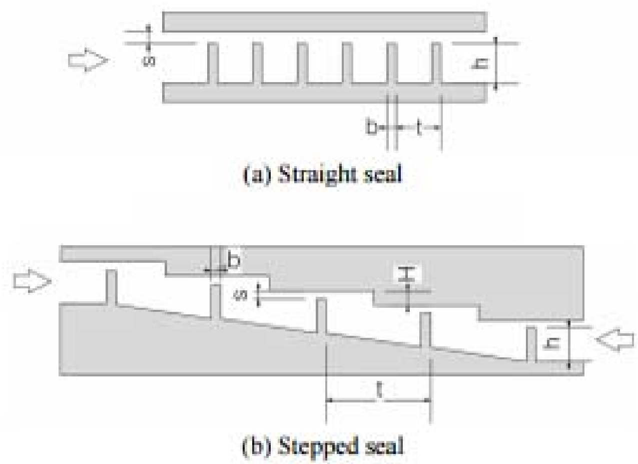


Figure 15: Comparing straight seals to stepped seals.

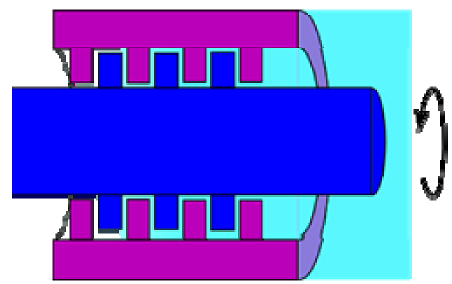


Figure 16: Straight through Labyrinth with interlocking teeth.

Design of Labyrinth Seal

- Interlocking Teeth
  - Optimal solution is 10 teeth.
  - Ideal for Cummins.
  - Difficult to machine and assemble.

- Single Row of Teeth
  - Optimal solution is 15 teeth.
  - Ideal for this scenario.
  - Easier to machine and assemble.

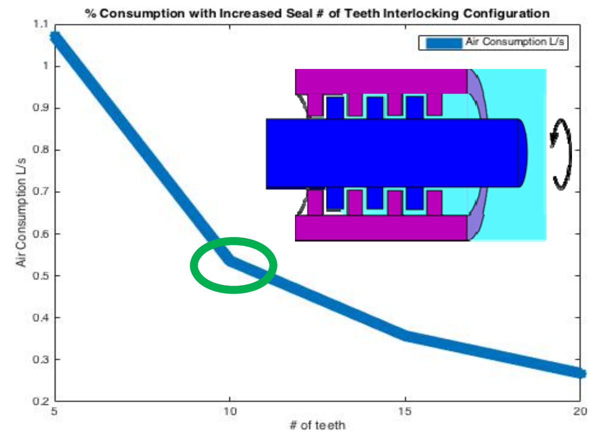


Figure 17: Interlocking tooth design solution.

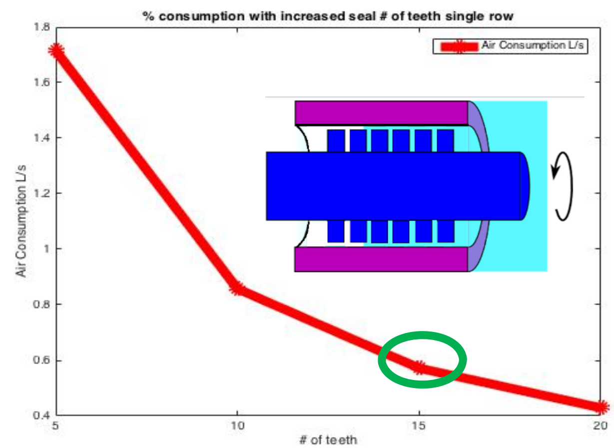


Figure 18: Single row tooth design solution.

Our Super Seal

- 15 tooth system
  - Created by stacking sheet metal circles of alternating diameters.

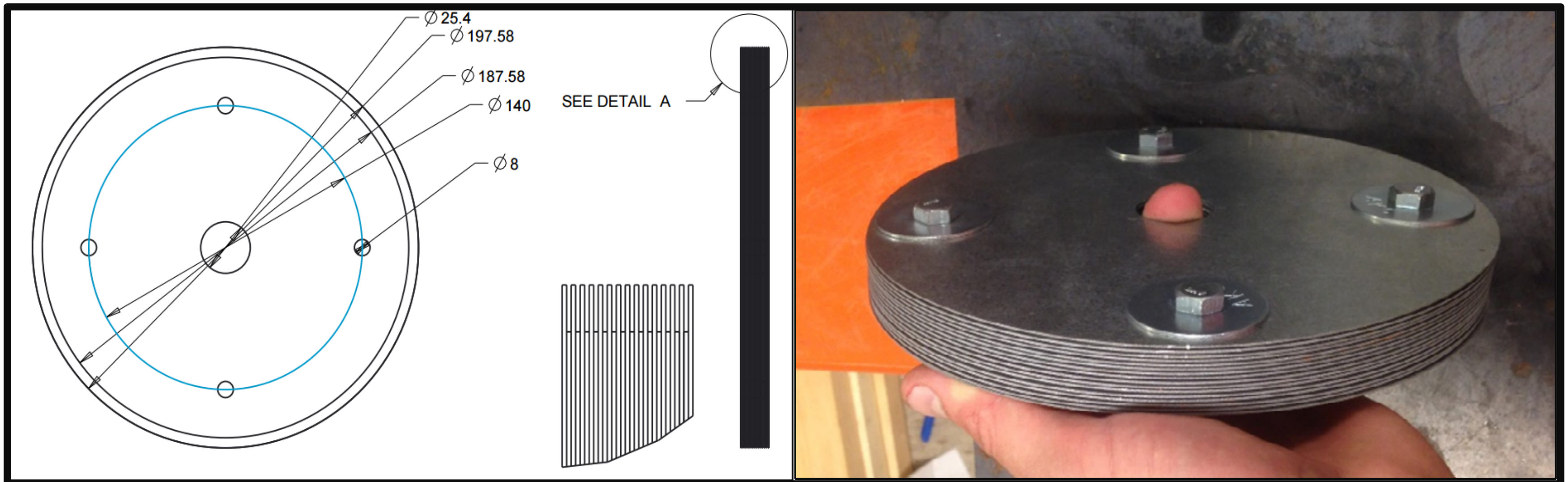


Figure 19: CAD vs. assembled labyrinth seal.

Project Economics

Bill of Materials

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 brac	$ 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 silico	$ 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 Acryli	$ 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	$ 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

Expenditure Breakdown Relative to Budget

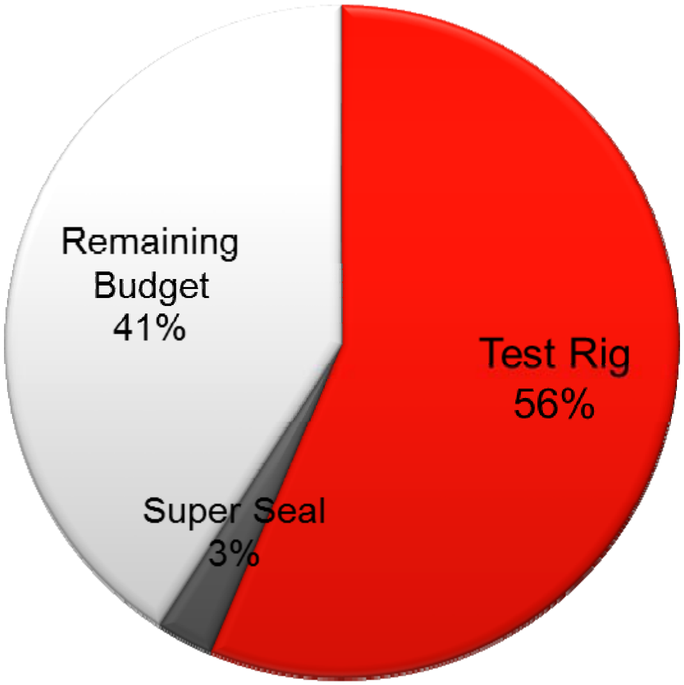


Figure 20: Cost comparison between components and budget.

Presenter: Jonathan Strickland

Project Economics

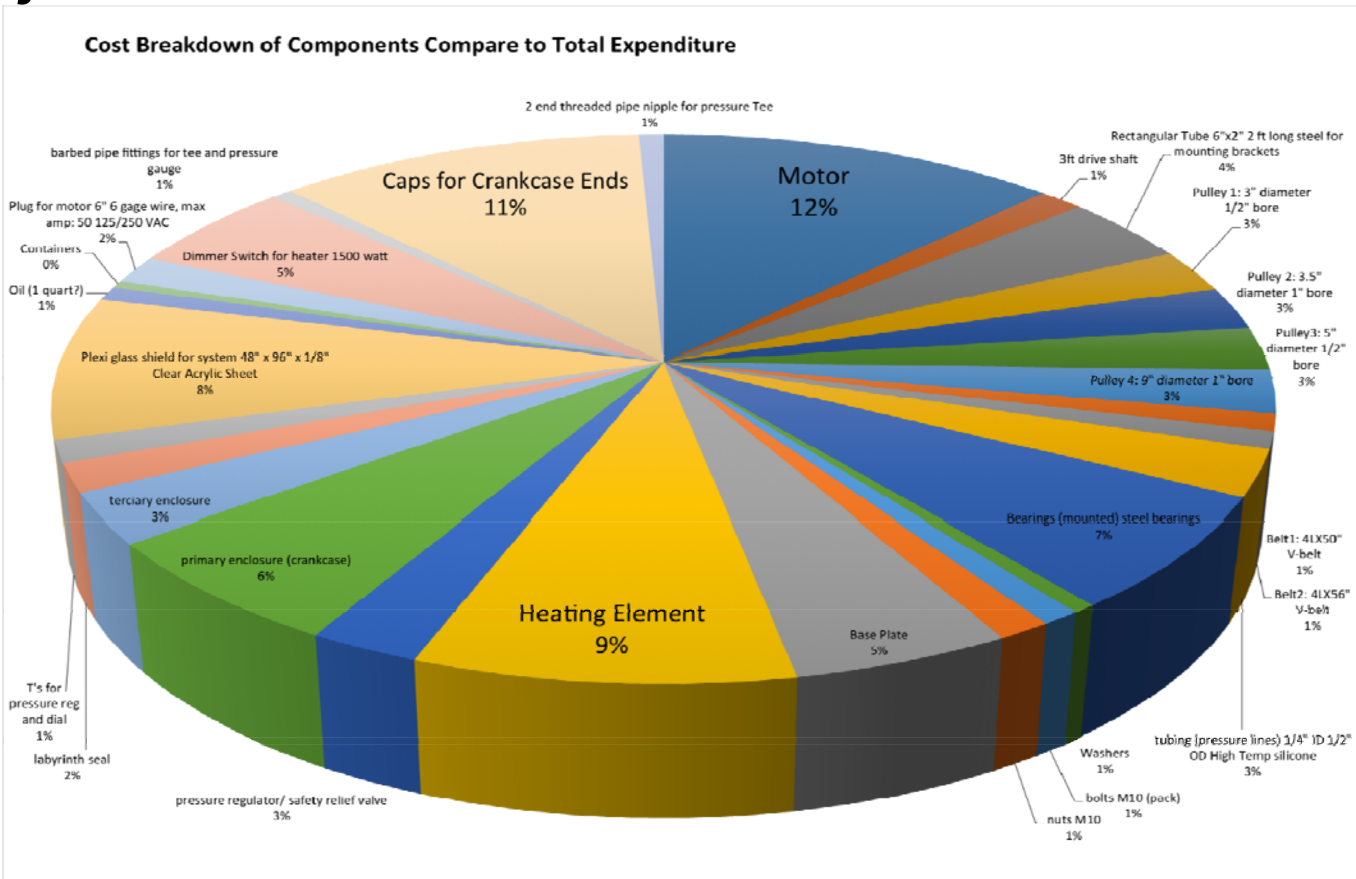
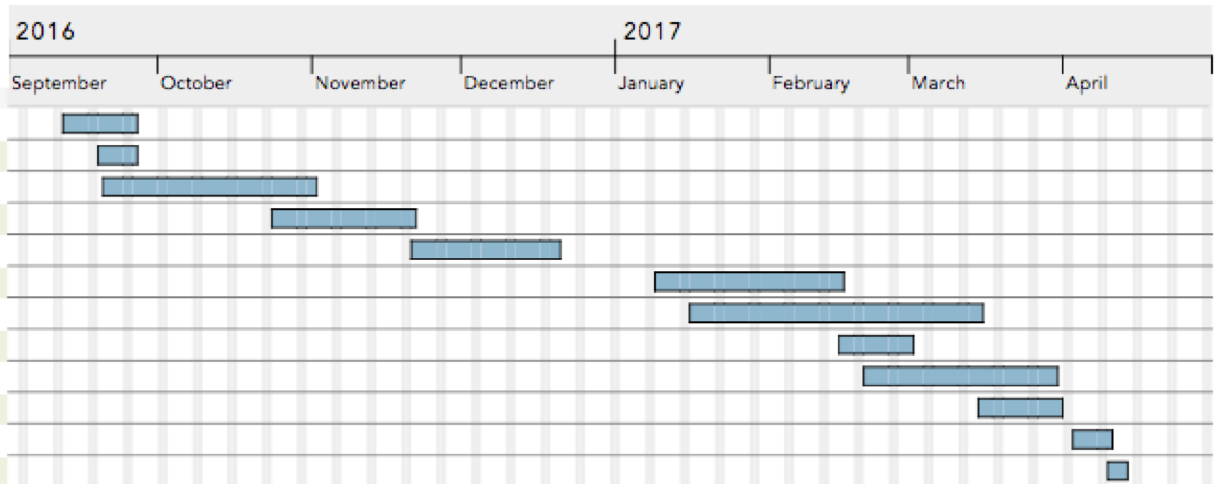


Figure 21: Pie chart of project expenditures.

Project Schedule (Gantt Chart)

Name	Begin date	End date
General Research	9/12/16	9/26/16
Needs Assessment	9/19/16	9/26/16
Conceptual Design	9/20/16	11/1/16
CAD Renderings	10/24/16	11/21/16
Finalize concepts	11/21/16	12/20/16
Finalize BOM	1/9/17	2/15/17
Order Parts	1/16/17	3/15/17
Air flow/Seal DFM	2/15/17	3/1/17
Assemble Test Rig	2/20/17	3/30/17
Performance Trials Test ...	3/15/17	3/31/17
Test Sealing Solution	4/3/17	4/10/17
Analyze results/ Adjustm...	4/10/17	4/13/17



Future Recommendations

- If this project has successors:
  - Redesign and enhance safety enclosure.
  - Investigate alternative materials for the labyrinth seal.
  - Plan and conduct a more rigorous trial.
  - Develop modular sealing alternatives for comparison.
  - Try to decrease the overall complexity of test rig assembly.
  - Examine changes that can be made to the OEM seal to address the root cause.

Conclusion

Project Goal

- Design a device to capture leaking oil from a rotating test crankshaft and deposit it into a reservoir so that is can be reintroduced to the crankcase.
  - Paying close attention to the test rig.

Ideal Design

- Design for test rig and capture device is finalized.
  - Minor changes may still be implemented.
  - Paying close attention to tolerances.

What's Next?

- Testing

References

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Questions?