Advanced Sealing Technology for Hydrogen Compressors

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Mohawk Innovative Technology, Inc.
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Project ID #
PD060

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Overview

Timeline

- Start 15 Aug 2008
- End 14 Feb 2011
- 98 Percent Complete

Budget

- Total proposed project funding
  - $743,000 DOE SBIR
  - $0 (SBIR – No Cost Share)
- $372,300 FY08 Funding
- $370,600 FY09 Funding

Barriers

- Hydrogen Delivery Compressor
  - Reliability
  - System Cost
  - H_2 Leakage
  - Contamination
  - Non-Contact

Partners

- Lead: Mohawk Innovative Technology, Inc. (MiTi)

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Relevance

Objective:

- *Develop and demonstrate feasibility of using a close clearance, **non-contacting**, and dynamic **compliant foil seal** for hydrogen and/or natural gas pipeline compressors.*
- **Hydrogen Compressor Requirements:**
  - **Flow to 1,000,000 kg/day**
  - **Pressure rise from 300-500 up to 1,200-1,500 psig**
  - **Contaminant-Free/Oil-Free**

Category	2005 Status	FY2012	Project Target FY2017
Reliability	Low	Improved	High
Energy Efficiency	98%	98%	>98%
Leakage	Undefined	TBD	< 5%
Maintenance (% of Total Capital Investment)	10%	7%	3%
Contamination	Varies by Design		None

Approach

- Design full-scale foil seal: 2.5” diameter and differential pressure to 250 psig
- Perform testing in Air and Helium without shaft rotation to validate design
- Revise design if necessary and fabricate final full-scale foil seal
- Test seals under dynamic conditions at speed up to 60,000 rpm with Air and Helium
- Demonstrate gas sealing capability for specified requirements of hydrogen pipeline delivery compressor

Project Milestones

Month/Year	Milestone
Jan/09	Preliminary Seal Testing
May/09	Design of Advanced Foil Seal and Dynamic Test Rig
Aug/09	Fabrication of Seal and Test Rig
Feb/10	Seal Dynamic Testing at Speed up to 60,000 rpm
June/10	Improve Seal Design and Test
May/11	Final Report

FY 11 **DOE Milestone:** Down select novel compression technology for hydrogen delivery – Centrifugal Compressor

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Technical Accomplishment

Seal Selection

- Types Considered
  - Labyrinth
  - Brush
  - Honeycomb
  - Abradable
  - **Advanced Compliant Foil Seal Concept**

- Requirements
  - Novel Configuration and Concept
  - Low Leakage
    - Tight Clearance
    - High Differential Pressure
    - Conformal to Runner Surface
  - Long Wear Life
  - No Contamination and Wear Debris
  - Material Compatibility with Hydrogen

Low leakage, non-contact, high-speed sealing is a critical requirement for centrifugal hydrogen compressor.

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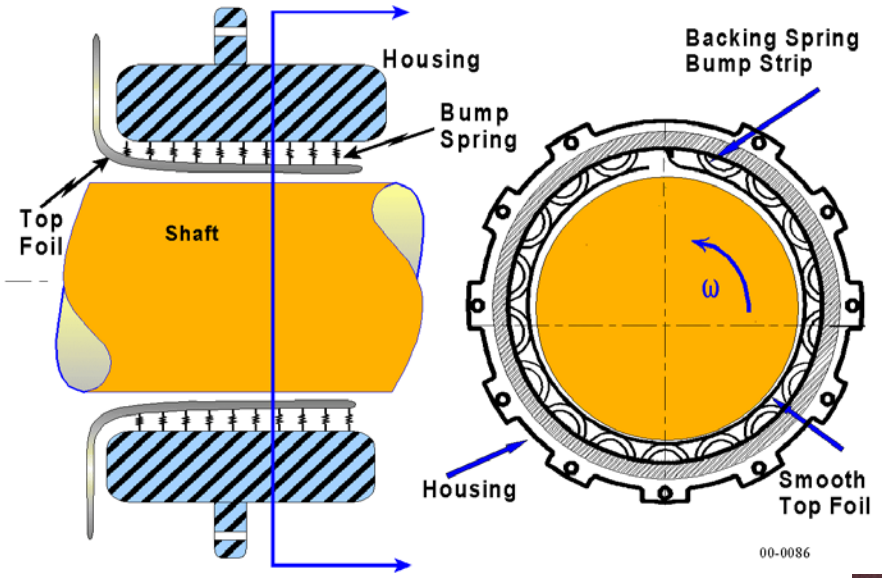
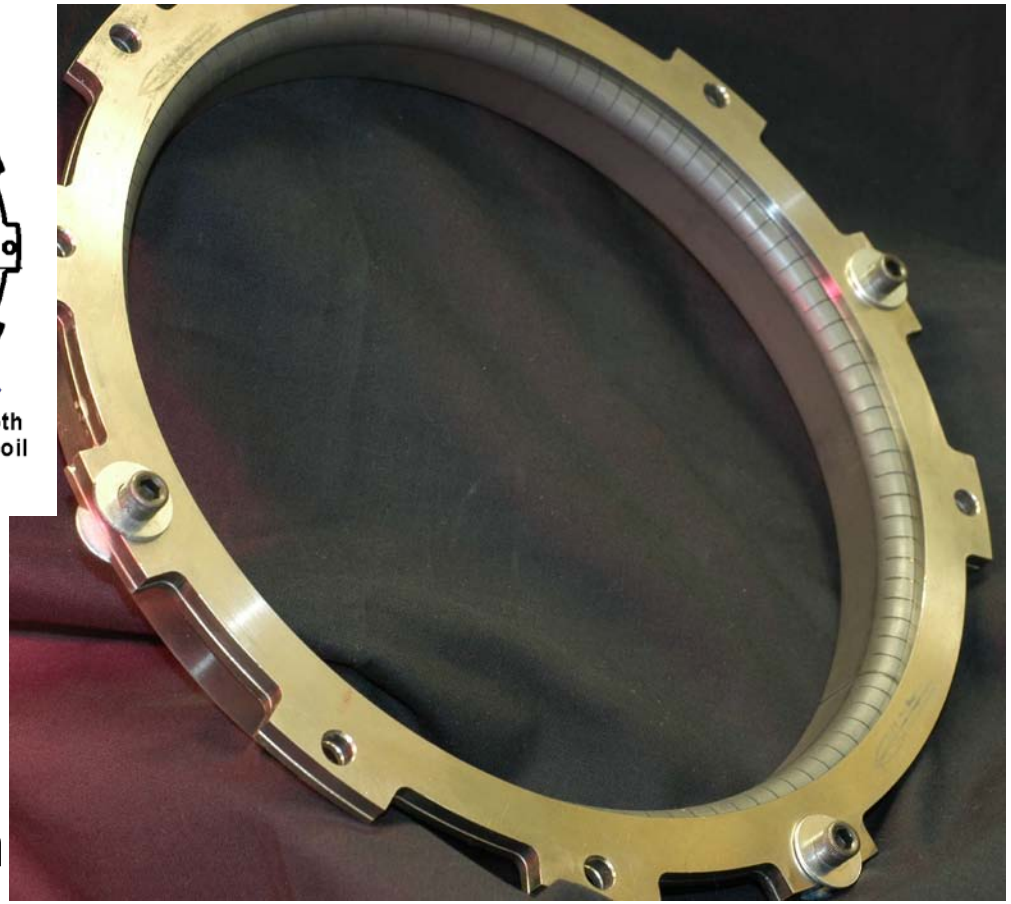
Foil Seal Concept





Φ 8.5” Radial Foil Seal Developed at MiTi and Performance Independently Verified at NASA to 30 krpm

US Patent: 6505837 Compliant Foil Seal

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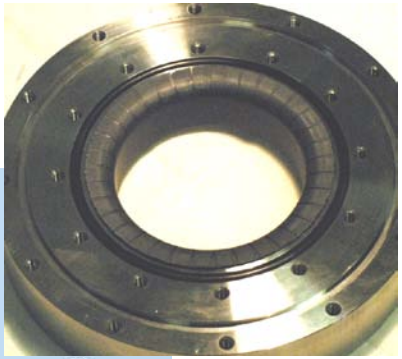
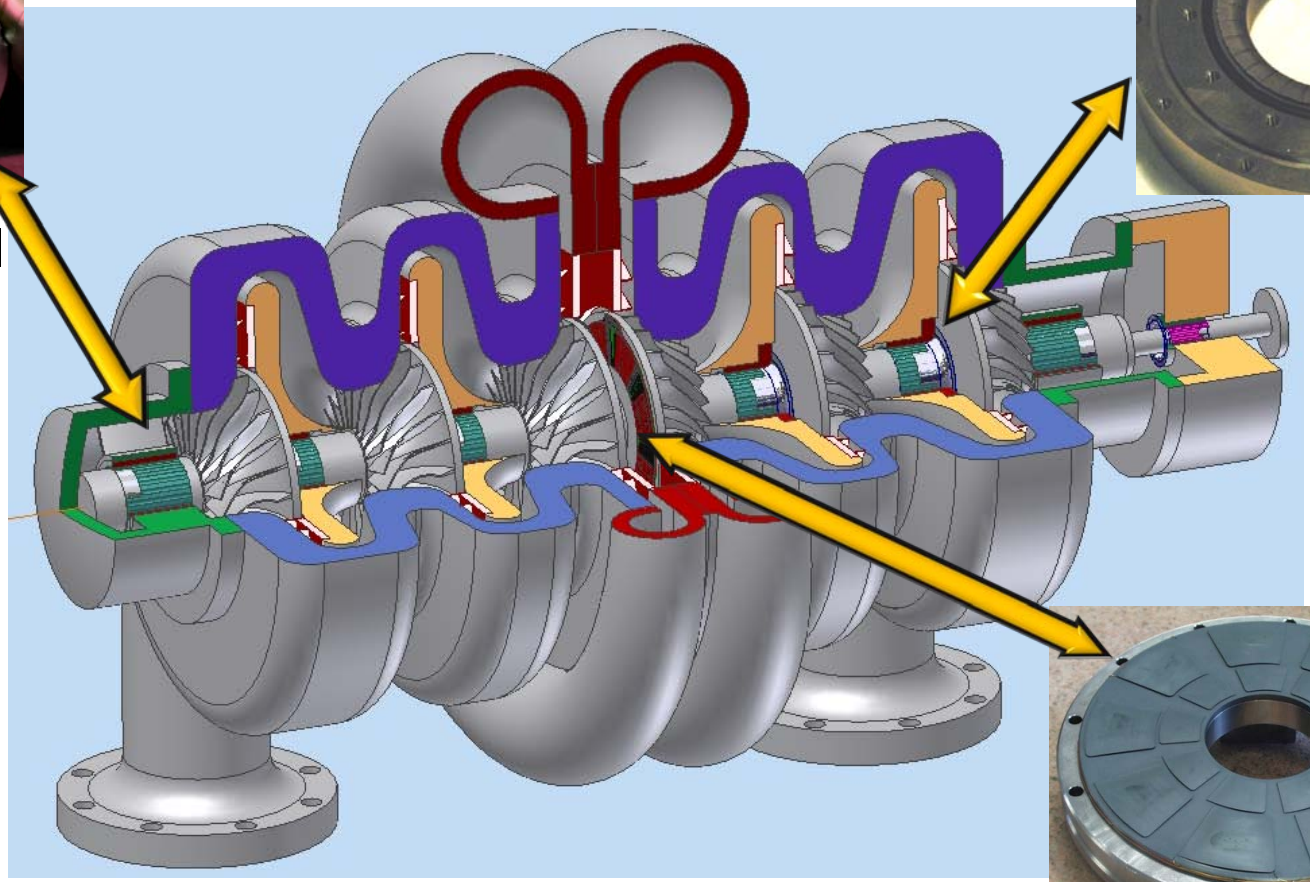
Hydrogen Compressor with Foil Bearings & Seals

Foil Journal Bearing

Radial Foil Seal





Foil Thrust Bearing

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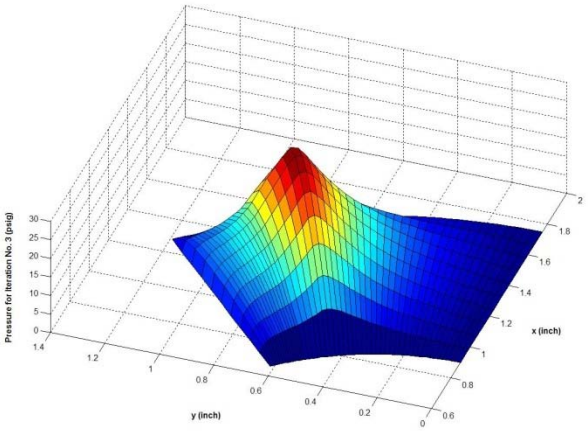
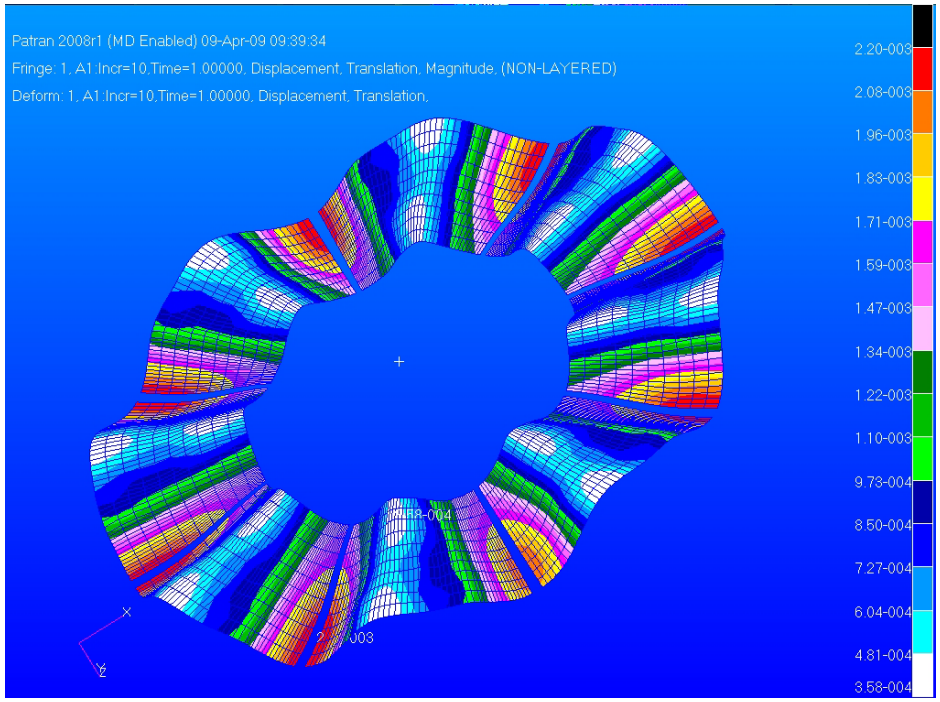
Foil Seal Design Methodology Applied to Axial Seal - Coupled FDA and FEA

- Compute gas film pressure with MiTi Elastohydrodynamic Software



Typical Hydrodynamic Pressure Profile over a Foil Seal Segment

- Compute seal deformation as a function of gas film pressure



Typical Elastic Deformation of Foil Seal

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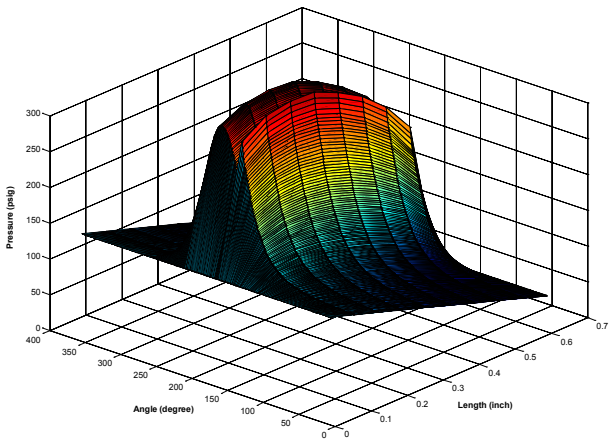
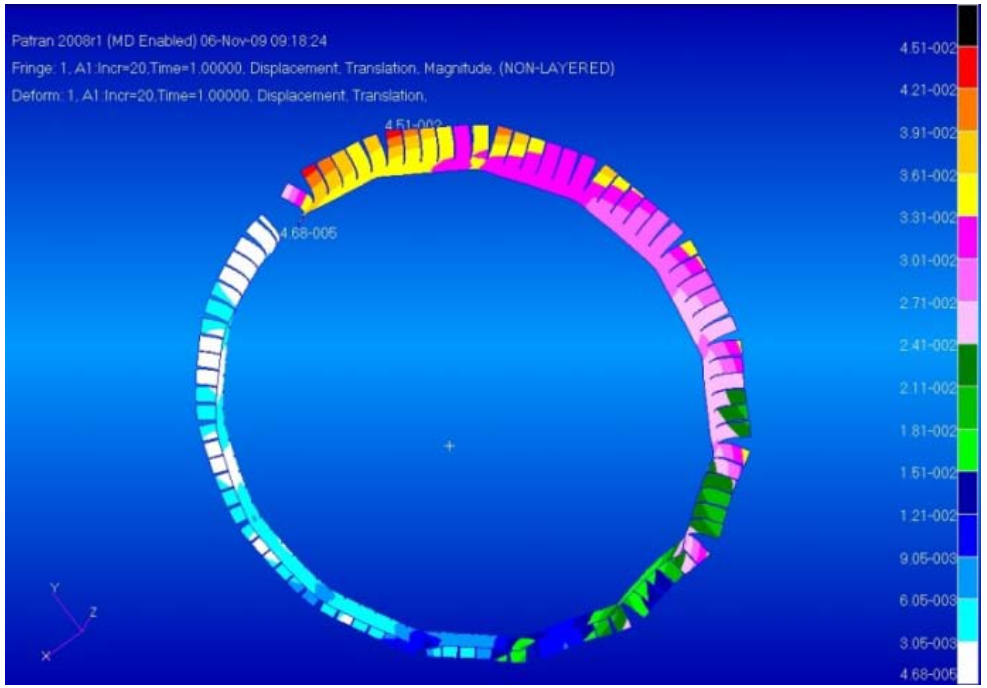
Foil Seal Design Methodology Applied to Radial Seal – Model & Analysis



Typical Hydrodynamic & Hydrostatic Pressure Applied to Foil Seal Surface



Typical Elastic Deformation of Foil Seal

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Performance of Foil Seal in Air, He & H2

- Seal performance gauged by flow factor:

$$\psi_{Air} = \frac{\dot{m}\sqrt{T}}{P_u D}$$

$\dot{m} = mass\ flow\ rate\ (lbm/\sec)$

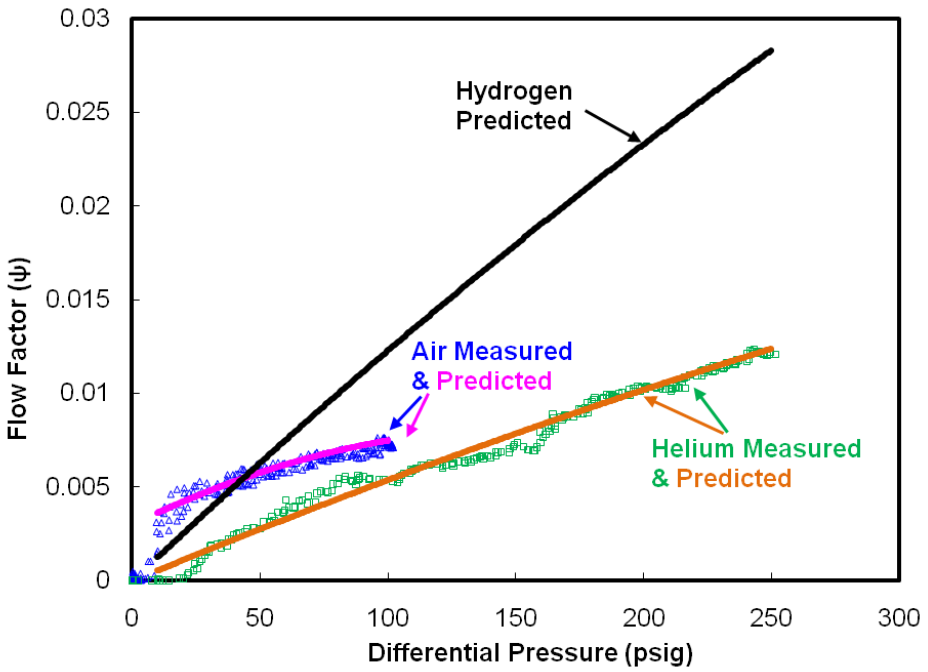
$T = Average\ Upstream\ Temperature\ (R)$

$P_u = Average\ Upstream\ Pressure\ (psia)$

$D = Seal\ Diameter\ (in)$

- Standard ψ is for Air, correction is needed for Helium:

$$\psi_{He} = \frac{\dot{m}\sqrt{T\left(\Re_{He}/\Re_{Air}\right)}}{P_u D}$$



- **Measured and Predicted Flow Factor for Air and Helium**
- **Verified Prediction for Hydrogen**

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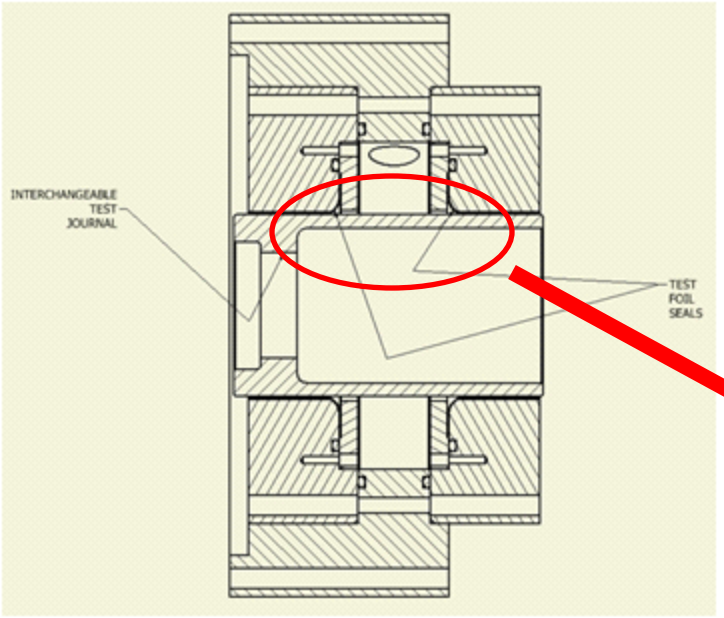
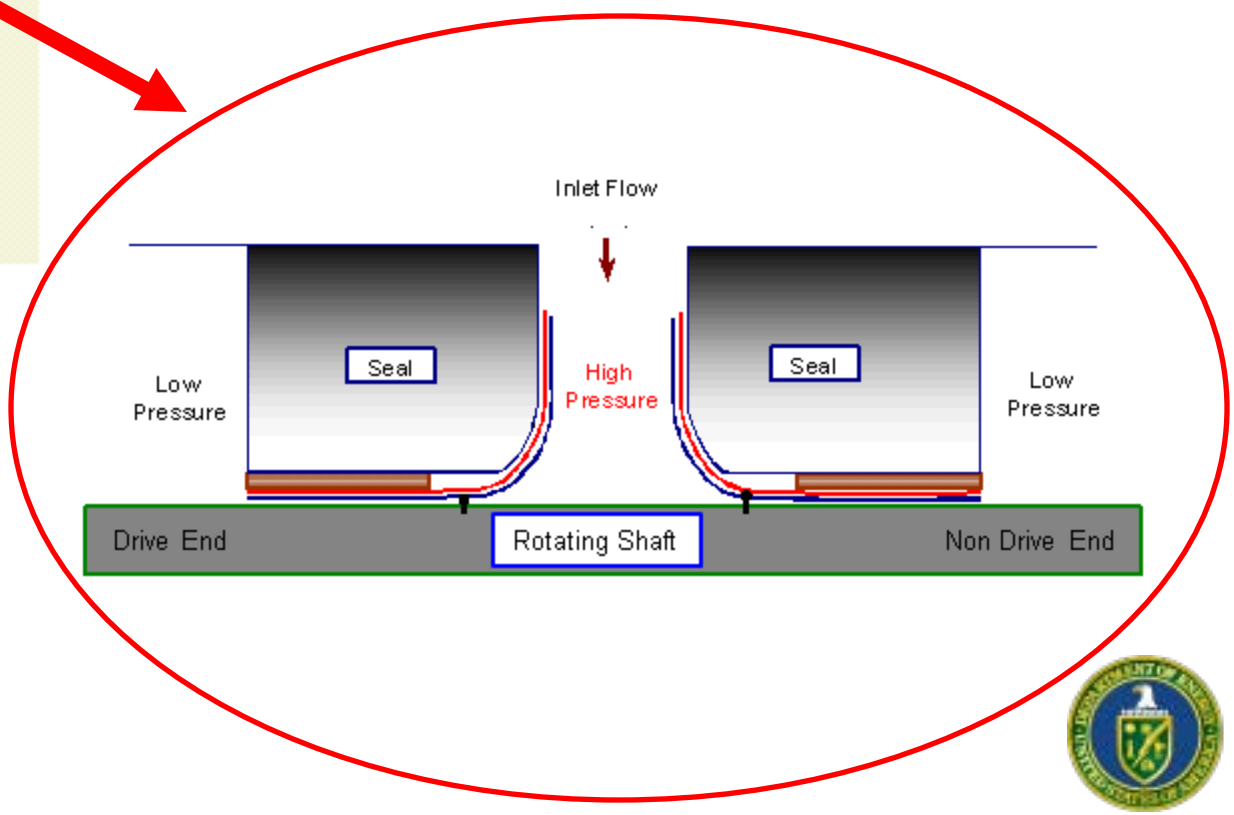
High-Speed Seal Testing



Location of Radial Seals in High Speed Test Rig

Schematic of Radial Seal Cavity



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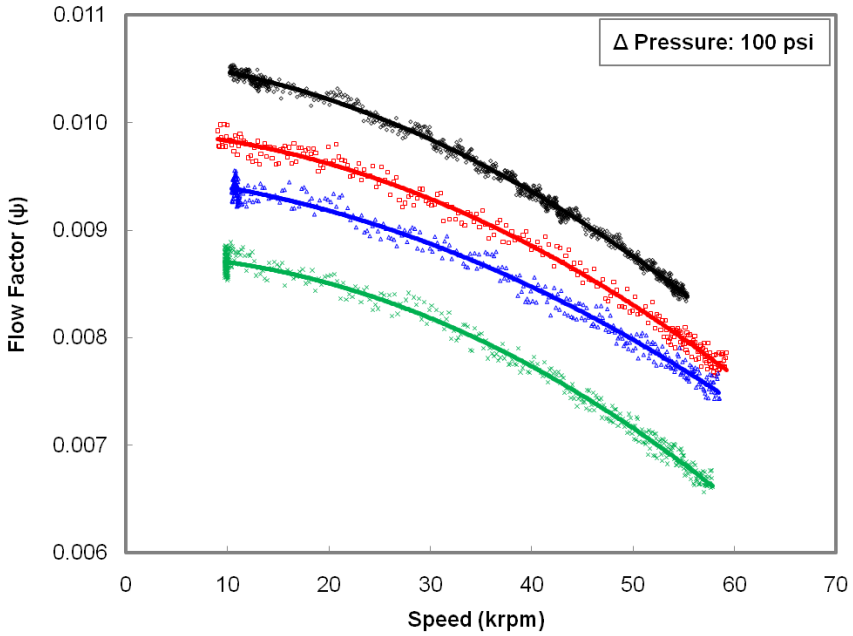
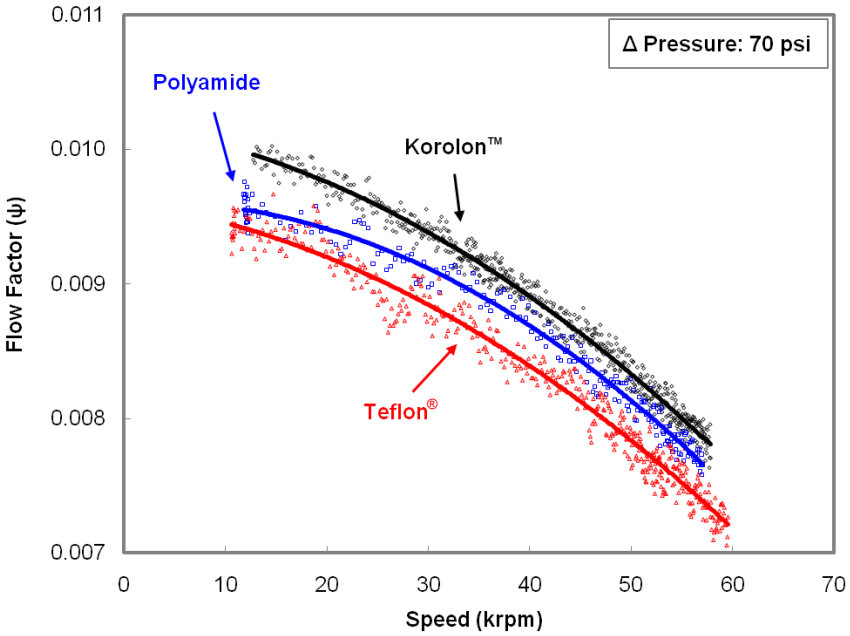
Seal Performance in Air up to 60,000 rpm



Seal Performance as a Function of Speed for Different Seal Configurations



Effect of Different Solid Coatings on Seal Performance

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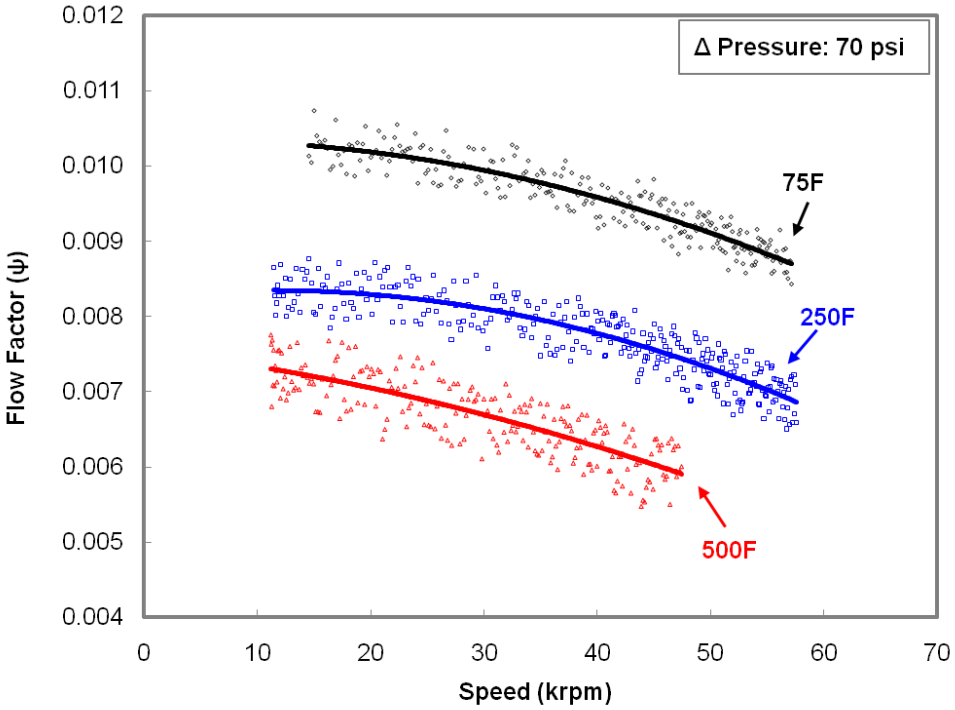
Seal Performance in Helium up to 60,000 rpm



Foil Seal Performance Improves with Temperature and Speed.

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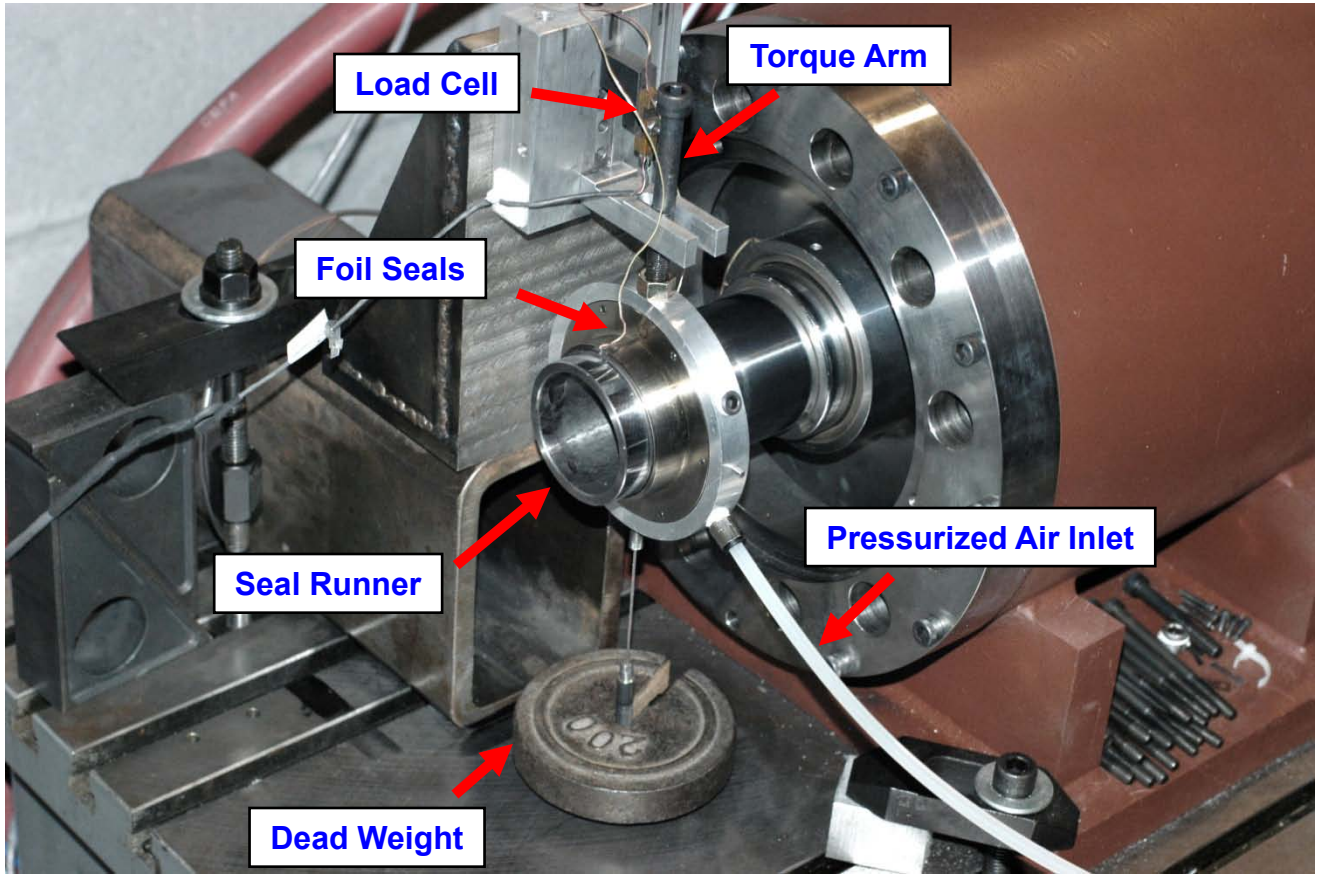
Seal Performance Testing During Start/Stop Operation

- Testing Conducted to Optimize Seal Length
- Test for Rotor Excursion:
  - Side Load Applied
  - Speed Increased
  - Δ Pressure Established
  - Friction Force Measured



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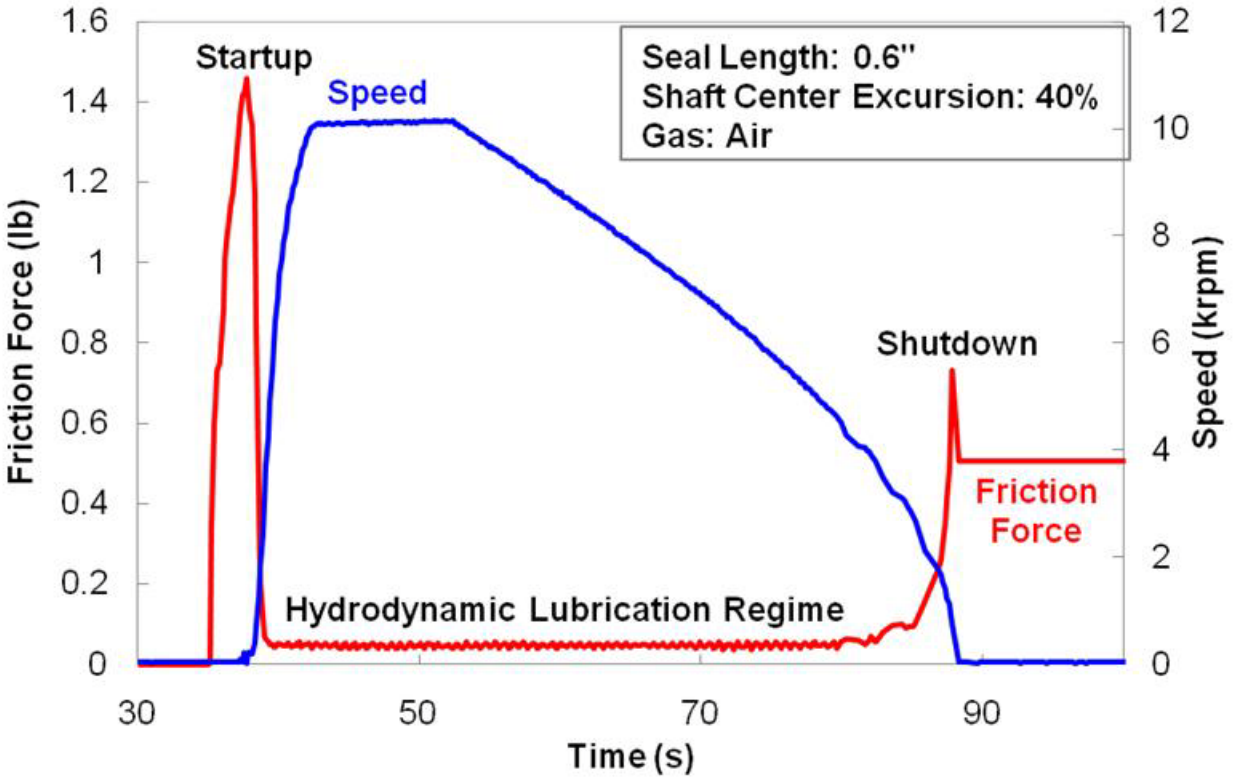
Typical Start/Stop Performance Data



Hydrodynamic film established rapidly as shown by drastic drop in friction.

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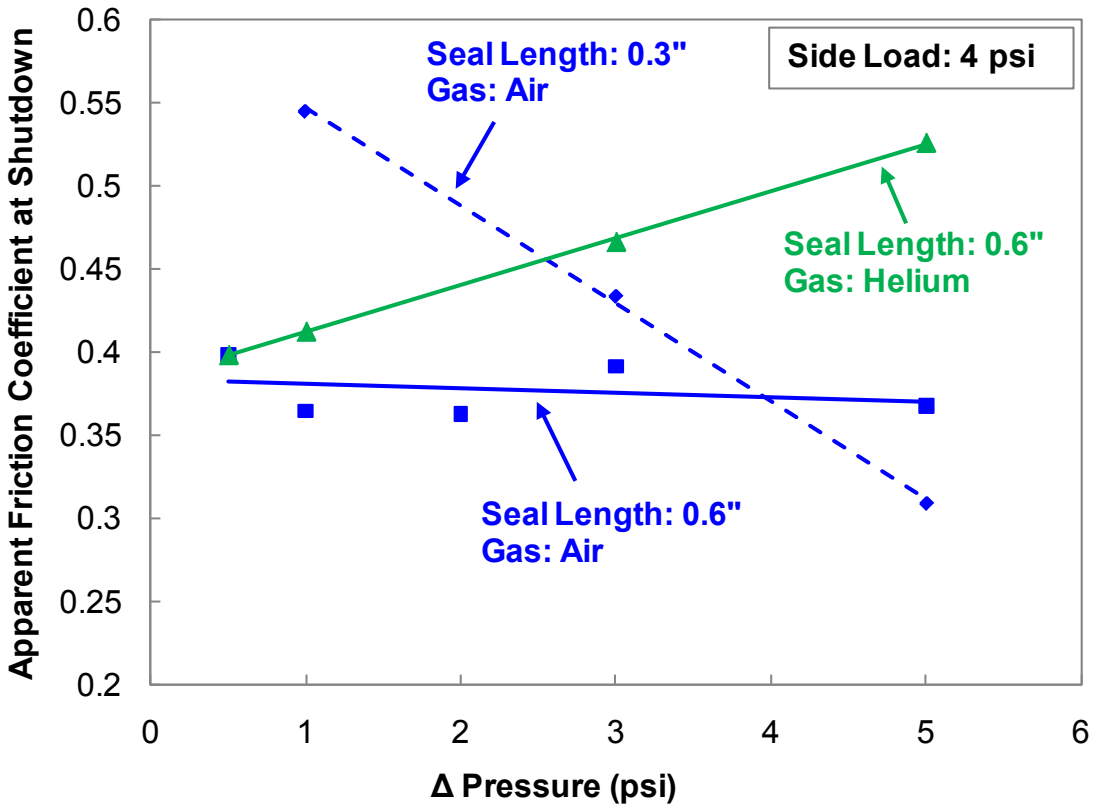
Optimization of Seal Length



Smaller seal length provides lower friction coefficient at high seal differential pressures.

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Future Work

- **Implementation and testing of advanced foil seals in hydrogen centrifugal compressor will be evaluated in a separate program.**

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Project Summary

- Novel Foil Seals Designed and Developed to Meet Hydrogen Compressor Requirements
- Seal Design Analysis Methodology Developed
- Seal Performance Testing Completed
- Compliant Foil Seal Operation Demonstrated
  - Non-Contact, Close Clearance Film Riding Seal Operation
  - Testing at ΔPressure above 200 psig Successfully Completed
  - Effects of Temperature, Speed, Solid Coating, Seal Configuration Determined
  - Performance Substantially Better Than Conventional Seals
- Start/Stop Testing Indicated Shorter Seal Performs Better and Occupies Smaller Space

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