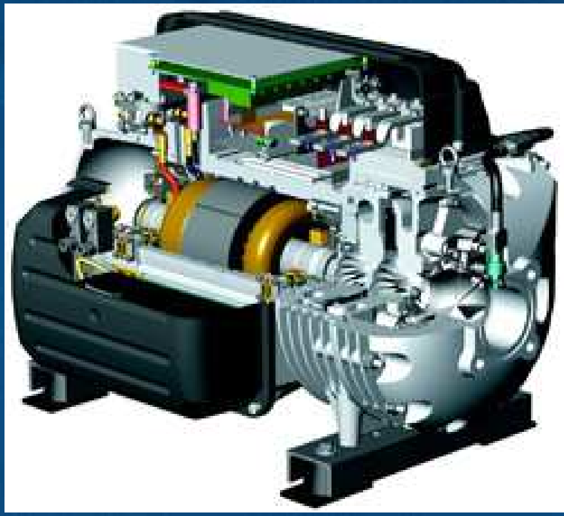
Labyrinth Seal Test Rig

Sponsored by Danfoss –Turbocor

Spring 2009 Final Presentation



Group 1

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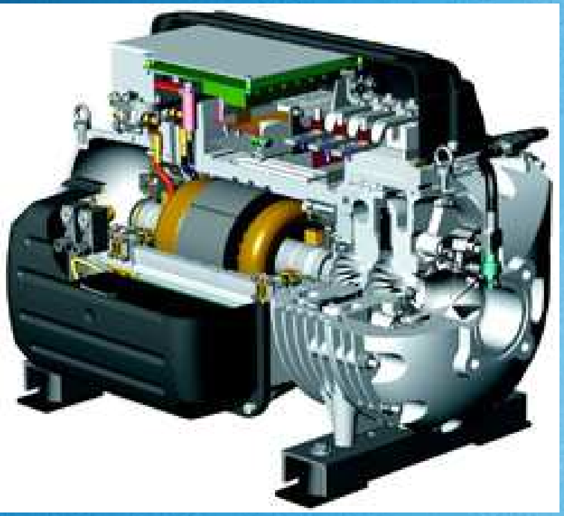
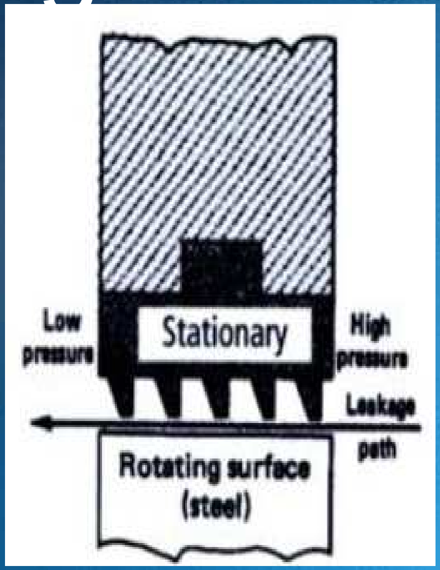
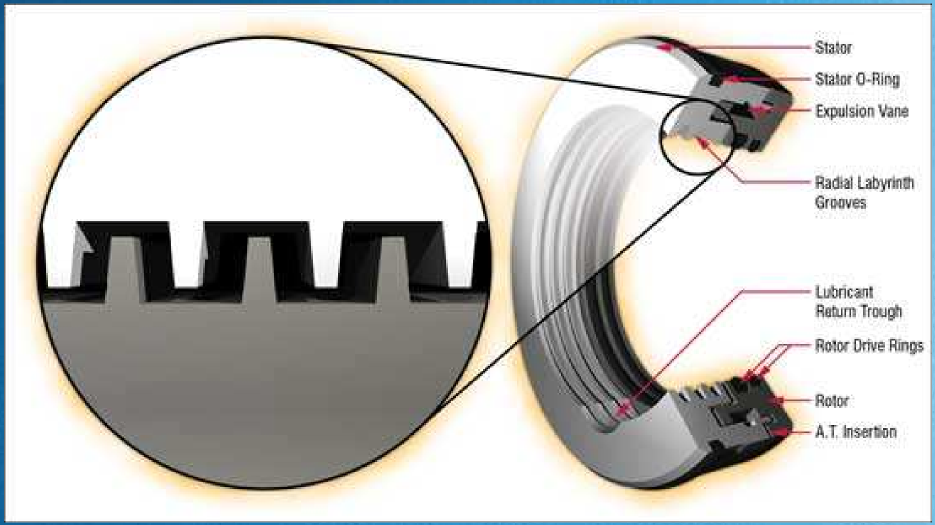


Introduction: Background

- Mechanical seal that fits around a shaft to prevent leakage of fluid
- Provide non-contact sealing by controlling flow of fluid
- Threads create a "maze" to induce turbulence and block flow





Introduction: Problem Definition

- Design and build a test rig that simulates conditions in a high speed centrifugal compressor
- The leakage flow through the seal must be measured to show which seal is superior

Needs Assessment

In order for the design to be a viable method for testing labyrinth seal efficiency, the test rig must:

- Adjust to fit seals of various sizes
- Give a quantitative measure of the amount of flow through a seal
- Vary seal-to-shaft concentricity
- Experience a variety of internal pressures
- Use air in place of R134a as the working fluid

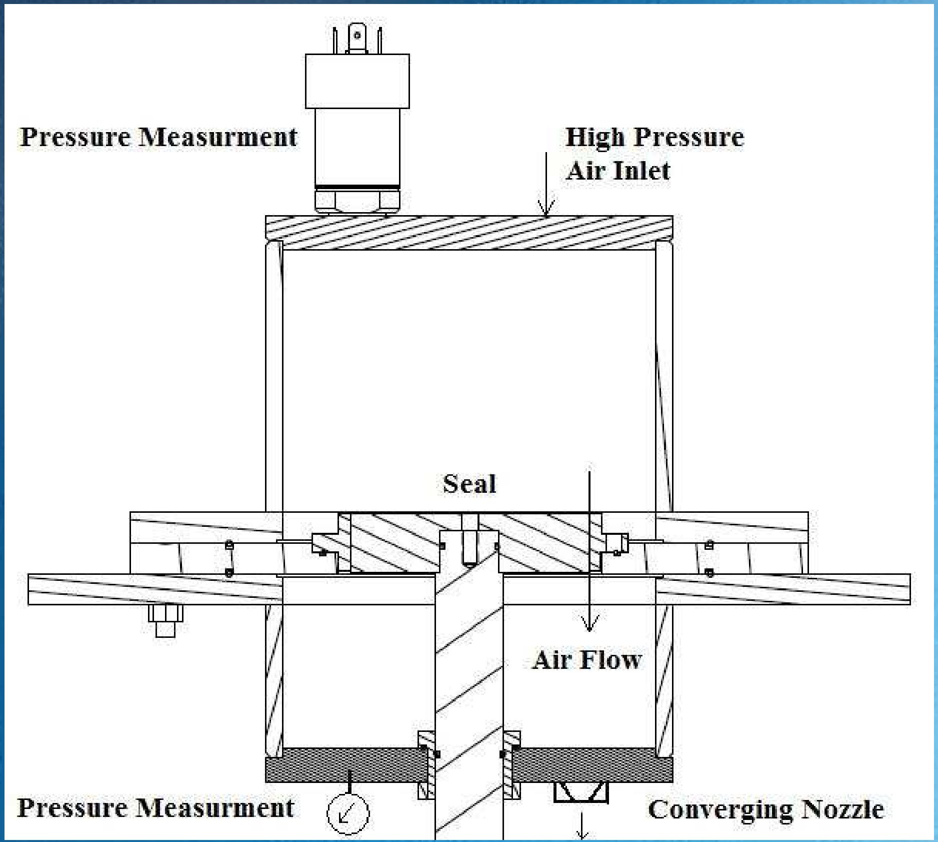
Final Design

- Create pressure difference across seal to induce flow.

- Capture and quantify flow rate through seal.

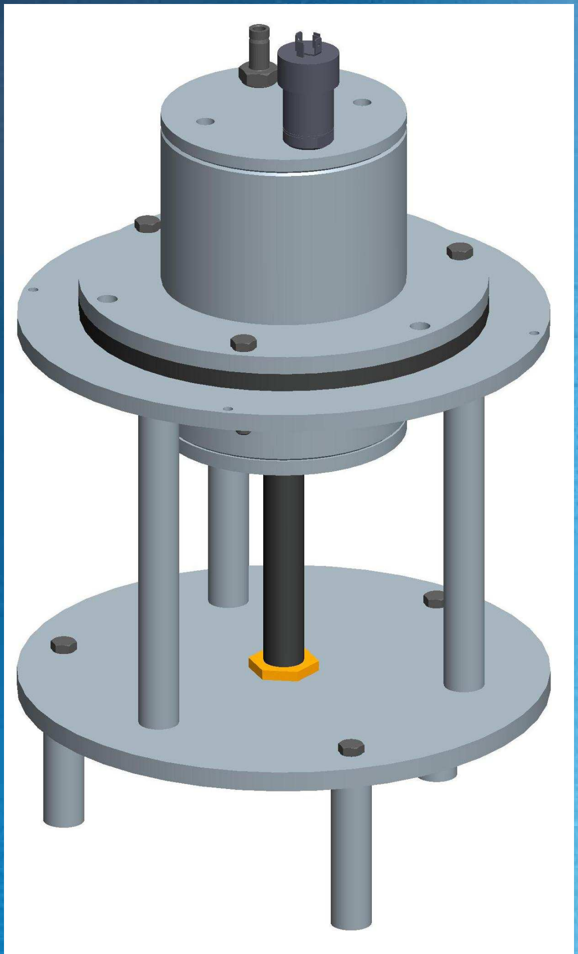
- Perform testing on various seal sizes and geometry.

- Adjust location of seal to measure flow rate for concentric and un-concentric positions.



Final Design

- High Pressure & Low Pressure Housing
  - Two pressure vessels were constructed from steel plating and cylinders.
  - The high pressure housing maintains high pressure on one side of the seal, and the low pressure housing contains the flow which leaks through the seal.
  - Connections to the measurement equipment and air source were manufactured into these components.
- Flow Measurement
  - A converging nozzle on the low pressure housing will be utilized for measurement of airflow.



Final Design

- Seal Mounting & Concentricity Adjustments
  - The seal is mounted to a steel plate, sandwiched between the two pressure housings.
  - The plate contains o-ring groove, which allows the rig to maintain a airtight seal.
  - Micrometer heads are connected to the low pressure housing, and provided displacement of the seal.
- Balancing Piston Support
  - The piston is positioned inside the seal.
  - It requires a support which is capable of supporting loading due to pressure.
  - A shaft is used to support the balancing piston, and it requires support bushings.

Design Changes

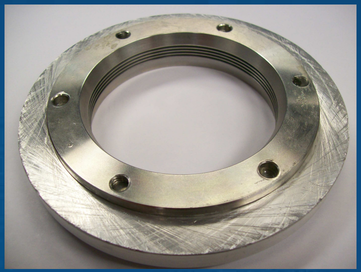
- Original fittings and tubing restricted flow rates. A throttling valve connected directly to the air line and a 3/8 inch hose corrected the supply issues.
- Analog pressure measurements were used in place of Danfoss Turbocor pressure transducers.
- The original method for concentricity measurements proved to be unsuccessful. A less accurate method was used during testing.

Manufacturing

- Primary manufacturing occurred at the Danfoss Turbocor machine shop
  - A meeting was held to introduce the design team to the shop crew mid-January
  - Machinists recommended alterations on design in order to simplify machining
    - Changed from roller bearings to brass bushings
    - Grooves for assisting alignment on parts to be welded
- Labor occurred around “primary” projects
  - Group checked in regularly to check progress and receive advice
  - Advised to change from counter-bored screw holes to chamfer-set screws due to material thickness
  - Future considerations – size limitations of shop equipment
  - Welding caused significant warping which required additional machining to correct

Manufacturing

- Time restrictions pushed final machine shop operations onto design team
  - Machining of the shaft
  - Machining of the Labyrinth seal adaptor and corresponding displacer piston
  - Leak check of the test rig
  - Machining of a nozzle for measuring flow
- Teeth were machined off the test labyrinth seal in order to show a relationship between number of teeth and flow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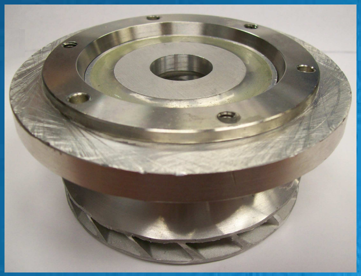
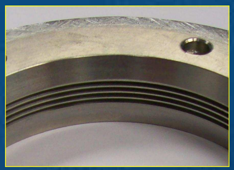
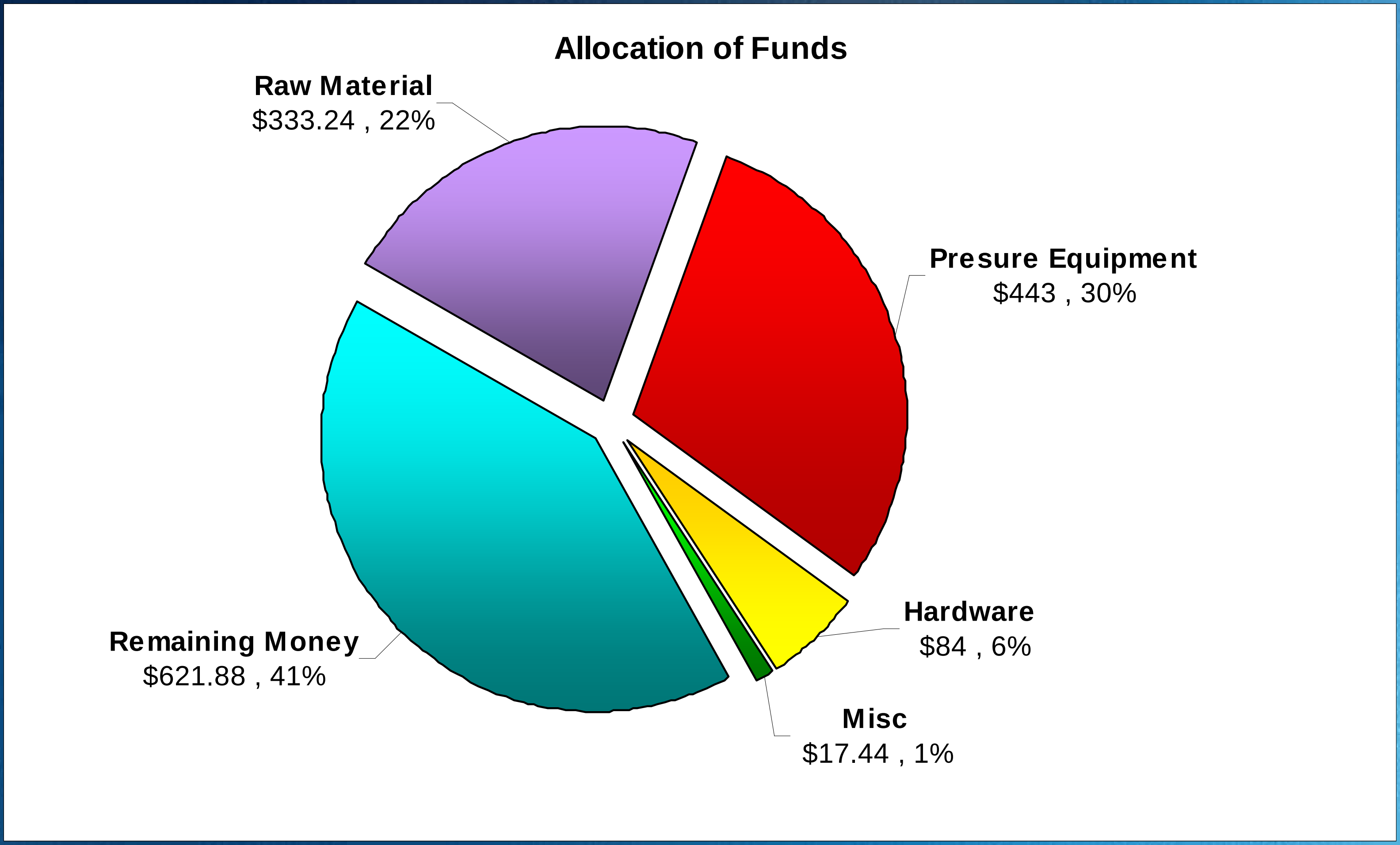



Cost Analysis

Total Spent: $878.12



Testing Methodology

- Due to time and manufacturing constraints, only 1 seal size was able to be tested D = 68 mm N=8 teeth
- To compare tooth effectiveness, a tooth was manually removed after each round of tests
- **Testing Summary:**

1. Non-Concentric test (Seal and shaft are touching)
2. Take Pressure measurements between 10-40 PSI (.177-.377 MPa)
3. Using magnetic dial gauge and micrometer heads, center the shaft with the seal & repeat test

$P_L = P_e \cdot \left(1 + \frac{\gamma - 1}{2} \cdot M^2\right)^{\frac{\gamma}{\gamma-1}}$

$a = \sqrt{\gamma \cdot R \cdot T}$

Mass Flow Rate Calculation

Theoretical: Egli Relations

- Uses $P_L:P_H$ ratio
- Properties taken from high side conditions
- Determines mass flow rate at seal exit
- Relies more on seal geometry

$$m_{dot} = \pi \cdot 2 \cdot r_o \cdot \delta \cdot C_t \cdot C_c \cdot C_r \cdot \rho_o \cdot \sqrt{R \cdot T}$$

$$X_1 = 15.1 - 0.05255 \cdot e^{0.507 \cdot (12 - N)} \qquad X_2 = 1.058 + .0218 \cdot N$$

$$C_t = 2.143 \cdot \frac{\ln(N) - 1.464}{n - 4.322} \cdot (1 - P_r)^{0.375 \cdot P_r} \qquad C_c = 1 + X_1 \cdot \frac{\frac{\delta}{p} - X_2 \cdot \ln\left(1 + \frac{\delta}{p}\right)}{1 - X_2}$$

$$C_r = 1 - \frac{1}{3 + \left(\frac{54.3}{1 + 100 \cdot \frac{\delta}{t}}\right)^{3.45}}$$

Actual: Mach Relations

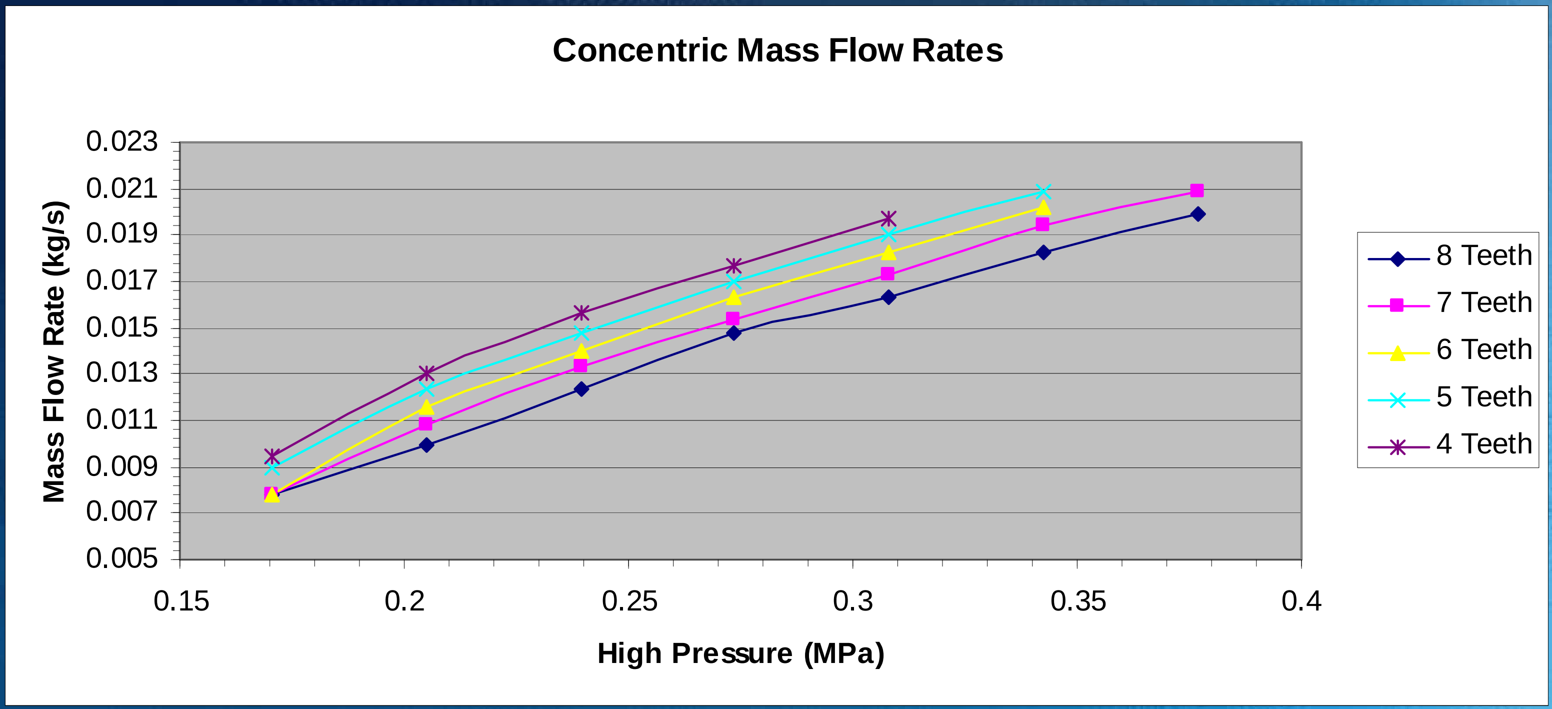
- Uses $P_L:P_e$ ratio
- Fluid properties taken from both vessel and exit conditions
- Determines mass flow rate at the test rig exit
- Relies more on property and pressure ratios

$$P_L = P_e \cdot \left(1 + \frac{\gamma - 1}{2} \cdot M^2\right)^{\frac{\gamma}{\gamma-1}}$$

$$V = M \cdot a \qquad m_{dot} = \rho A V$$

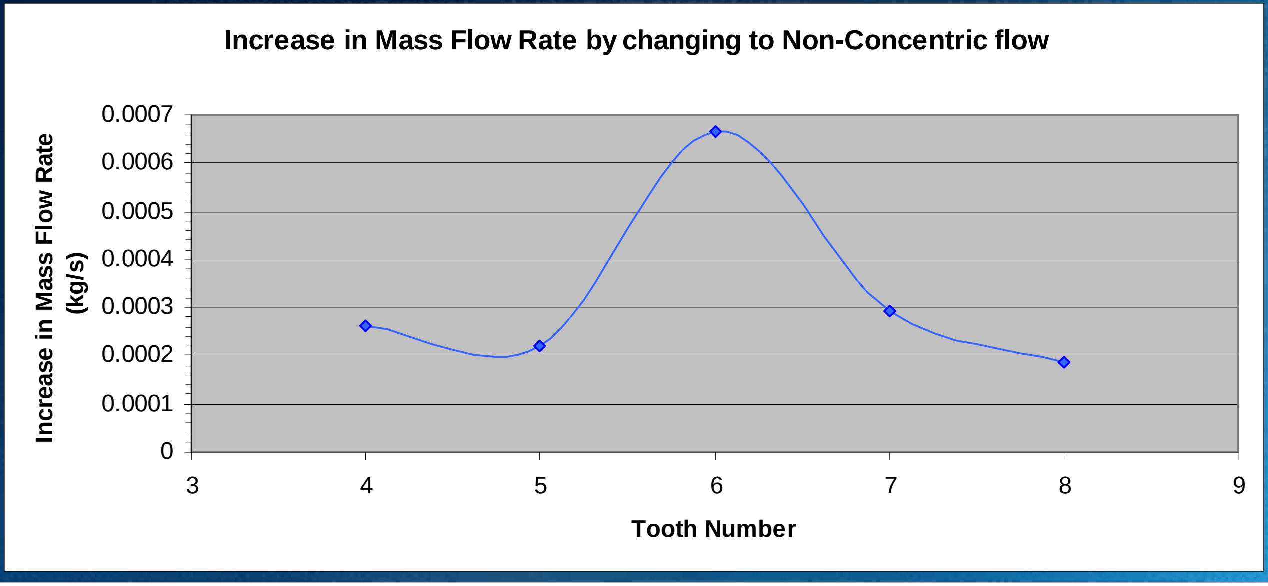
$$a = \sqrt{\gamma \cdot R \cdot T} \qquad A = \pi r^2 \qquad \rho = \frac{P}{RT}$$

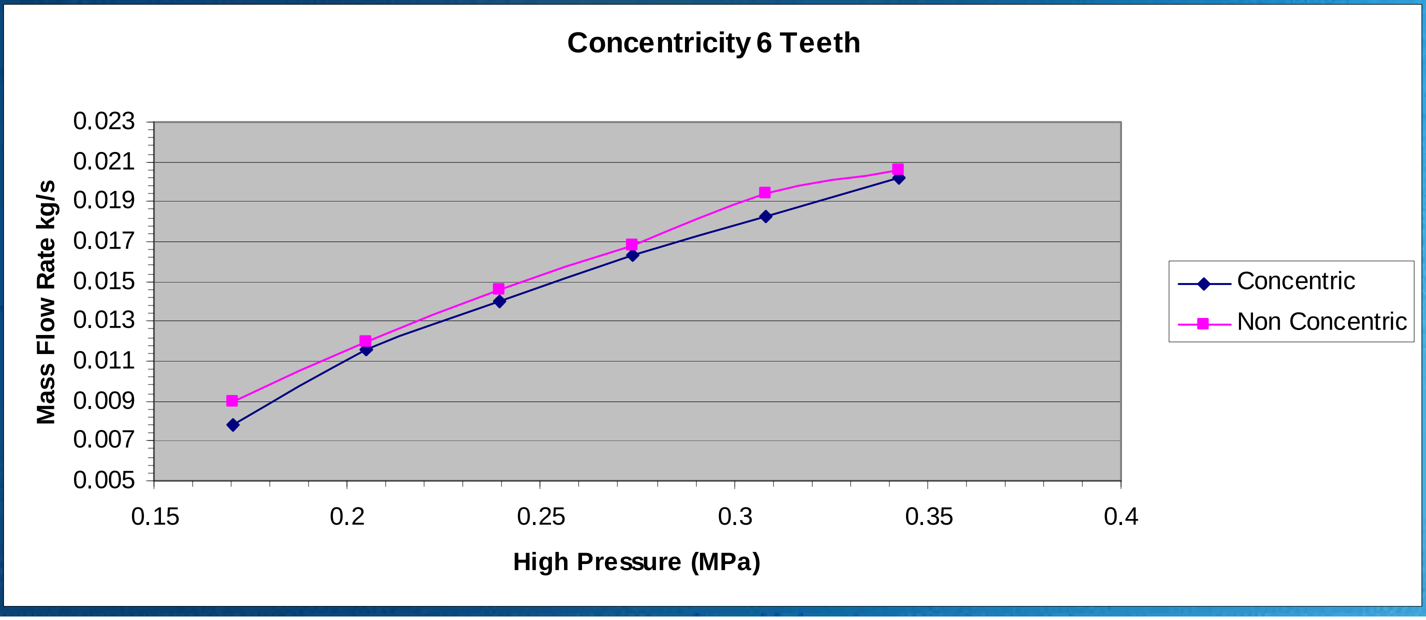
Results: Leakage due to Tooth Removal



- Removal of teeth increases the leakage through the seal
- Tooth remove has a greater impact on flow rate at higher pressures
- The increase in mass flow rate with each tooth removal is approximately equal
- The exception is the increase between 8 and 7 teeth

Results: Concentricity Analysis





Future Work

- Test more seals of different sizes
- Use more accurate instrumentation
  - High quality mass flow meter
  - More accurate pressure sensors connected to a computer
- Concentricity study
  - Use a more accurate method of moving the seal in relation to the shaft
  - Test varying degrees of concentricity
- Study the effects of shaft rotation on leakage
  - Modify the test rig so the shaft can spin at high speeds

Conclusion

- The test rig was successfully constructed and was able to provide data on the mass flow rate through a labyrinth seal
- Due to time constraints only one seal was tested
  - Teeth were manually removed from the seal so that a flow analysis could still be performed
- It was proved that removing teeth had a negative effect on the seal leakage
- Concentricity does have an impact on leakage, but it is minimal
- The total cost was: $878.12
- There are many aspects available for follow up studies

Aknowledgements

- **Danfoss – Turbocor Staff:**
  - **Jesper Nielsen**
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  - **Joost Brasz**
  - **Robert Parsons**

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  - **Dr. Chiang Shih**
  - **Dr. Daudi Waryoba**
  - **Mr. Bill Starch , Shop Supervisor at ASC, NHMFL**

? Questions ?