FILM RIDING LEAF SEALS
FOR IMPROVED SHAFT SEALING

Authors - Clayton M. Grondahl and James C. Dudley.
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Power for Land, Sea and Air
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CMG Tech, LLC
29 Stony Brook Drive
Rexford, NY 12148
Seal operating environment and need for a film riding seal:

A. Typical seal illustration

B. Axial view showing asymmetric seal clearance variation
FILM RIDING PRESSURE ACTUATED LEAF SEALS

Pressure Actuated Leaf Seal structure incorporated in FRPALS.

- **Stator**: cut away to show leaf seal assembly.
- **Backring**: keyed in stator.
- **Leaf Seal elements**: slotted ‘shim’ stock
  - multiple frusto-conical layers
  - wear resistant alloy.
- **Support member**: assembled with seal members and backing ring.
- **Rotor / shaft**: seal surface.

High pressure side.

Rotation

Axial direction of rotor / shaft.

Center of rotation.
Basic PALS passive closure.

- **Cold clearance - large.**
  - P1 = P2
  - Seal elements *not in* contact with support.
  - Seal rubs avoided.

- **Operating clearance - small.**
  - P1 >> P2
  - Seal elements *in* contact with support.
  - Leakage minimized, for performance gain.

- **Shutting down clearance - increasing.**
  - ∆P decreasing with RPM.
  - Seal elements *retract* from support.
  - Seal rub damage avoided.

**Large startup & shut down clearance:** Rub avoidance.

**Minimum operating clearance:** Performance gain.

**Non-contacting operation:** Long seal life.
Pressure Actuated Leaf Seal (PALS) test seal and leakage:

- Large startup & shut down clearance → rub avoidance.
- Minimum operating clearance → performance gain.
- Non-contacting operation & rub tolerance → long seal life.
FILM RIDING PRESSURE ACTUATED LEAF SEALS: Isometric view.

- Leaf Seal elements - multiple layers.
- Stator - cut away to show seal assembly.
- Backing ring - keyed in stator, weld assembled with seal members & leaf support members.
- Leaf Support Members.
- Runner positioning leaves - runner retention, parallel displacement.
- Rotor / shaft - seal surface.
- Hydrodynamic runners - Large startup clearance.

High pressure side.

Center of rotation:
FILM RIDING PRESSURE ACTUATED LEAF SEALS: Section view.

- Backing ring: keyed in stator.
- Sealing leaves.
- Hydrodynamic runners.
- P1 - High pressure side.
- Assembly welds. Leaf support members.
- Positioning leaves.
- Large cold clearance.
- Rotor / shaft - seal surface.

CMG Tech, LLC
Rexford, NY
Filming Riding Pressure Actuated Leaf Seals: Function.

**Startup:**
- P1 ~ P2
- Straight leaves.
- Large clearance.

**Normal operation:**
- P1 > P2
- Leaves deflect.
- Compliant, forces balanced.
- Small clearance, low leakage.

**Eccentric rotor:**
- P1 > P2
- Leaves deflected from support.
- Runners ride on hydrostatic/hydrodynamic film.
FILM RIDING PRESSURE ACTUATED LEAF SEALS: Components.
FILM RIDING PRESSURE ACTUATED LEAF SEALS

Seal application for hydrodynamic-hydrostatic analysis:

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<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
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</thead>
<tbody>
<tr>
<td>Rotor seal diameter</td>
<td>60.0 in.</td>
<td>1.52 m</td>
</tr>
<tr>
<td>Runner segment angle</td>
<td>18.0 deg.</td>
<td>0.314 rad</td>
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<tr>
<td>Temperature</td>
<td>1000 F</td>
<td>538 K</td>
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<tr>
<td>Speed</td>
<td>3600 RPM</td>
<td>3600 RPM</td>
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<tr>
<td>Ambient pressure</td>
<td>50.0 psig</td>
<td>345 kPa</td>
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<tr>
<td>Pressure differential</td>
<td>40.0 psi</td>
<td>276 kPa</td>
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Seal analysis goals: < 2 lbs/sec (0.91 kg/s) seal leakage, rotor centered. + / - 0.100 inches rotor eccentricity. < 50°F (28°C) temperature rise.

Film analysis by Wilbur Shapiro using NASA Industrial code GCYLT.

Seal film geometry selected to meet performance goals:

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<tr>
<td>Runner axial length</td>
<td>1.500 inch</td>
<td>38.1 mm</td>
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<tr>
<td>Inlet Rayleigh step height</td>
<td>0.010 inch</td>
<td>0.254 mm</td>
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<tr>
<td>Inlet Rayleigh step length</td>
<td>0.300 inch</td>
<td>7.62 mm</td>
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<tr>
<td>Runner inside radius</td>
<td>30.100 inch</td>
<td>0.76454 m</td>
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**FILM RIDING PRESSURE ACTUATED LEAF SEALS**

Evaluation studies:
- Hydrodynamic contribution at 3600 RPM vs 0 RPM
- Operating temperature of 1000F vs RT

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<td>20</td>
</tr>
<tr>
<td>30</td>
</tr>
</tbody>
</table>

Expect meaningful static test results at room temperature.

Additional film analysis calculations:
- cross coupled stiffness and damping coefficients,
- power loss and
- center of film force.

CMG Tech, LLC
Rexford, NY
FILM RIDING PRESSURE ACTUATED LEAF SEALS: Force analysis.

Key Design Parameters
- Assembly Clearance: 0.120 inch (3.05 mm)
- Leaf Angle from Axial: 30.0 deg (0.52 rad)
- Leaf Thickness: 0.029 inch (0.74 mm)
- Leaf Length (knee to ankle): 2.000 inch (50.8 mm)
- Arc Length of Support: 1.600 inch (40.6 mm)
- Support Radius: 4.500 inch (114 mm)

Runner conditions when rotor is centered
- Lpad: 1.500 inch (38.1 mm)
- Lstep: 0.300 inch (7.62 mm)
- Step: 0.010 inch (0.25 mm)
- HMIN: 0.010 inch (0.25 mm)
- ALPHA: -0.001 radians (ccw positive)
- LOAD: 347.7 lbf (one 18 deg pad)
- Zpi: 0.539 inch (13.7 mm)
- 360 deg Leakage: 2.280 lbm/s (1.03 kg/s)

Forces are all per inch (25.4 mm) of circumference.

CMG Tech, LLC
Rexford, NY
FILM RIDING PRESSURE ACTUATED LEAF SEALS: Clearance vs Eccentricity.

- Clearance between rotor and seal runner:
  - 0.1 inches rotor toward stator.
  - 0.003 in. Clearance.
  - 0.017 in. Clearance.
  - 0.010 in. Clearance.

- Seal runner radial deflection:
  - Toward rotor.
FILM RIDING PRESSURE ACTUATED LEAF SEALS: Clearance vs Eccentricity.

- Clearance: 0.003 In., 0.017 In., 0.010 In.

- Displacement Y Component:
  - 0.1 In.
  - 0
  - -0.1 In.

- Time: 1 s
- Time Step: 200 of 1400
- Maximum Value: 0.12 In.
- Minimum Value: -0.00376432 In.

CMG Tech, LLC
Rexford, NY
Design analysis results:

1. Practical seal runner geometry: adequate hydrostatic load capacity.

2. Static seal leaf and hydrostatic film force analysis:
   • Reduced seal leakage at 0.010 inch nominal clearance.
   • Non-contacting at rotor eccentricity of 0.100 inches.
   • Compliant seal clearance vs. rotor eccentricity:

<table>
<thead>
<tr>
<th>Eccentricity, inches</th>
<th>-0.100</th>
<th>0.000</th>
<th>+0.100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seal clearance, inches</td>
<td>0.017</td>
<td>0.010</td>
<td>0.003</td>
</tr>
</tbody>
</table>
Seal Development Plans:

1. Full-scale 2-D static test:
   • Confirm 2-D seal leaf actuation and runner translation with pressure.
   • Measure clearance over range of ‘eccentricities’.
   • Measure runner film pressure vs. axial position.
   • Measure seal leakage.
   • Acoustic monitoring for dynamic activity.
   • **Validate predictive seal design tools & methodology.**

2. Full-scale 3-D segment static test:
   • Confirm 3-D seal actuation and runner translation with pressure.
   • Measure clearance over range of ‘eccentricities’.
   • Measure seal leakage.
   • Measure dynamic activity
   • **Demonstrate 3-D seal operability and reduced leakage.**

3. Sub-scale rotating rig seal testing:
   • Measure multi-segment leakage.
   • **Evaluate dynamic performance.**
2-D Test Rig Sketch to Measure FRPALS Runner Pressure Distribution.

- **FRPALS - runner section.**
- **Runner attitude adjustment.**
- **Translation screw.**
- **Base, alum ~22” long, tapered shoulders and pressure tap.**
- **Pressure tap 0.012 in. dia. at surface.**
- **Tapper on both base and sides for ~ 0.005 in. height change per in. of horizontal movement of sides.**
- **Side plates, brass, ~ 11” long, tapered bottom, attached end yoke.**
2-D Test Rig For Film Riding PALS Runner Pressure Distribution Measurement.

Bench test – arrangement of 2-D FRPALS modification, pressure transducers, flow meter (background) and NI USB data acquisition with NI Signal Express software.

A closer look at 2-D FRPALS tapered slide to lift the runner, translation screws and pressure transducers.

Lead screw to translate the tapered lift (0.005 inch lift per inch of translation).

Lead screw to translate the runner (0.050 in per turn of ¼-20 thread.).
FILM RIDING PRESSURE ACTUATED LEAF SEALS

Bench Test Comparison with GCYLT

Bench Test on 4/9/2014 with 6 mil

Summary Results

<table>
<thead>
<tr>
<th>Force/inch width</th>
<th>Center of Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.4 lbf/in</td>
<td>0.429 in</td>
</tr>
</tbody>
</table>

Bench Test (11-point moving average)
Design evaluation conclusions:

- Feasibility established.
- Continue development.

Reduced leakage → superior performance.
Rub avoidance → sustained performance.
Compliant seal → design for performance.