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 Aug 2010
- 96 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

Partners

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

Relevance

Objective:

- *Develop and demonstrate feasibility of using a close clearance, **non-contacting**, and dynamic **compliant foil seal** in hydrogen and/or natural gas pipeline compressors.*
  - **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

- Revise the full-scale seal design from Phase I: full size 2.5” diameter, differential pressures to 250 psig
- Perform additional static testing in air and He to validate the design
- Fabricate the final full-scale design
- Test seals under dynamic conditions (up to 60,000 rpm and 100 psi in air, 250 psi in He)
- Demonstrate that performance capability meets the specified needs of a hydrogen transportation and delivery compressor

Project Milestones

Month/Year	Milestone or Go/No-Go Decision
Jan/09	**Project Milestone:** Preliminary Seal Testing
May/09	**Project Milestone:** Seal and Dynamic Test Rig Design
Aug/09	**Project Milestone:** Seal and Test Rig Fabrication
Feb/10	**Project Milestone:** Seal Dynamic Testing
June/10	**Project Milestone:** Update Seal Design

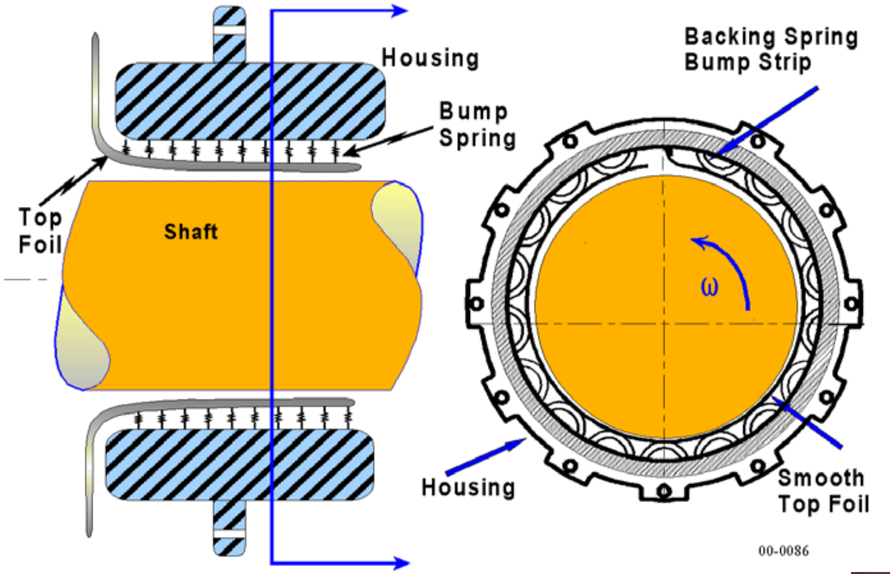
Oct/10	**DOE Milestone:** Down select novel compression technology for hydrogen delivery

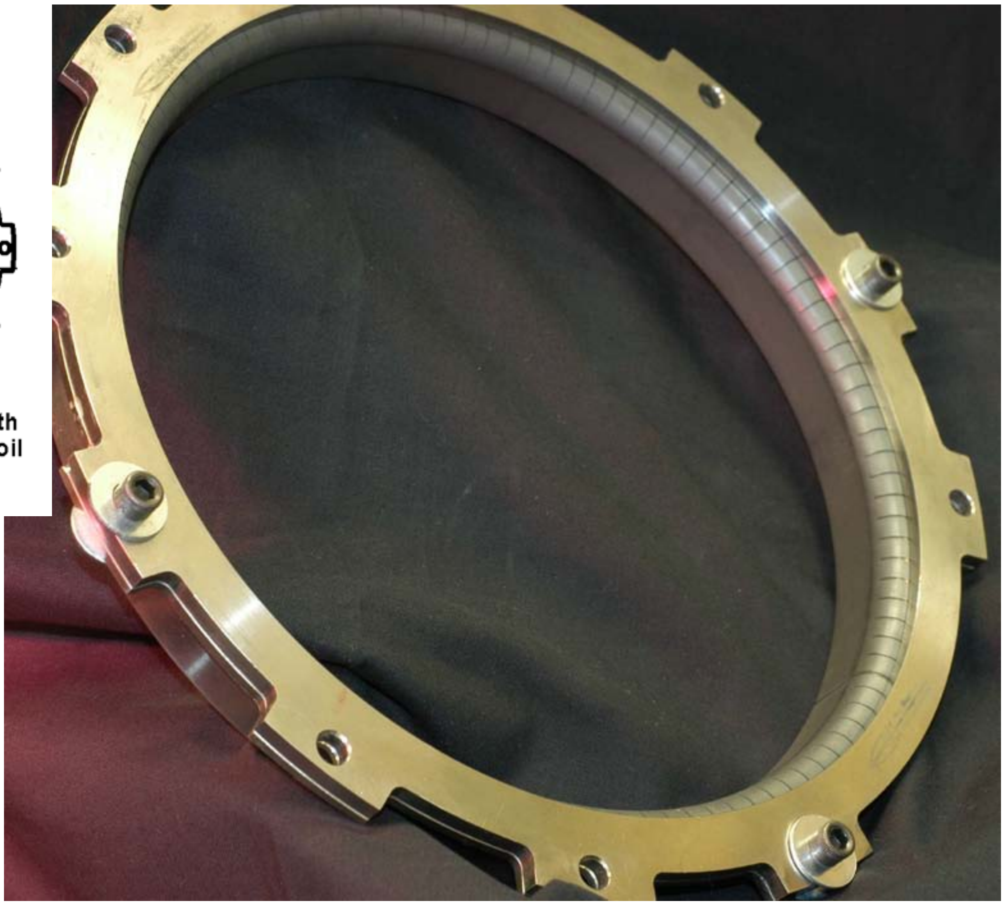
Technical Accomplishment

Seal Selection

- Types Considered
  - Labyrinth
  - Brush
  - Honeycomb
  - Abradable
  - **Dynamic Compliant Foil**
- Issues
  - Leakage
    - Clearance
    - Differential Pressure
  - Wear Life and Debris
  - Material Compatibility

Foil Seal Concept





8.5" Foil Seal Developed at MiTi and Independently Verified at NASA to 30,000 rpm

US Patent: 6505837 Compliant Foil Seal

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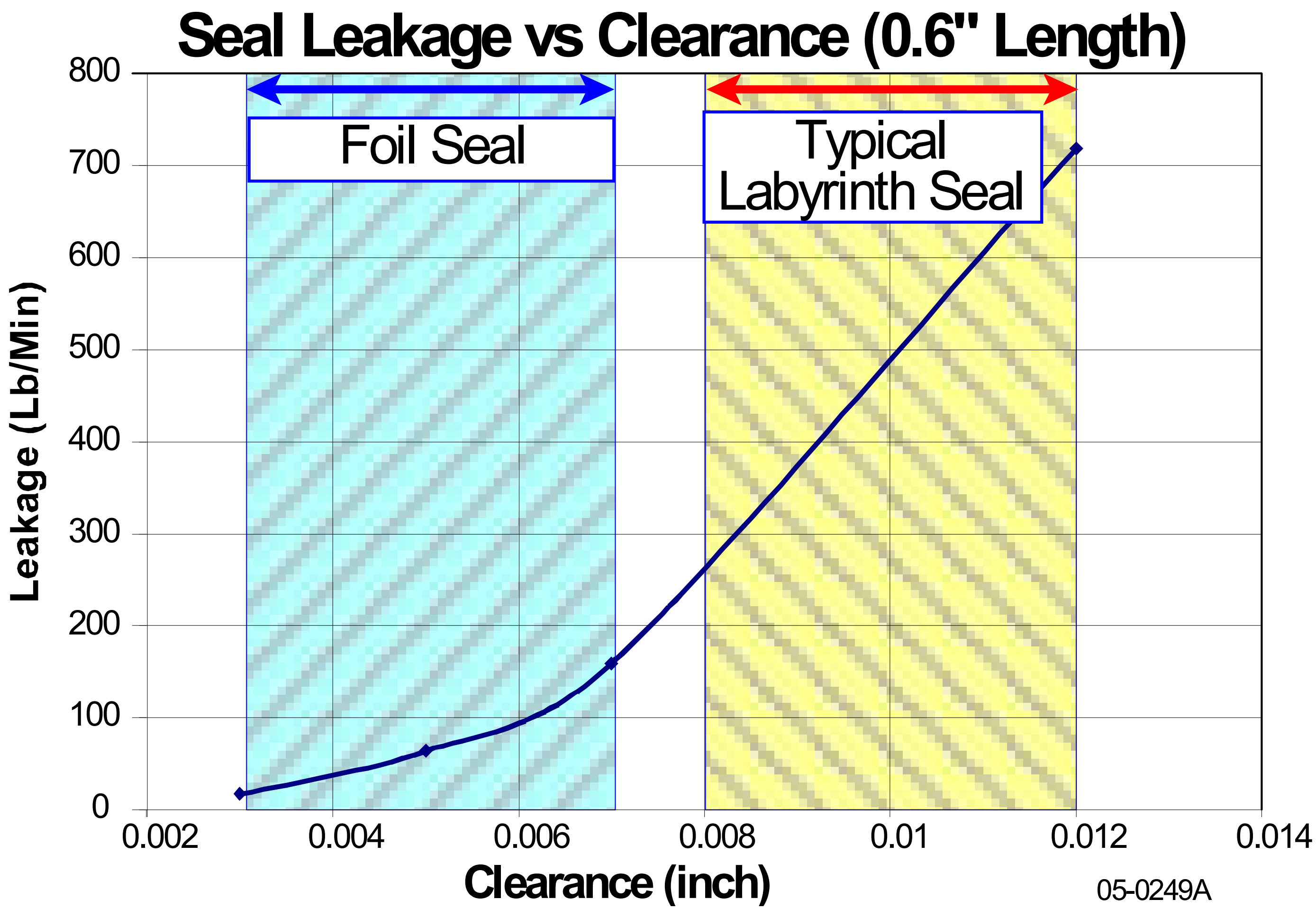
Foil & Labyrinth Seal Comparisons



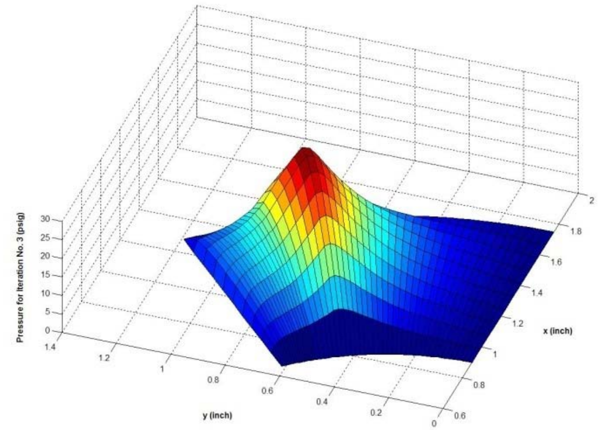
Impact of Seal Design For H_2

- Dynamic Compliant Foil Seal
  - Non contact, small clearance and compliant structure
  - Seal Design Parameters:
    - Differential Pressure Across Seal: 80-250 psig
    - Total Leakage = 13 to 30 lb/min
    - Leakage <= 2% of Total Compressor Flow

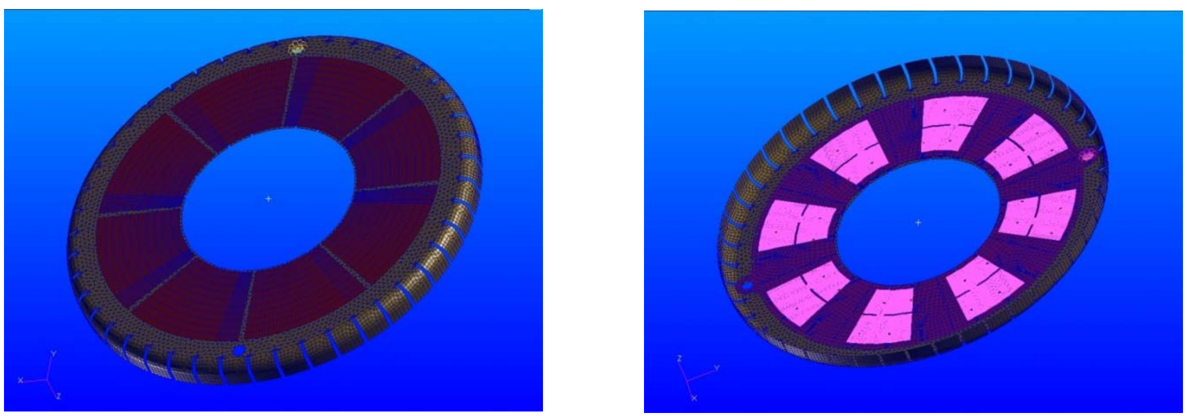
Reduces Required Compressor Power by 3,000 HP

Seal Design Analysis

- Calculate hydrodynamic pressure using MiTi Elastohydrodynamic Software (Finite Difference Analysis, FDA)
- Input to structural FEA to calculate deformation and stiffness

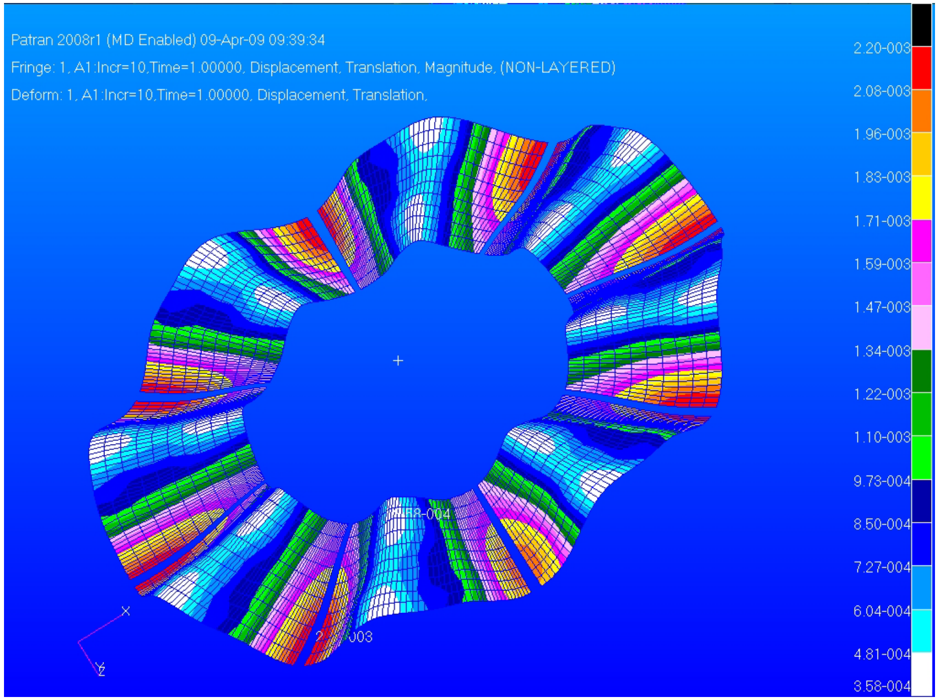


Single Pad Pressure Profile
From Hydrodynamic Analysis

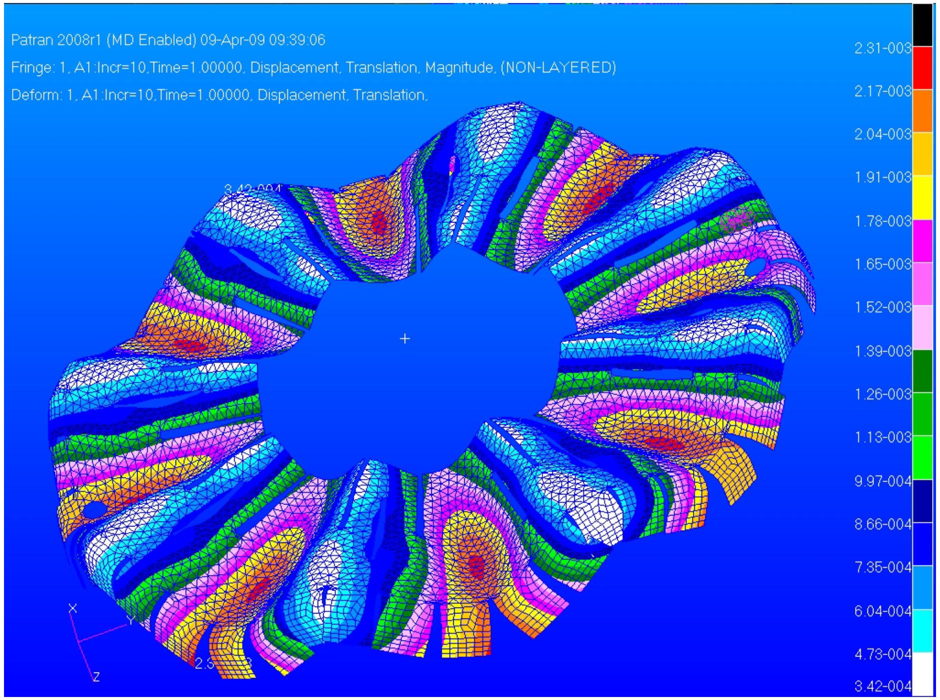


Full FEA Modeling of Face Seal

Coupled Finite Difference and Finite Element Seal Analysis

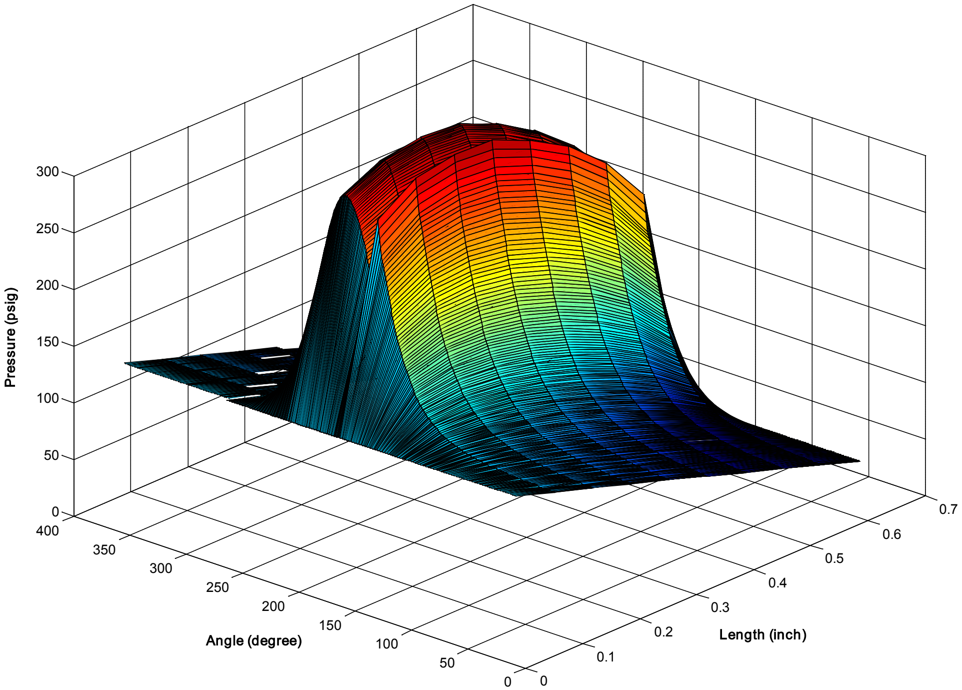


Deformed Smooth Foil (Visually Enhanced)

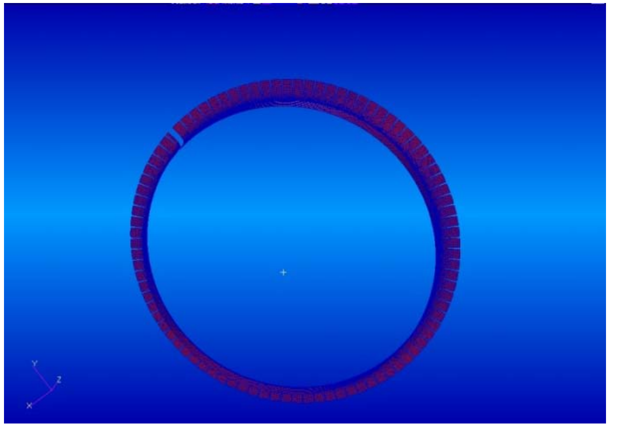


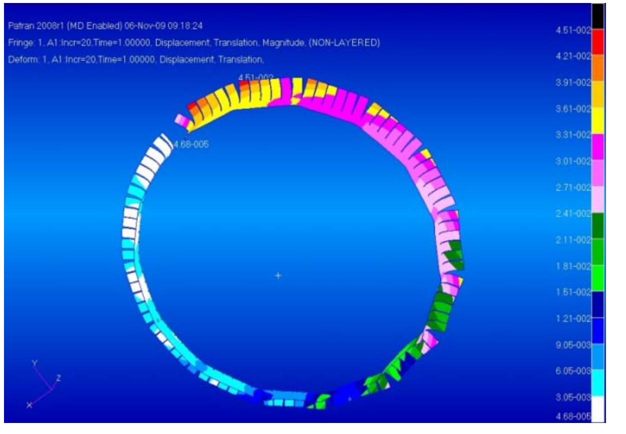
Deformed Seal Plate (Visually Enhanced)

FEA Modeling of Radial Seal



Interpolated hydrodynamic plus hydrostatic pressure applied to inner smooth foil





Un-deformed and deformed inner smooth foil under combined hydrodynamic hydrostatic pressures

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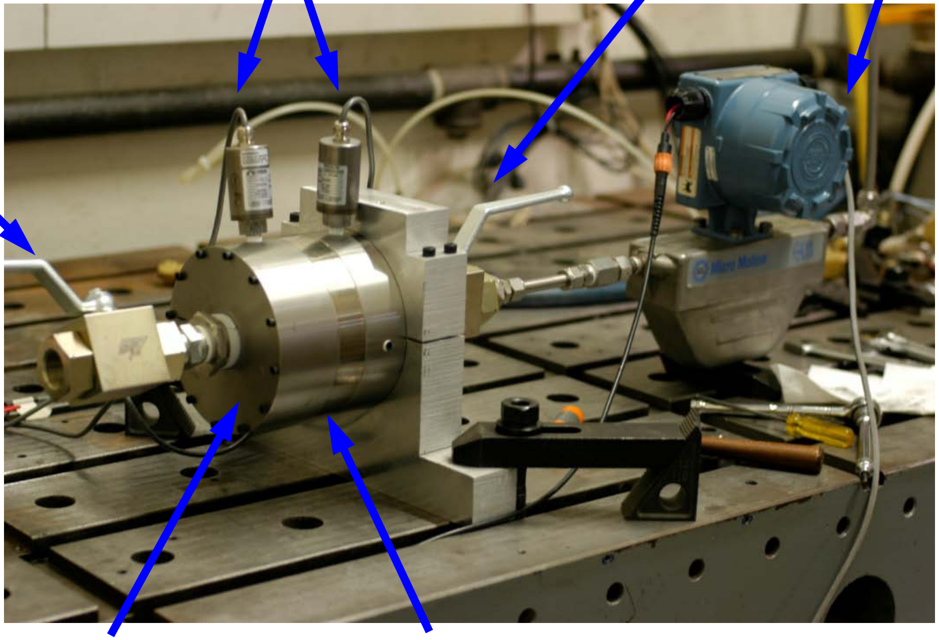
Static Seal Test Rig



Preliminary Seal Test Data

Prior to conducting additional tests, the flow factor data from Phase I were reviewed.

The flow factor is defined as

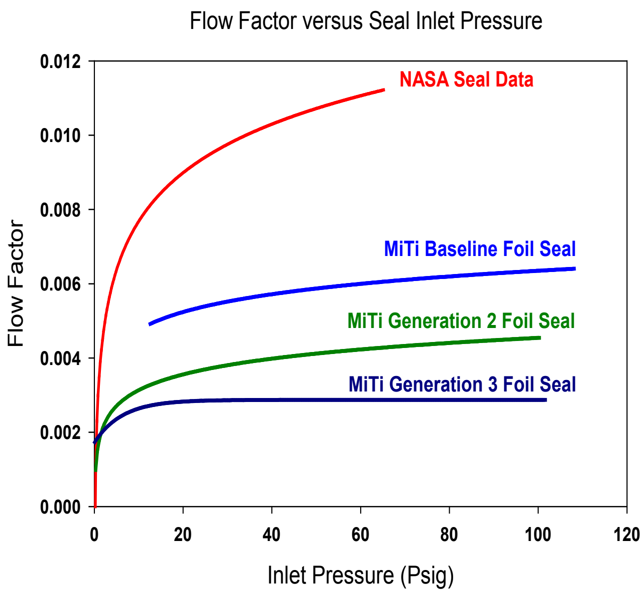
$$\psi = \frac{\dot{m}\sqrt{T}}{P_u\, D}$$

$\dot{m} = mass\ \ flow\ in\ lbm/\sec$

$T = Average\ Upstream\ Temperature\ in\ Degrees\ Rankine$

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

$D = Shaft\ \ Sealing\ \ Surface\ Diameter\ (in)$



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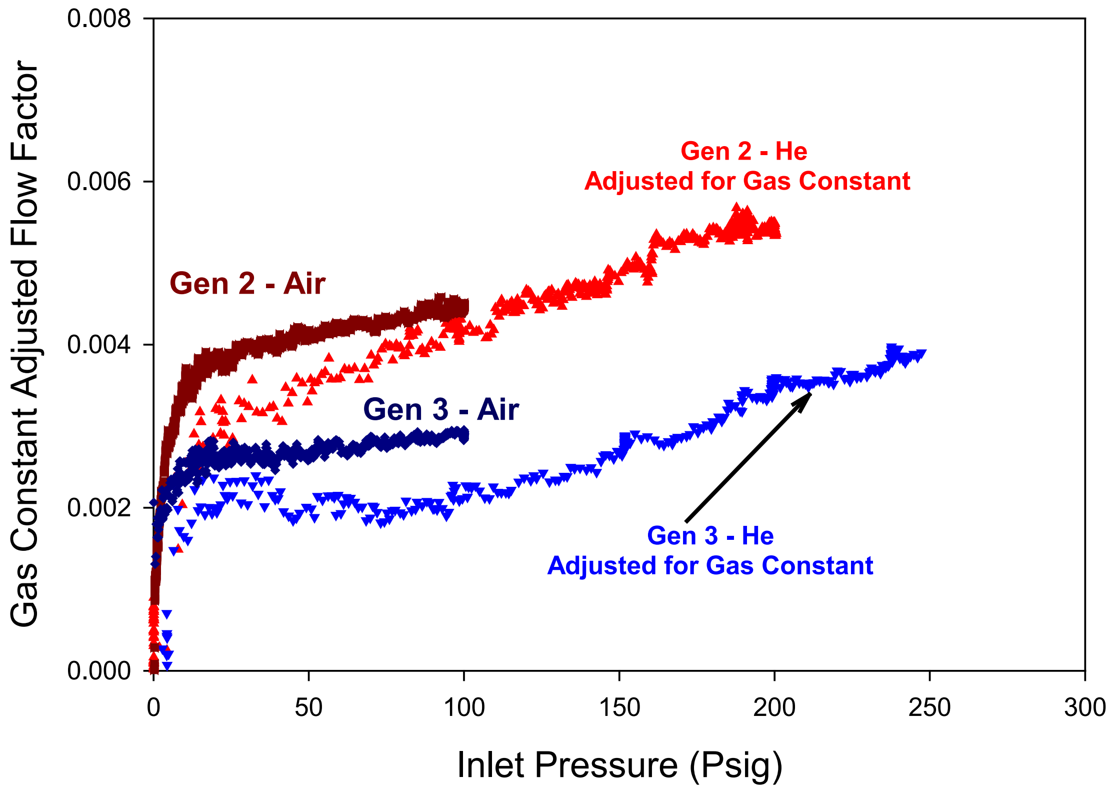
Corrected Seal Flow Factor for Helium

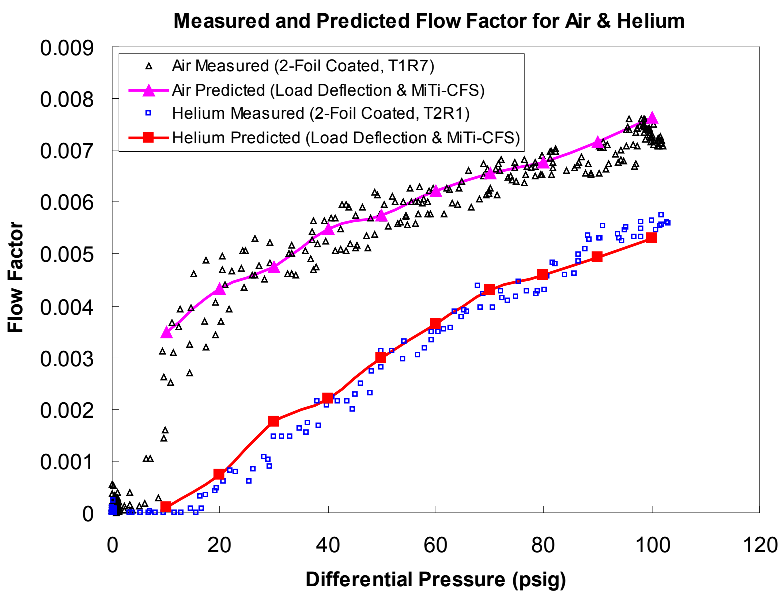
$$\psi = \frac{\dot{m}\sqrt{T\left(\Re_{He} / \Re_{Air}\right)}}{P_u\, D}$$

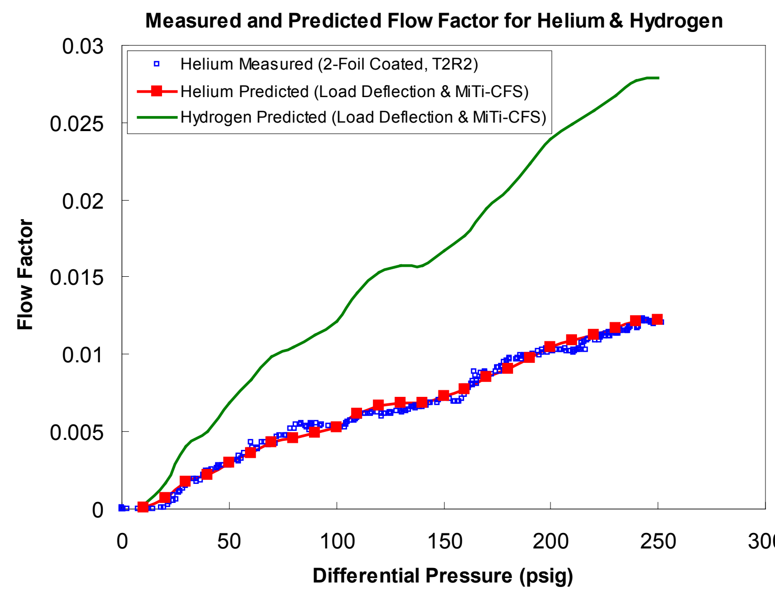
Flow Factor for Helium is Slightly Less than for Air for Both Seal Designs



Flow Factor Adjustment Was Based on Differences in Gas Constants Between Helium and Air

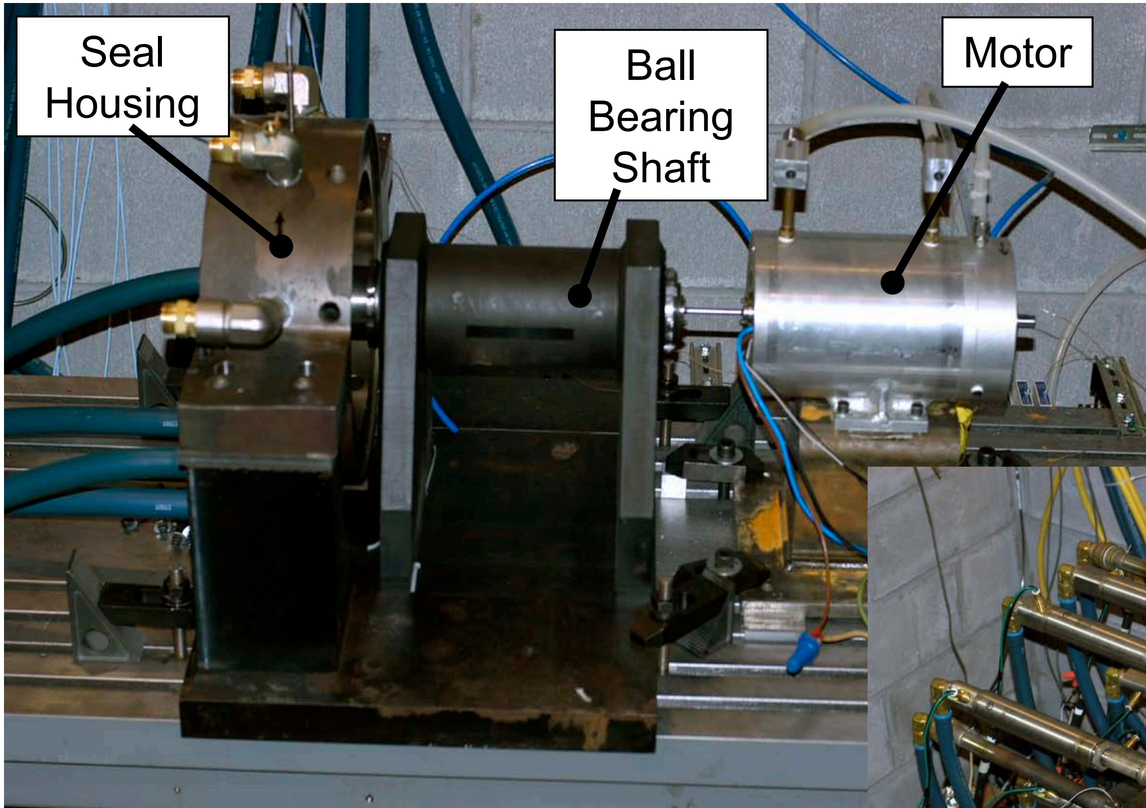
Flow Factor for Air, He, and Hydrogen

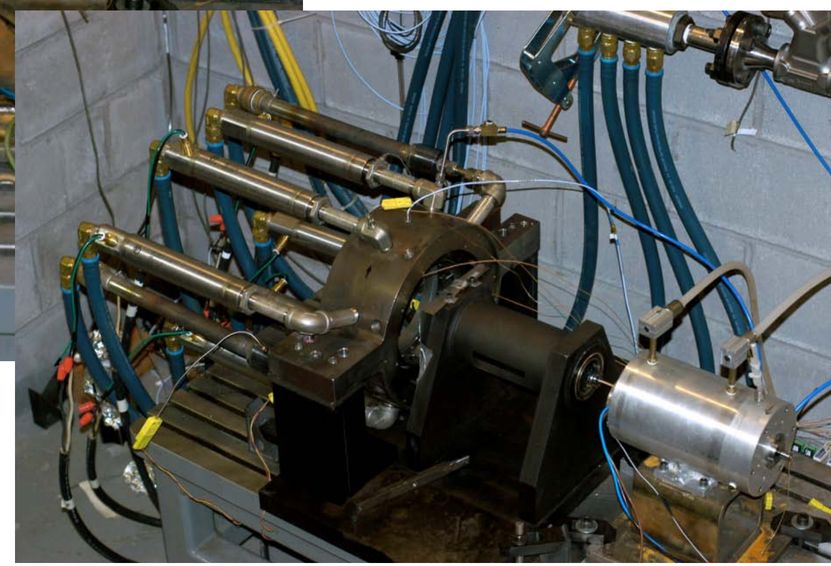




Measured And Predicted Flow Factor For Air And Helium And Hydrogen

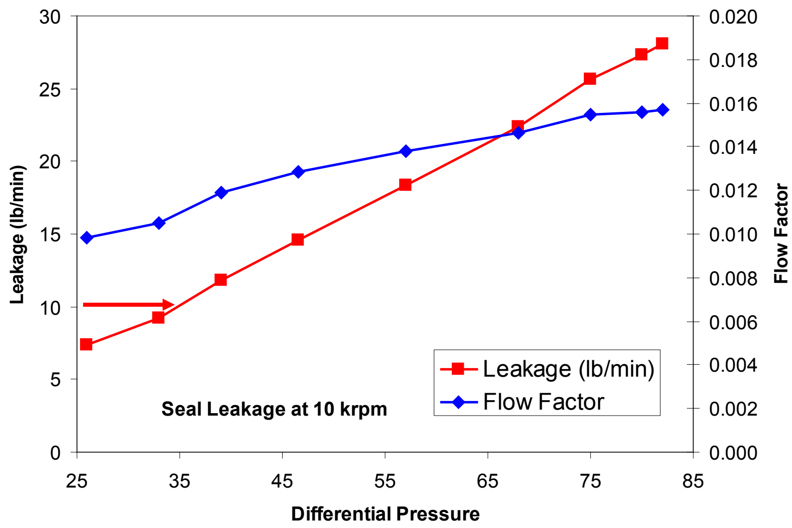
Low-Speed Electric Motor Driven Test Rig

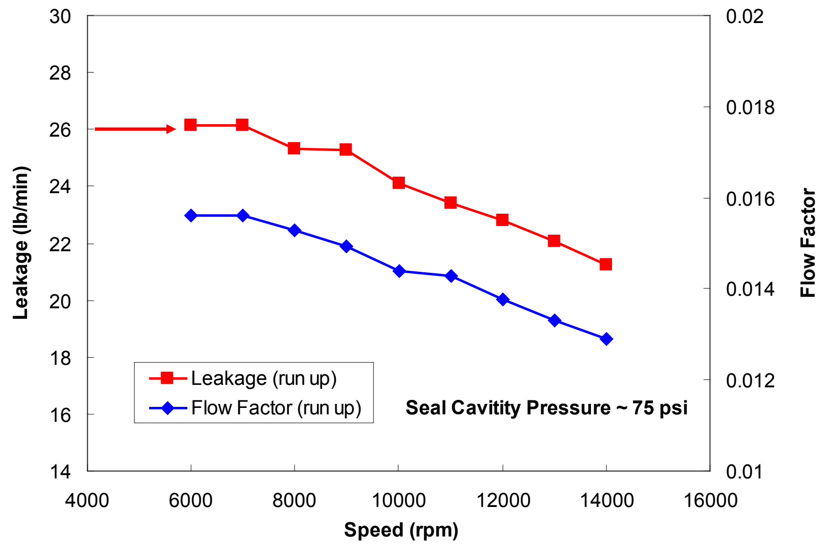




With Heaters for High Temperature Tests

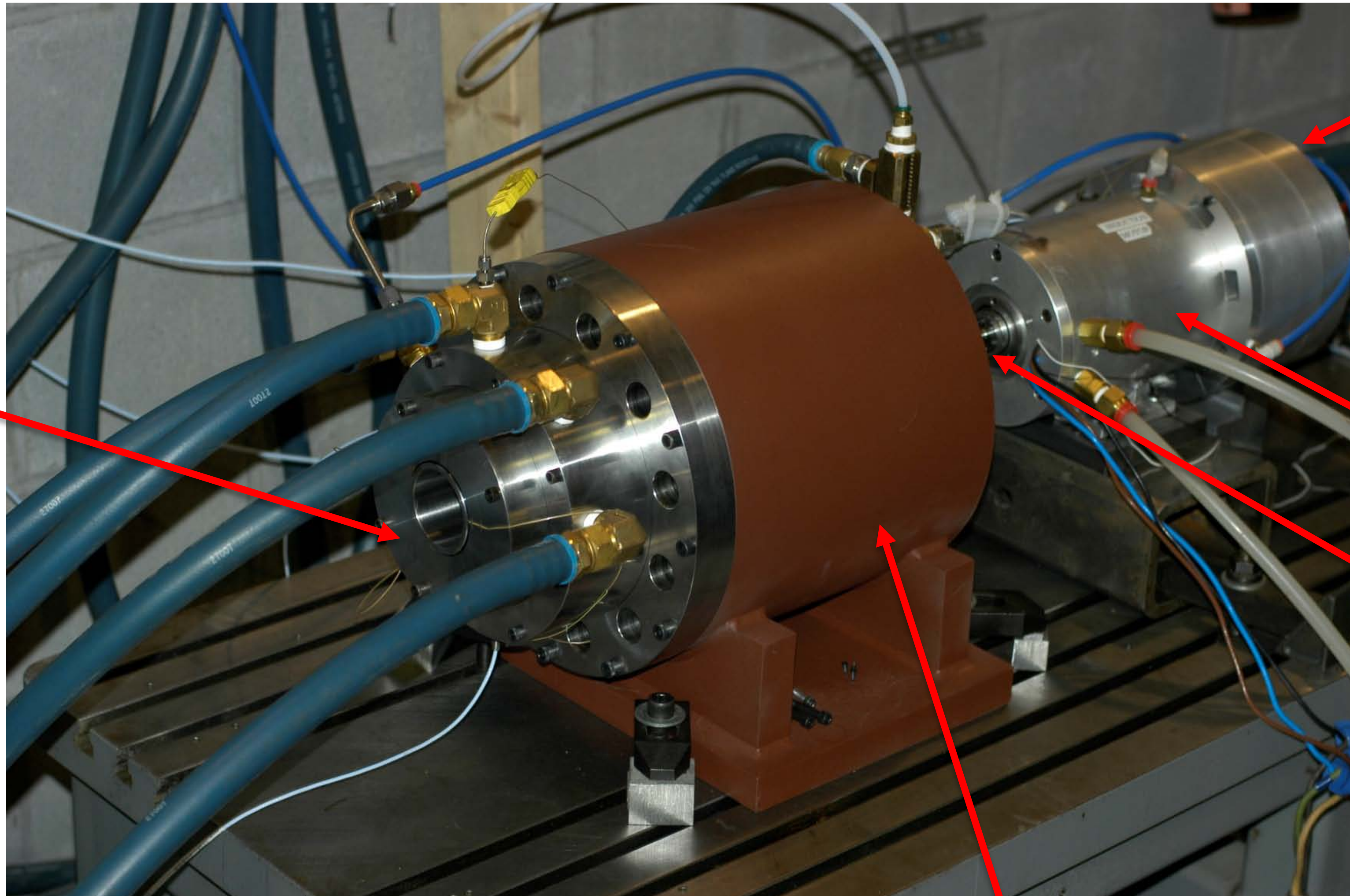
Seal Leakage vs Pressure and Speed





Leakage Increases With Pressure And Decreases With Speed

High-Speed Instrumented Test Rig



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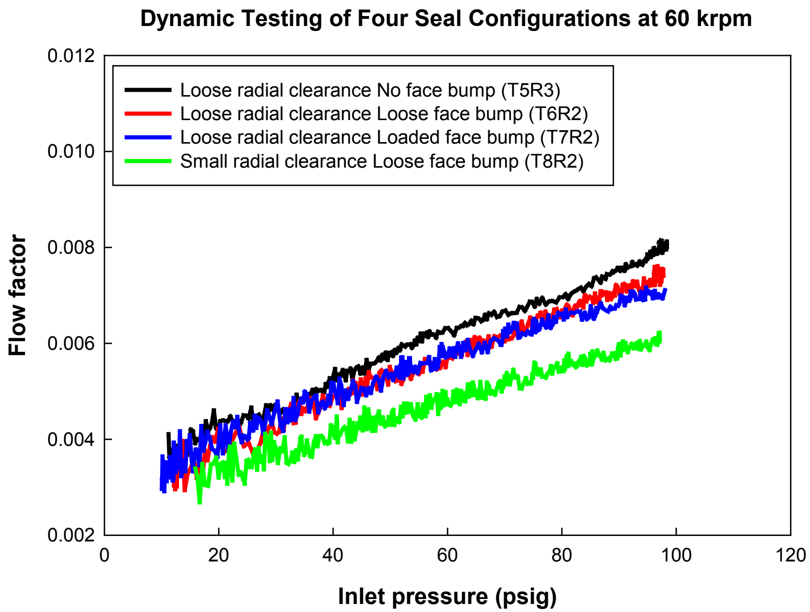
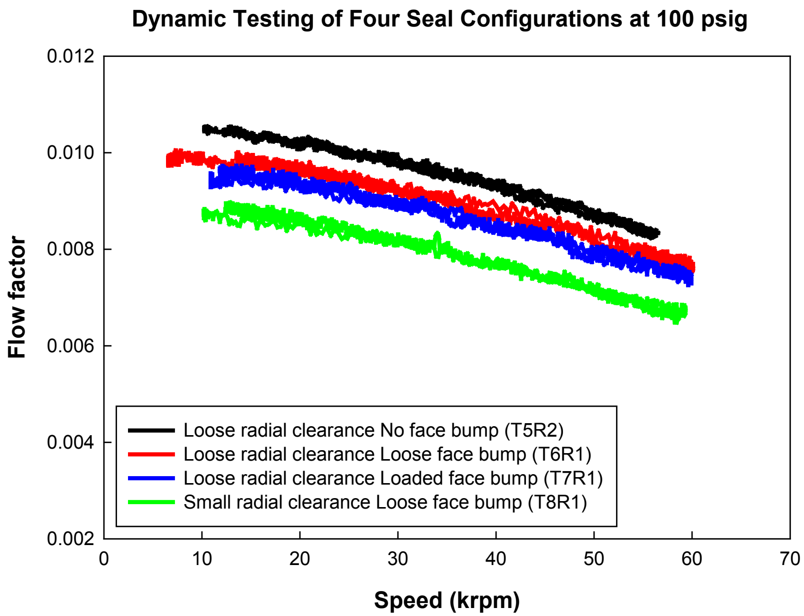
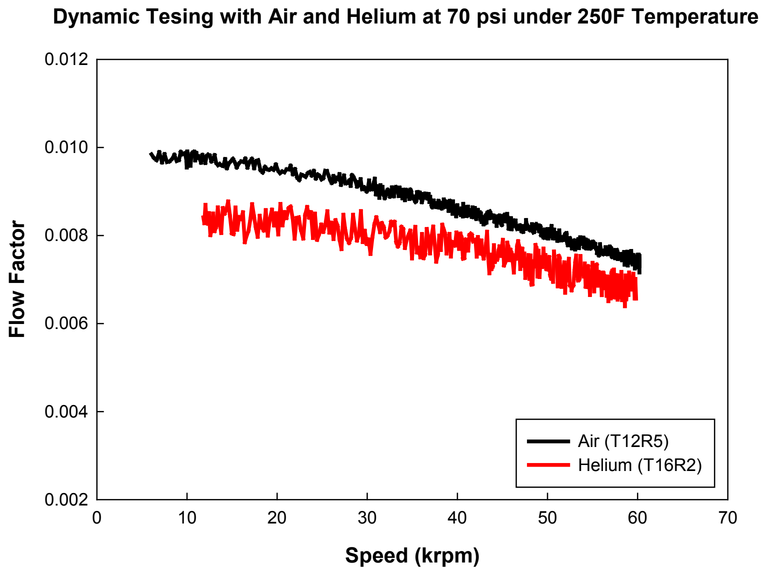
Testing of Different Seal Configurations

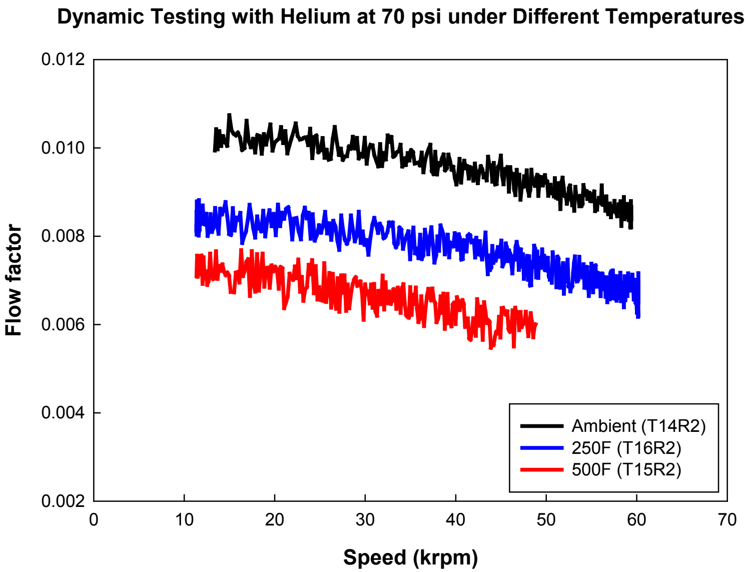




Leakage Increases With Pressure And Decreases With Speed

Comparison Between Air and He



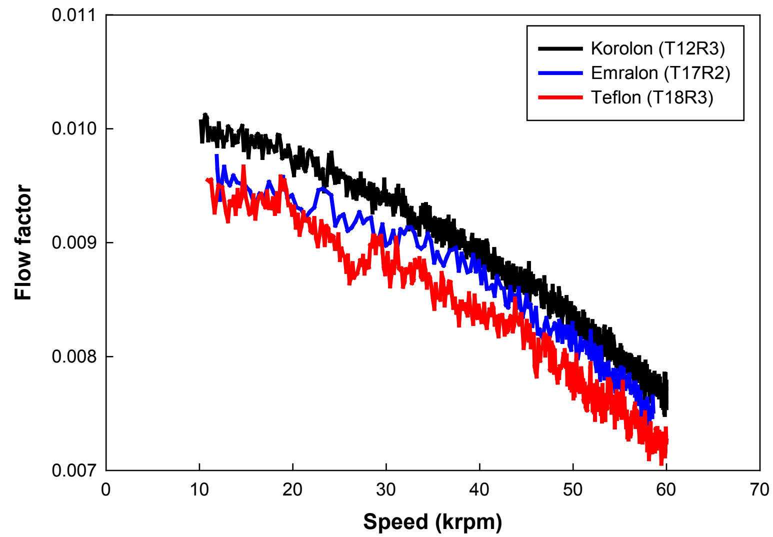


Leakage is Lower for Helium Than Air and Decreases with Temperature and Speed

Lubricating Coatings and Durability

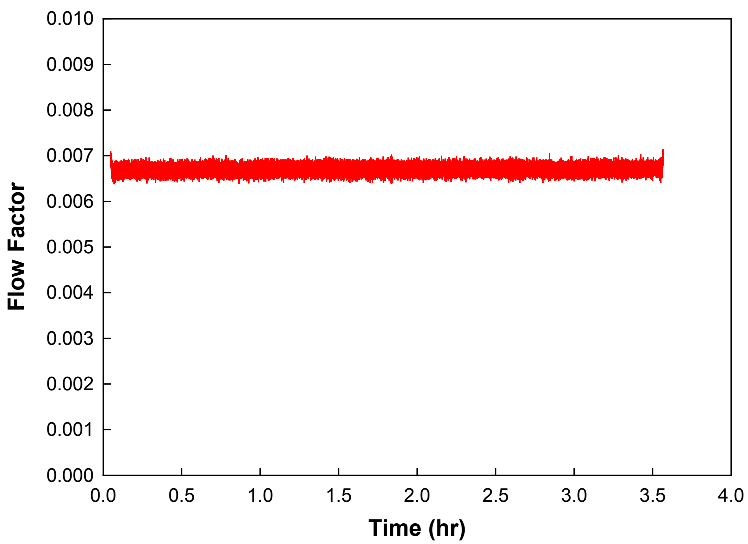
Solid Lubricant Coatings Reduce Leakage

Dynamic Testing with Air at 70 psig under Ambient Temperature



Durability Testing with Air

(T21R2: Ambient Temperature, 40 krpm Operating Speed, 50 psi Inlet Pressure)



Seal Behavior During Long-Term Durability Testing with Air

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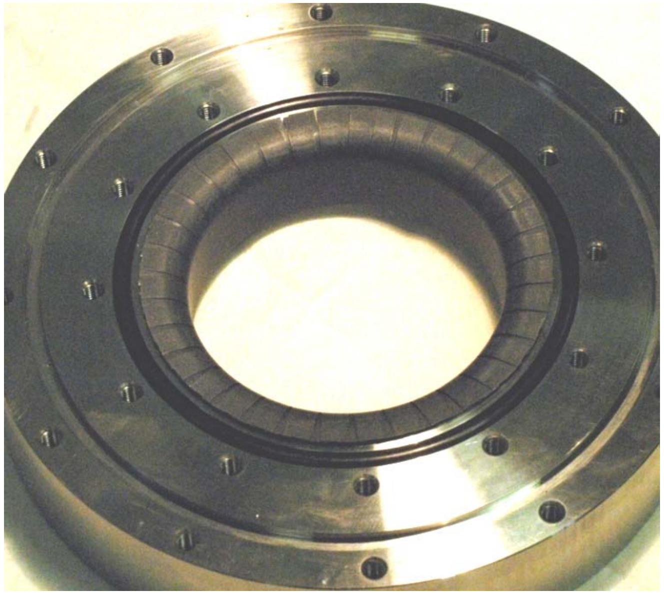
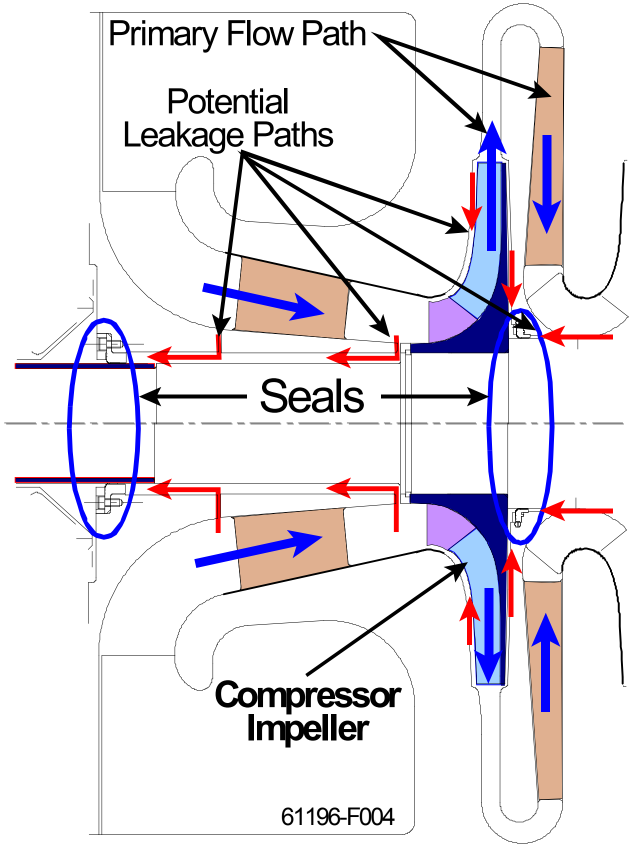
Future Work for FY10

- **Complete Final Report Including Recommendations for Implementation of the New Foil Seals in Hydrogen Centrifugal Compressor**





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Project Summary

- Coupled Elasto-Hydrodynamic Seal Design Analysis Methodology Developed
- Static and Dynamic Seal Testing Completed
- Compliant Foil Seal Operation Demonstrated
  - Close Clearance Film Riding Seal Operation Demonstrated
  - Testing at Pressures Above 200 psig Successfully Completed
  - Effects of Temperature, Speed, Solid Lubrication, Seal Configuration Determined
  - Low Flow Factor and Leakage- Substantially Less Than Labyrinth Seals

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