Overview of Turbine Seal Testing at GRC

Margaret P. Proctor & Irebert R. Delgado
NASA Glenn Research Center & U.S. Army Research Laboratory

Contributors
J. Flowers, Army; B. Steinetz, Jay Oswald, CWRU

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Turbomachinery Seal Development Objectives

• Evaluate feasibility of advanced seal concepts and materials of meeting next generation engine speed and temperature requirements.

• Provide a state-of-the-art turbomachinery seal test rig capable of testing seals under known and anticipated design conditions.

• Work with industry to assess and demonstrate performance of their seals prior to test in engine.
Improved Non-contacting Finger Seal

- **Pressure forces causes seal to lift preventing contact.**
- **Small clearances promote low leakage.**
- **Structural and fluid analysis being used to determine the design geometry and performance.**

**Features**

- **Standard upstream fingers**
  Intentional small clearance with rotor prevents upstream finger wear.
- **Lift pads only on downstream side**
  Hydrostatic pressure may be adequate to provide lift. Lift grooves, which generate hydrodynamic lift during shaft rotation may be removed based on test results.
- **Pressure forces causes seal to lift preventing contact.**
- **Small clearances promote low leakage.**
- **Structural and fluid analysis being used to determine the design geometry and performance.**
Objective:
Develop non-contacting finger seal to overcome finger element wear and heat generation for future turbine engine systems

Approach:
• Solid modeling for finger and pad motion/stresses
• Fluid/solid interaction for leakage evaluation
• Experimental verification

Status:
• Developed a simplified spring-mass-damper model to assess seal’s dynamic response.
• CFD-ACE+ (3-D Navier-Stokes code) utilized to analyze the thermofluid behavior and to obtain stiffness and damping parameters.
• First prototype built: Testing underway

Program:
NASA/Univ. of Akron Coop. Agreement:
Dr. Braun (U. of Akron) M. Proctor, Monitor
Finger Seal Equivalent Model for Dynamic Simulation – 2-DOF

Solid model and Equivalent Spring-Mass-Spring/Damper representation for use in the equation of motion simulation

Fixed positions due to anchoring to the torroidal root

Fluid layer equivalent Spring + Damper
High Temperature Turbomachinery Seal Test Rig

- Test rig is designed to test at speeds and temperatures envisioned for next generation commercial and military turbine engines.
- Test rig is one-of-a-kind. More capable than any known test rig in existence at either engine manufacturers or seal vendors.
- Temperature  Room temperature thru 1500 °F
- Surface speed  1500 fps at 40,455 rpm, 1600 fps at 43,140 rpm
- Seal diameter  8.5” design; 8.308 in. design; other near sizes possible
- Seal types  Air seals: brush, finger, labyrinth, film riding rim seals
- Seal pressure  250 psig maximum, reduced by current air heater
  - Current air heater flange limited to 125 psig at 1500 °F
  - New Air Heater capable of 250 psig to be installed this spring
- Motor drive  60 hp (60,000 rpm) Barbour Stockwell Air Turbine with advanced digital control for high accuracy/control
Test Parameters

• Seal flow vs. pressure, speed, temperature
  (Both test rig and test seal are heavily instrumented)

• Seal performance vs. simulated ramp cycles using new digital air
  turbine speed controller. Multiple speed step mission profile
  capabilities

• Seal durability vs. once-per-rev rotor runout condition

• Seal durability for prescribed seal offset condition (e.g. 3 mil seal
  offset)

• Accelerated life tests

• Seal and coating wear
Rig Features Unique Measurement Systems

Calibrated Optical Pyrometer
Rotor Rim & Seal Temperature

Mirror

Pyrometer "Light Tube"
(sapphire windows)

Test Seal

1500 °F Capacitance Probe

Monitor Relative Movement Function of Speed, Rotor Temp, Seal Holder Temp

Rotation
Torquemeter

- Installed between rig and air turbine
- Torquetronic model ET10MS
  - Maximum torque rating of 22 Nm (16 ft-lb)
  - Maximum speed of 50,000 rpm
  - Absolute accuracy of 0.13%
    - 0.029 Nm or 0.021 ft-lb
    - 0.032 Hp
- Phase shift principle
  - Circumferential coil in stator ring provides toroidal flux path
  - Toothed shaft – teeth generate sinusoidal signals in stationary coils, whose phase displacement is directly proportional to shaft twist and hence torque.
High-Temperature, High-Speed Turbine Seal Rig

- Torque-meter housing
- Balance piston housing
- Bypass line
- Test section
- Seal exhaust line
- Seal supply line

Turbine
Test Rig Status - Key Accomplishments

• Achieved 1200 °F at the seal inlet.

• Determined tare torque
  • at ambient conditions up to 34,400 rpm.
  • at 650, 800, 1000, 1200 °F up to 32,500 rpm.

• Checkout tests w/ brush seal conducted at ambient, 600, 800, 1000 °F.

• Tested of Honeywell’s finger seal up to 1200 fps, 1200 °F, and 75 psid. (AIAA-2002-3793, NASA/TM--2002-211589, ARL-TR-2781)

• Conducted static testing with highly instrumented rotor.

• Tested 4-knife labyrinth seal for baseline comparisons.

• Tested 3 new seal concepts for 2 small businesses.
Open issues:

• Rotordynamic instabilities limit max speed to 32,500 rpm.

  Planned action: Install redesigned squeeze film dampers and check rotordynamic performance.

• Rig operating temperature and pressure is limited by current air heater.

  Planned action: Install new air heater and upgrade hot piping and insulation.
## Current Schedule

<table>
<thead>
<tr>
<th>Activity</th>
<th>Dates</th>
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<tbody>
<tr>
<td>Test Arora’s non-contacting seals</td>
<td>Oct 04-Mar 05</td>
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<tr>
<td>Cylindrical Seal Baseline Tests</td>
<td>March 2005</td>
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<tr>
<td>Install redesigned dampers</td>
<td>March-April 2005</td>
</tr>
<tr>
<td>Install new air heater</td>
<td>April-July 2005</td>
</tr>
<tr>
<td>Test Non-contacting Seals:</td>
<td></td>
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<tr>
<td>NASA’s Improved NC Finger Seal</td>
<td>Aug-Sep 2005</td>
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<tr>
<td>U. of Akron</td>
<td>Aug-Sep 2005</td>
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Summary Points

- Current research focuses on non-contacting seal designs.
- NASA/Army research team collaborates with industry.
- State-of-the-art turbine seal test stand is operational.
  - Unique combinations of high speed, high pressure, and high temperature
- Upgraded test facility has
  - Improved heater temperature and pressure capability
  - Improved speed control with Barbour Stockwell air turbine motor/controller
  - Test control through Modicon PLC
  - Torquemeter
- Test stand and facility is an asset to the U.S. Engine/Seal Community.
  - 1st customer was Honeywell for JTAGG III Engine Seal Program
  - Non-contacting seal designs for SEC program
  - Mohawk’s Foil Seal
  - Arora’s hot seal designs for TBCC’s Revolutionary Turbine Accelerator