GAS SEAL LEAKAGE AT HIGH TEMPERATURE: A LABYRINTH SEAL AND AN ALL-METAL COMPLIANT SEAL OF SIMILAR CLEARANCES

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LEAKAGE IN ALL METAL SEAL AT HIGH TEMPERATURES
Industrial gas turbine manufacturers interested in benchmarking novel seal technologies against (traditional) labyrinth seal to realize benefits and to ensure potential gains.

- To quantify leakage of two test seals varying:
  - Supply pressure (upstream) from 1 bar to 8 bar (max)
  - Air inlet temperature from 30°C to 300°C
- To determine the effect of rotor speed in terms of leakage
Labyrinth Seal

**Advantages**

- Non-contacting
- Operates at a wide range of pressures, temperatures, and speeds
- Inexpensive

**Disadvantages**

- Leakage largely dependent on clearance
- Inevitable wear (enlarges clearances) and worsens leakage
- Long seals lead to instability i.e. large cross-coupled stiffness
Hydrostatic Advanced Low Leakage Seal

**Advantages**
- Low leakage
- Radial compliance and stiff in axial direction
- Pads generate hydrodynamic wedge separating seal from rotor (non-contacting)

**Disadvantages**
- Difficult to manufacture (EDM)
- Unproven, except for military
- Expensive
### EXPERIMENTAL FACILITY

**Maximum**

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Power</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heater</td>
<td>240 V</td>
<td>12 kW</td>
<td>300°C</td>
</tr>
<tr>
<td>Motor</td>
<td>90 V</td>
<td>850 W</td>
<td>3,000 rpm</td>
</tr>
</tbody>
</table>

**Diagram:**
- Heater
- Exhaust duct
- Air pressurization cylinder
- Test seal
- Roller bearings
- Rotor
- Flow in
- Flow out
### EXPERIMENTAL FACILITY

#### Component List

1. Tapered roller bearings  
2. Shaft  
3. Disk  
4. Pressure vessel  
5. Air inlet  
6. Motor  
7. Quill shaft  
8. Flexible coupling  
9. Test seal  
10. Metal Mesh Foil Bearing  
11. Position rods  
12. Eddy current sensors (X and Y directions)

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gas Constant</td>
<td>287 J/kg-K</td>
</tr>
<tr>
<td>Supply Pressure, $P_s$</td>
<td>101 kPa - 808 kPa</td>
</tr>
<tr>
<td>Inlet Temperature, $T_s$</td>
<td>303°K - 573°K</td>
</tr>
<tr>
<td>Exhaust Pressure, $P_a$</td>
<td>101 kPa</td>
</tr>
<tr>
<td>Ambient Temperature, $T_a$</td>
<td>303°K</td>
</tr>
</tbody>
</table>
Test rig

- Bearing assembly
- Hot air inlet ~100 psig (7 bar) max
- Support rod
- Eddy current sensors
- Support rod
- Metal mesh
- Journal
- Disk
- Test seal

- Shaft
<table>
<thead>
<tr>
<th>Seal Dimensions and Properties</th>
<th>Labyrinth Seal</th>
<th>HALO™ Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seal Material</td>
<td>4140 Steel</td>
<td>Inconel 718</td>
</tr>
<tr>
<td>Linear Coefficient of Thermal Expansion, $\alpha$</td>
<td>$11.2 \times 10^{-6}/^{\circ}C$</td>
<td>$12.0 \times 10^{-6}/^{\circ}C$</td>
</tr>
<tr>
<td>Outer Diameter, $S_{OD}$</td>
<td>183.11 mm</td>
<td>183.05 mm</td>
</tr>
<tr>
<td>Inner Diameter, $S_{ID}$ (Upstream)</td>
<td><strong>167.36 mm</strong></td>
<td><strong>167.28 mm</strong></td>
</tr>
<tr>
<td>Seal Axial Length, $l$</td>
<td>8.40 mm</td>
<td>8.48 mm</td>
</tr>
<tr>
<td>Number of Teeth</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Teeth Tip Width</td>
<td>0.17 mm</td>
<td></td>
</tr>
<tr>
<td>Number of Cavities</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Cavity Depth</td>
<td>3.0 mm</td>
<td></td>
</tr>
<tr>
<td>Number of Pads</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Pad Allowable Radial Movement</td>
<td></td>
<td>0.27 mm</td>
</tr>
<tr>
<td>Pad Axial Length, $l$</td>
<td></td>
<td>8.05 mm</td>
</tr>
<tr>
<td>Pad Arc Length (40°)</td>
<td></td>
<td>58.42 mm</td>
</tr>
<tr>
<td>Disk Material</td>
<td>4140 Steel</td>
<td>4140 Steel</td>
</tr>
<tr>
<td>Linear Coefficient of Thermal Expansion, $\alpha$</td>
<td>$11.2 \times 10^{-6}/^{\circ}C$</td>
<td>$11.2 \times 10^{-6}/^{\circ}C$</td>
</tr>
<tr>
<td>Outer Diameter, $D$</td>
<td>166.85 mm</td>
<td>166.85 mm</td>
</tr>
<tr>
<td>Disk Thickness</td>
<td>44.45 mm</td>
<td>44.45 mm</td>
</tr>
<tr>
<td>Diametral Clearance ($C_d = S_{ID} - D$)</td>
<td><strong>0.51 mm</strong></td>
<td><strong>0.43 mm</strong></td>
</tr>
<tr>
<td>Uncertainty in Lengths</td>
<td>± 0.01 mm</td>
<td>± 0.01 mm</td>
</tr>
</tbody>
</table>
Compare leakage from seals

Max. air temperature (300°C), No rotor speed
Radial clearance is 0.20 mm without a pressure differential and decreases to 0.03 mm at a pressure ratio of ~1.7
Compare flow factors

- Air temperature affects little the seals’ flow factor.
- HALO seal has low flow factor, \( \sim \frac{1}{5} \) of LS

\[
\Phi = \frac{m\sqrt{T}}{P_s D}
\]

Max. air temperature (300ºC), No rotor speed
(At low temperature <100°C) Rotor speed has negligible effect on leakage for the labyrinth seal. At 2.7 krpm, tip speed = 23.6 m/s
(At low temperature <100ºC) Rotor speed has negligible effect on leakage for the HALO seal. At 2.7 krpm, tip speed = 23.6 m/s
Measured clearance agrees well with model based on thermal expansion for a long cylindrical solid

\[ \Delta \zeta = \alpha \times \Delta T \times \zeta \]

\( \zeta \) denotes the outer diameter

\(~15\%\) Decrease
Results from XLLaby1CV agree well with the measured leakage.
CONCLUSIONS

• Flow factor $\Phi$ characterizes well the leakage of the test seals operating at high temperature (300°C) and supply pressure (~8 bar abs).

• Without rotor speed, the HALO seal shows $\frac{1}{5}$ less leakage than similarly sized labyrinth seal.

• For the labyrinth seal: rotor speed as minor effect on reducing leakage at high temperature (300°C).
THANK YOU!

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• Turbomachinery Research Consortium for funding the project.
• Advanced Technologies Group (Mr. John Justak) for donating HALO™ seal

QUESTIONS (?)

Learn more at http://rotorlab.tamu.edu