

Advanced Sealing Technology For Hydrogen Compressors

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Project ID #
PD060

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
 - H₂ 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

Hydrogen, Fuel Cells & Infrastructure Technologies Program
October 2007

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

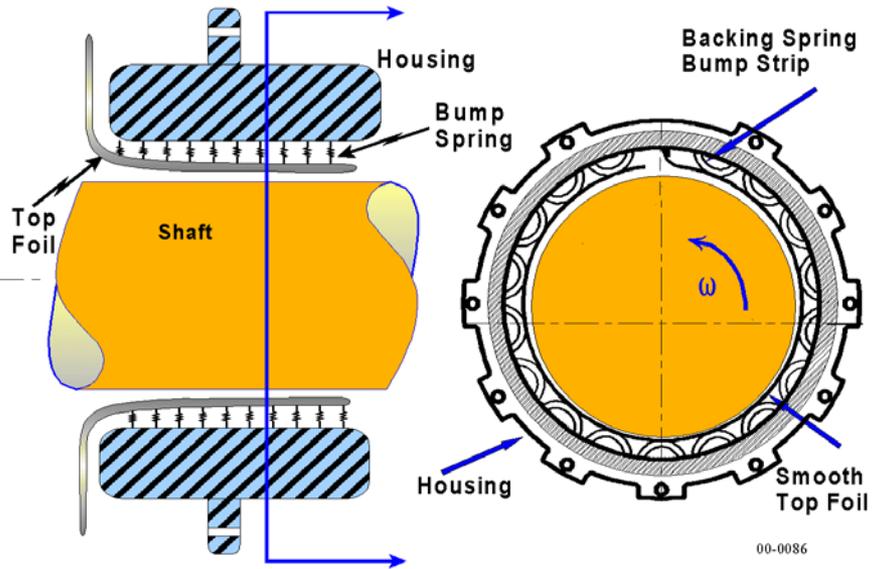
DOE Milestone: Down select novel compression technology for hydrogen delivery

Technical Accomplishment

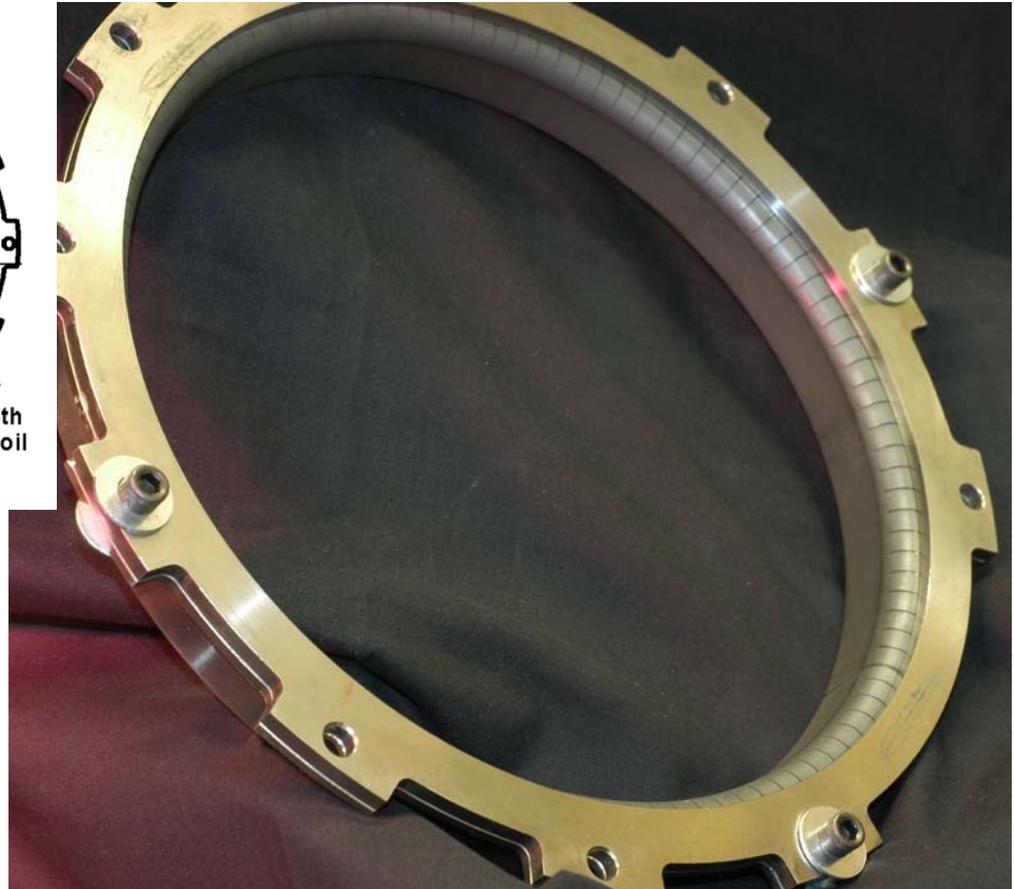
Seal Selection

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

Foil Seal Concept

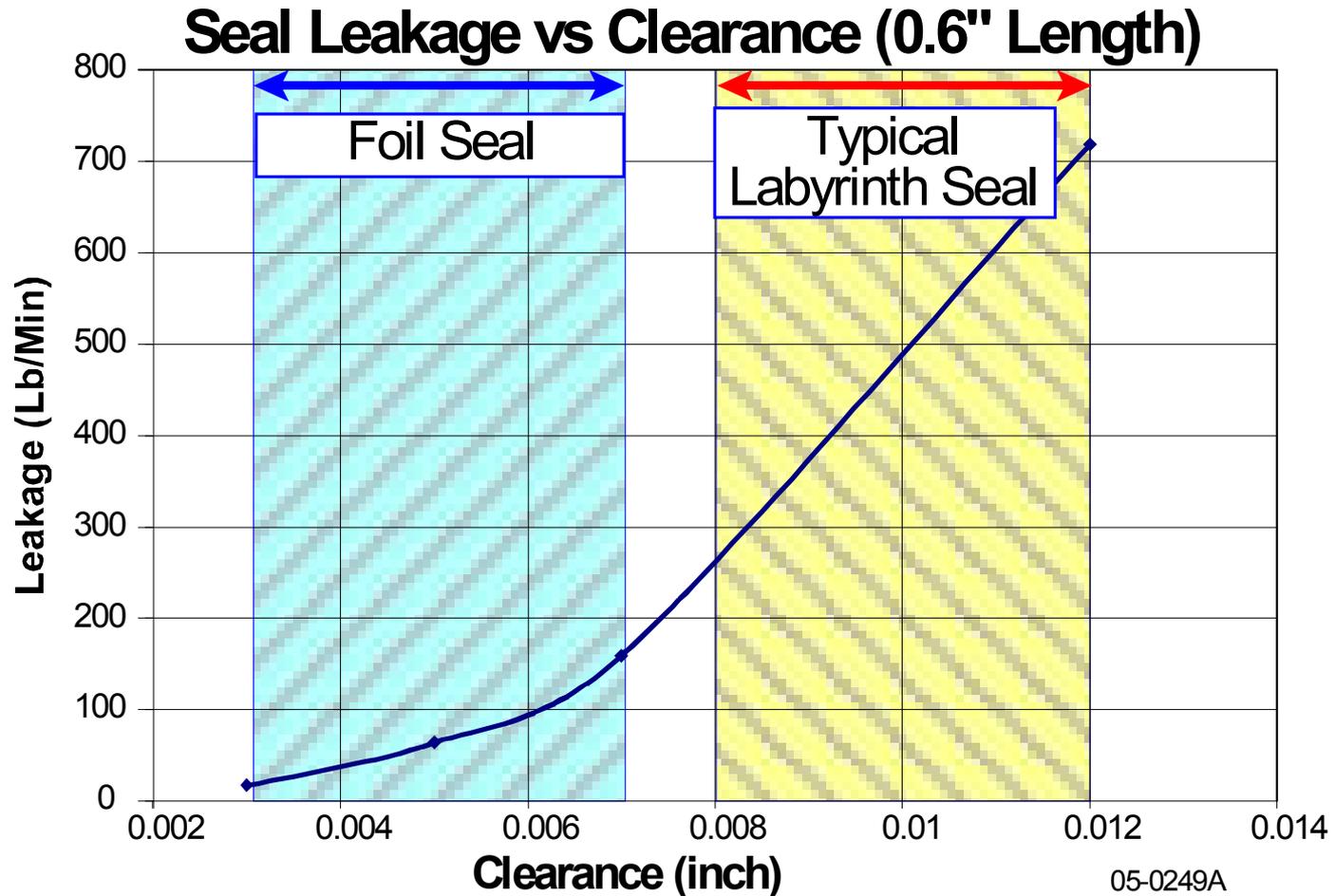


8.5" Foil Seal Developed
at MiTi and
Independently Verified at
NASA to 30,000 rpm



US Patent: 6505837 Compliant Foil Seal

Foil & Labyrinth Seal Comparisons



05-0249A

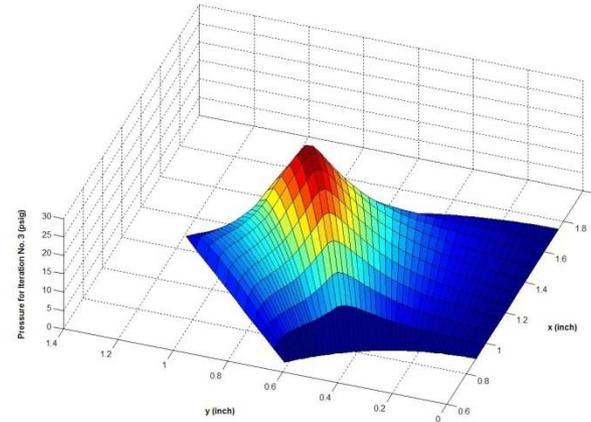
Impact of Seal Design For H2

- 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 \leq 2% of Total Compressor Flow

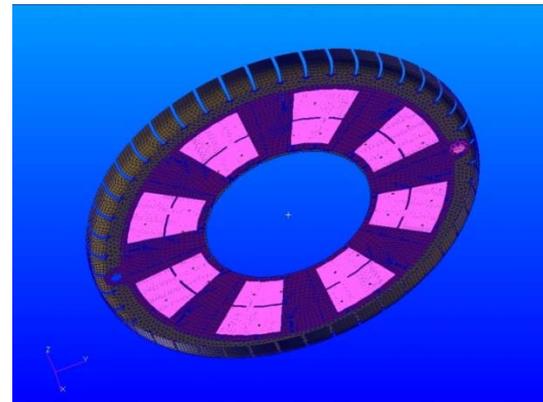
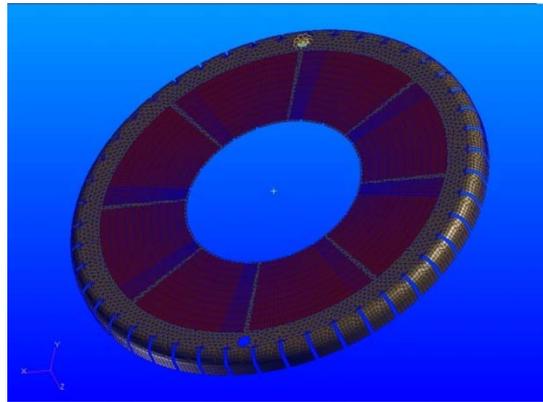
Reduces Required Compressor Power by 3,000 HP

Seal Design Analysis

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

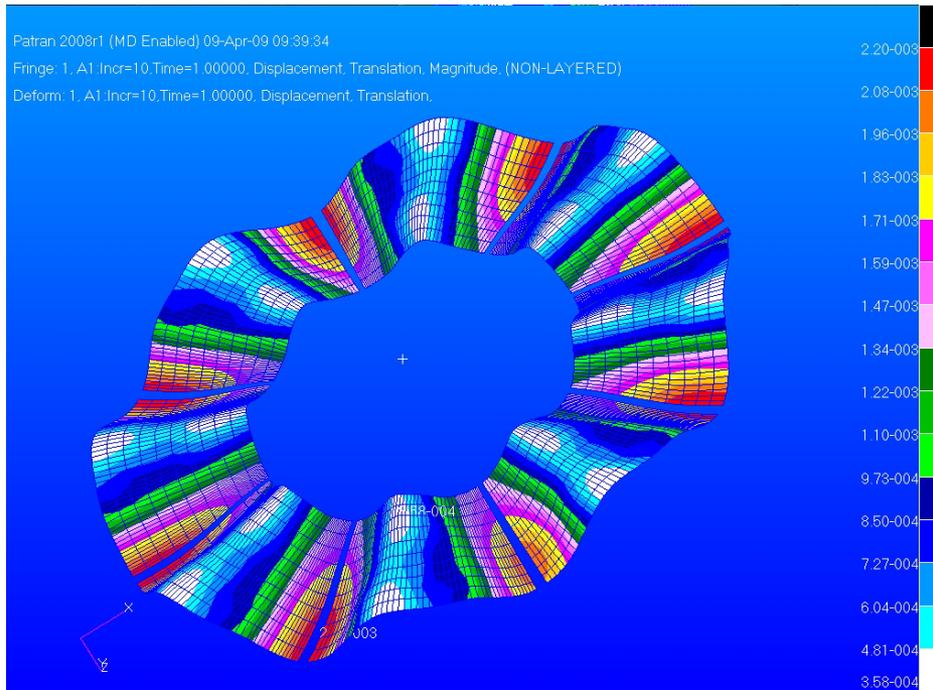


Single Pad Pressure Profile
From Hydrodynamic Analysis

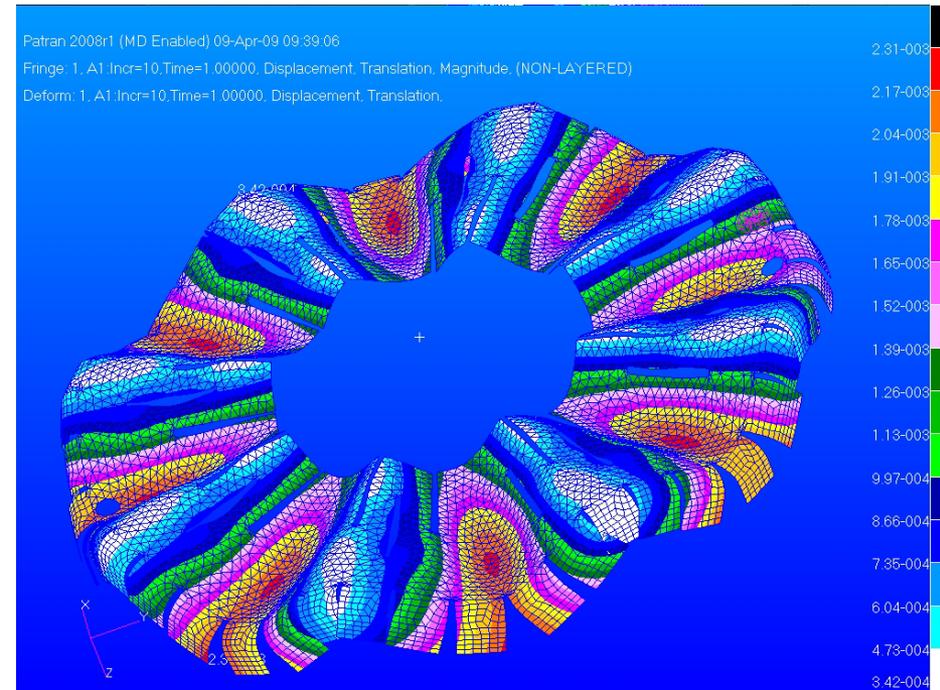


Full FEA Modeling of Face Seal

Coupled Finite Difference and Finite Element Seal Analysis

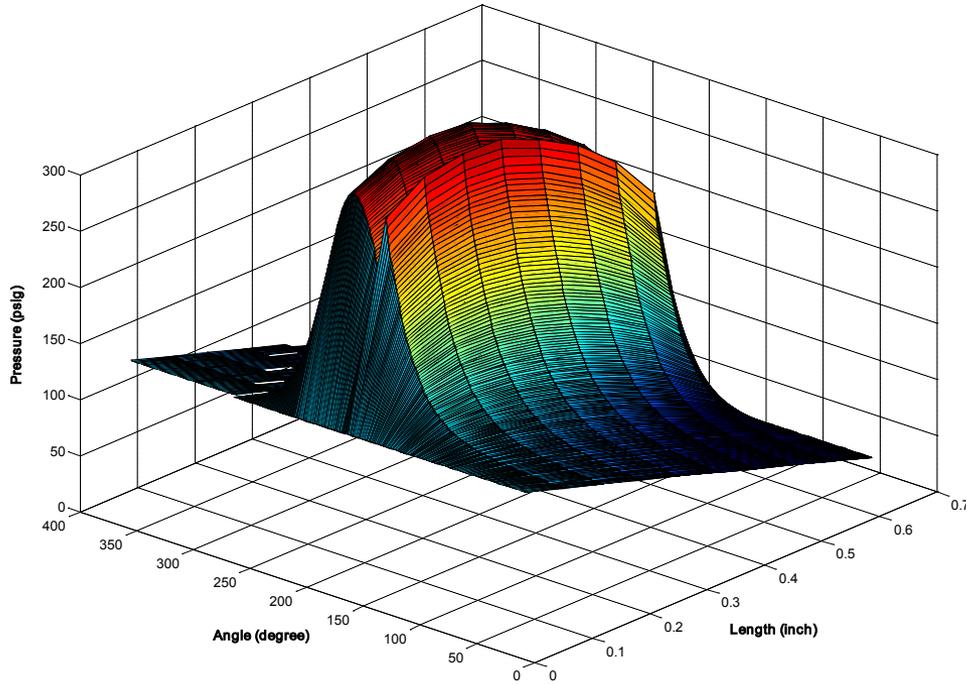


Deformed Smooth Foil (Visually Enhanced)

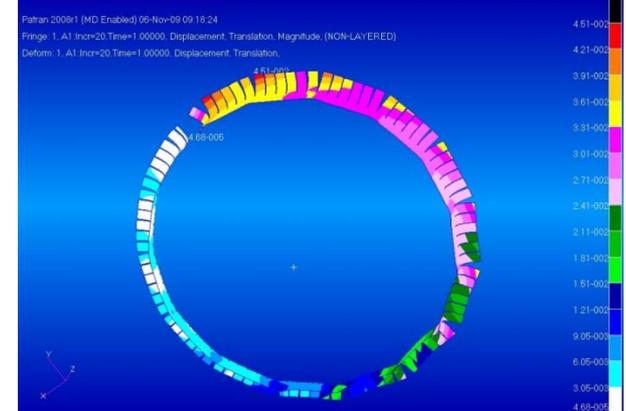
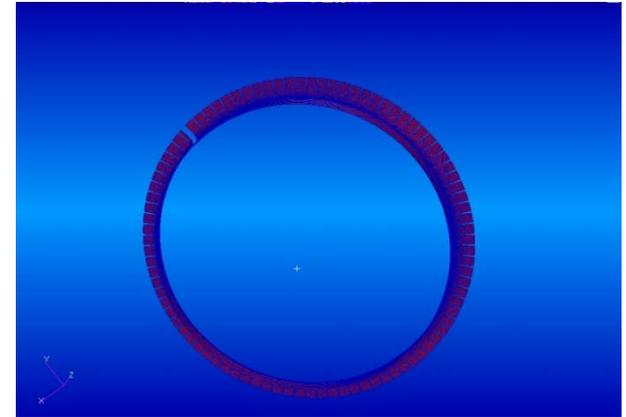


Deformed Seal Plate (Visually Enhanced)

FEA Modeling of Radial Seal

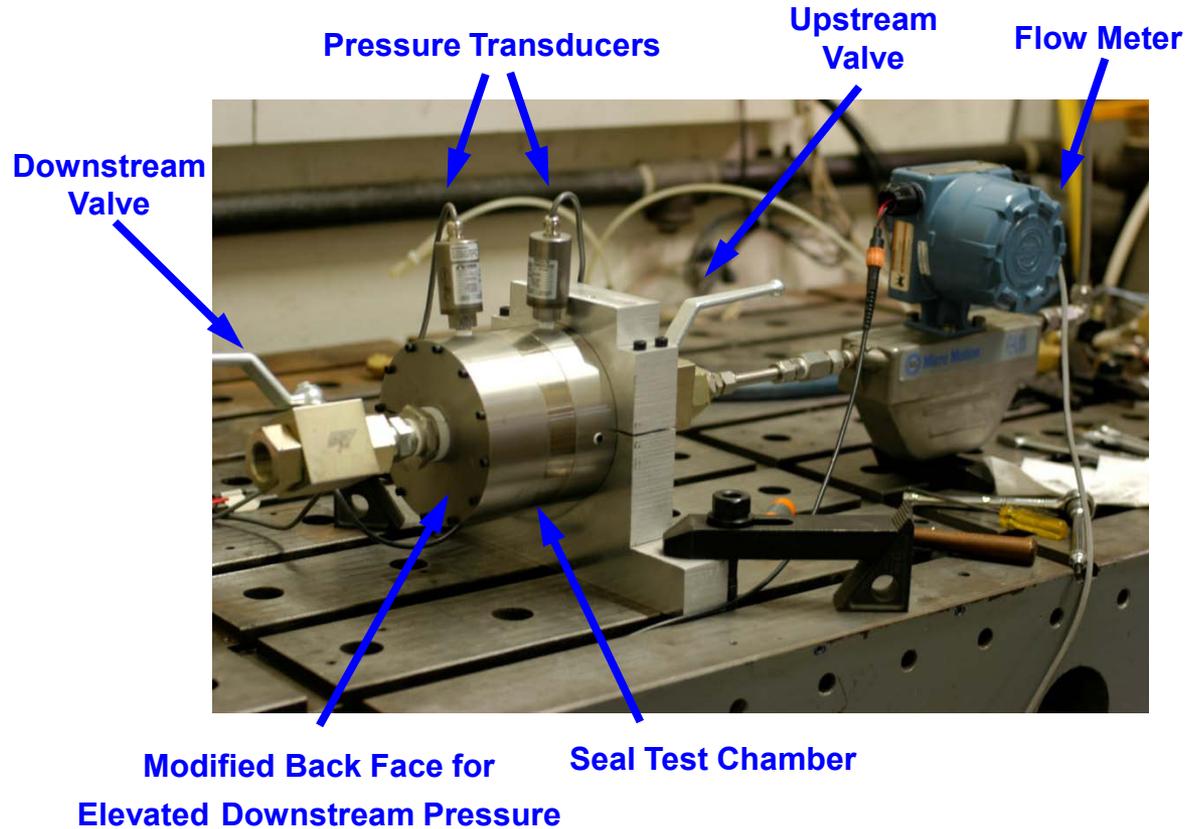


Interpolated hydrodynamic plus hydrostatic pressure applied to inner smooth foil



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

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

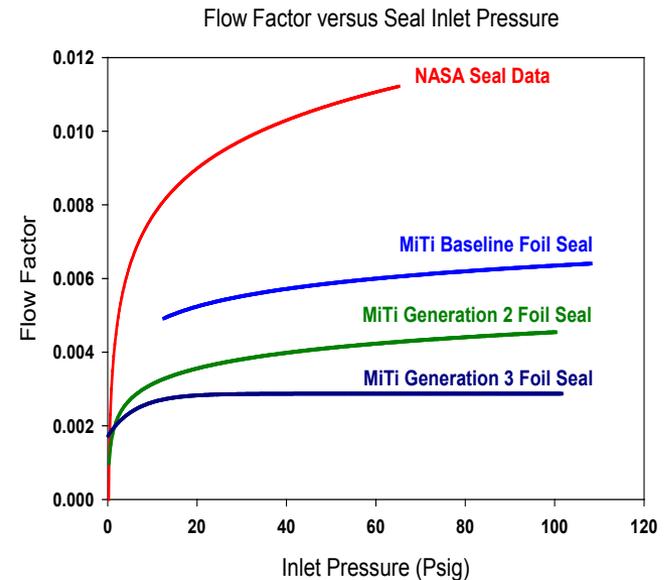
$$\psi = \frac{\dot{m} \sqrt{T}}{P_u D}$$

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

T = Average Upstream Temperature in Degrees Rankine

P_u = Average Upstream Pressure (psia)

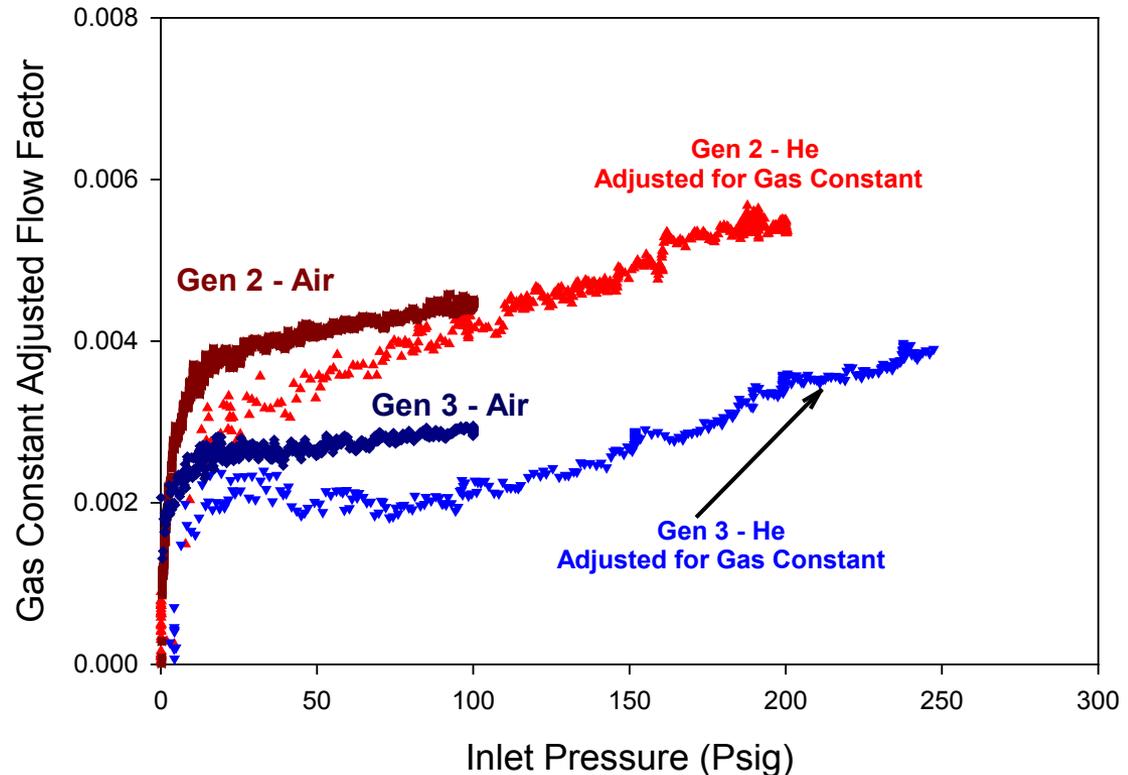
D = Shaft Sealing Surface Diameter (in)



Corrected Seal Flow Factor for Helium

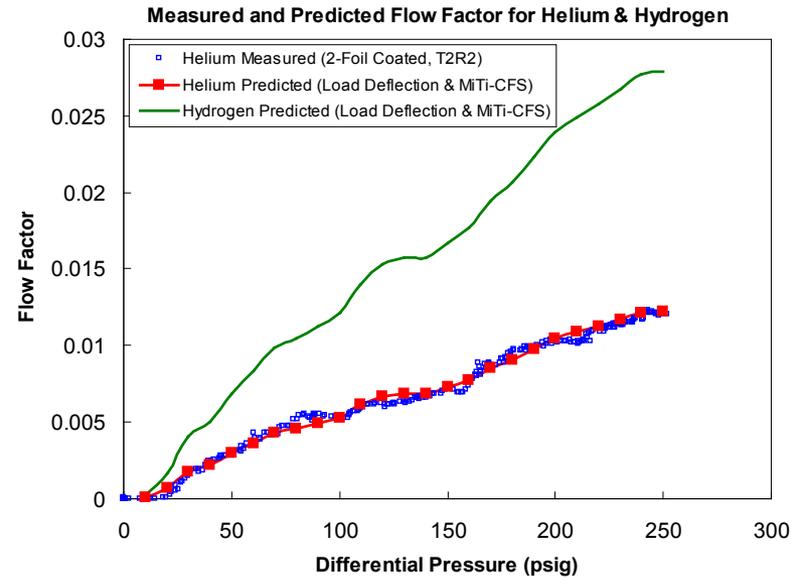
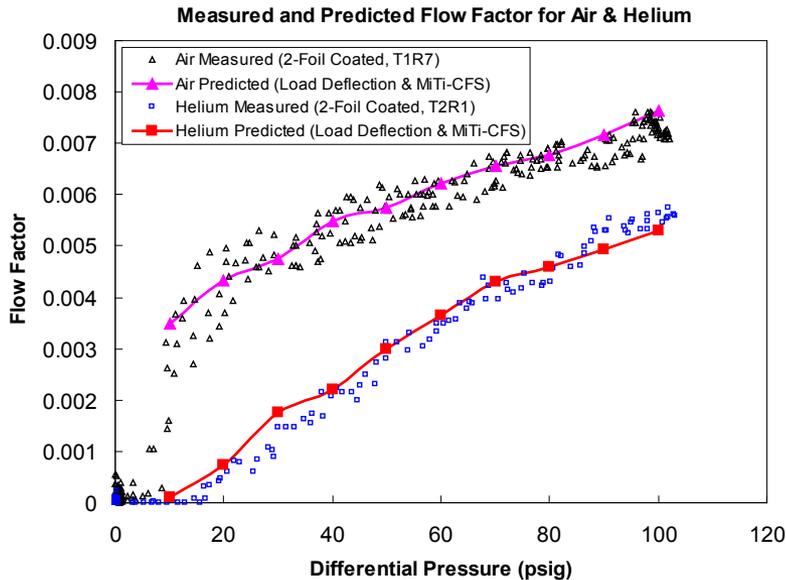
$$\psi = \frac{\dot{m} \sqrt{T \left(\mathcal{R}_{He} / \mathcal{R}_{Air} \right)}}{P_u D}$$

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



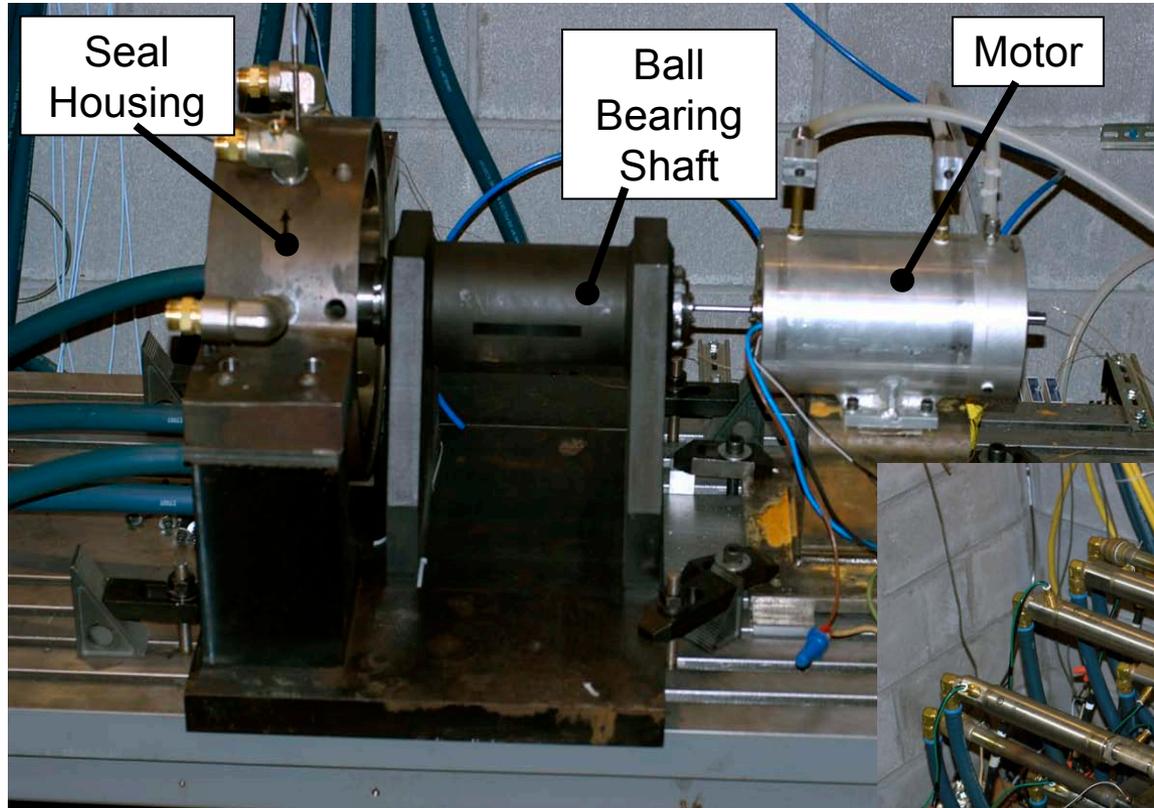
Flow Factor Adjustment Was Based on Differences in Gas Constants Between Helium and Air

Flow Factor for Air, He, and Hydrogen



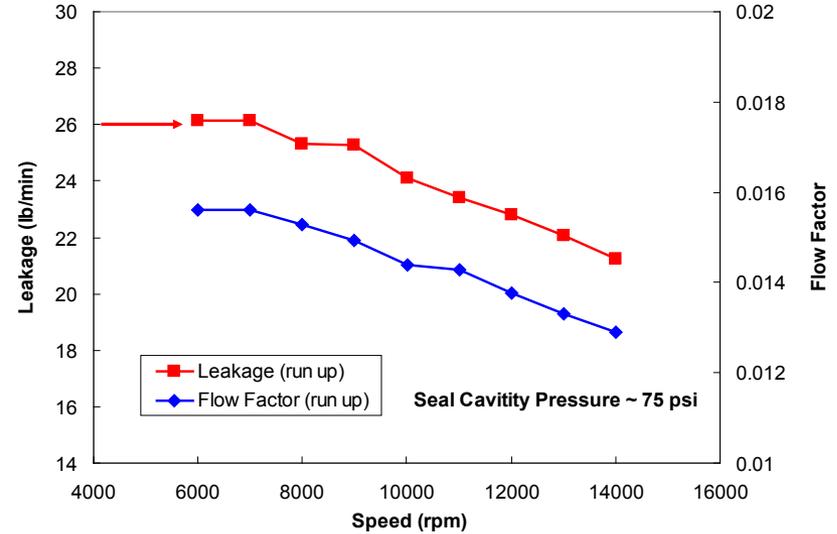
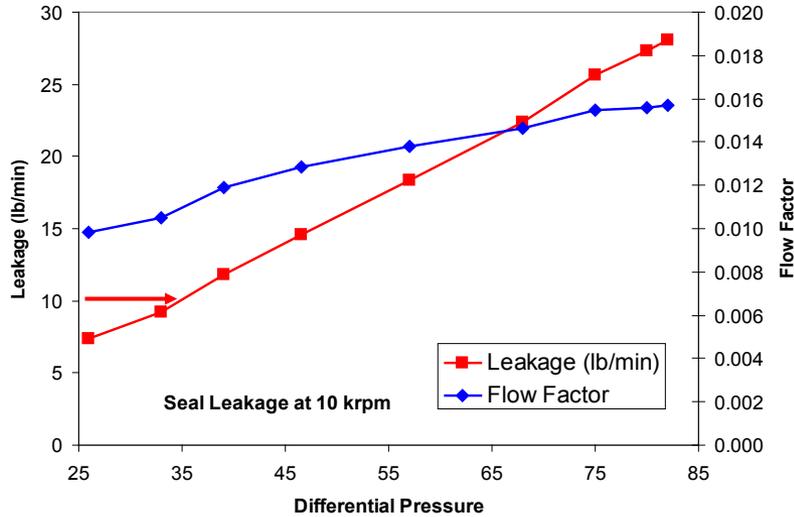
Measured And Predicted Flow Factor For Air And Helium And Hydrogen

Low-Speed Electric Motor Driven Test Rig



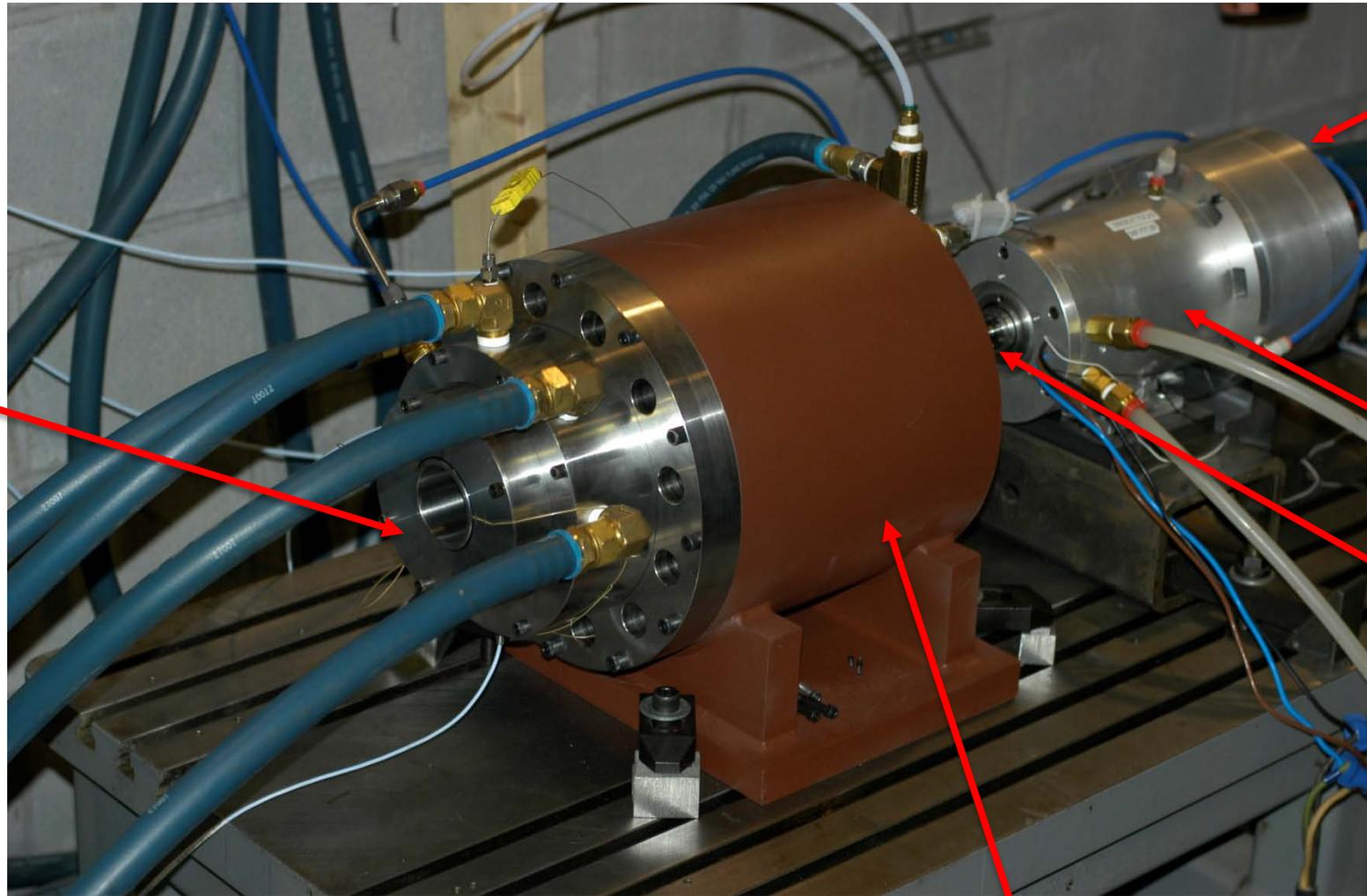
With Heaters for High Temperature Tests

Seal Leakage vs Pressure and Speed



Leakage Increases With Pressure And Decreases With Speed

High-Speed Instrumented Test Rig



Seal
Assembly

Turbine

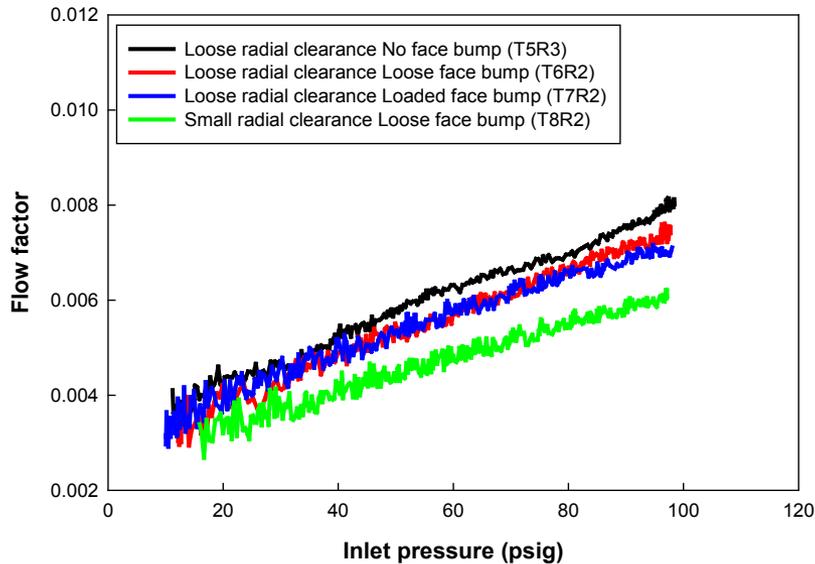
Motor

Coupling

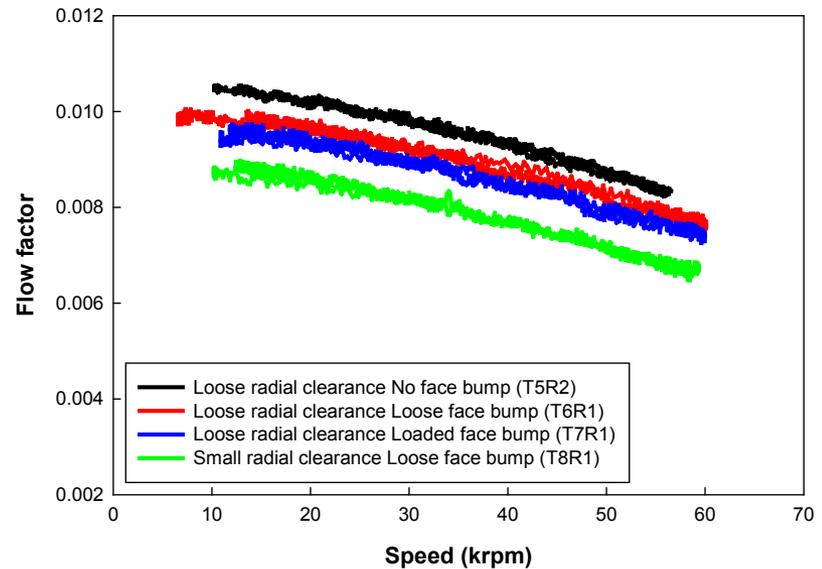
Test Spindle & Housing

Testing of Different Seal Configurations

Dynamic Testing of Four Seal Configurations at 60 krpm



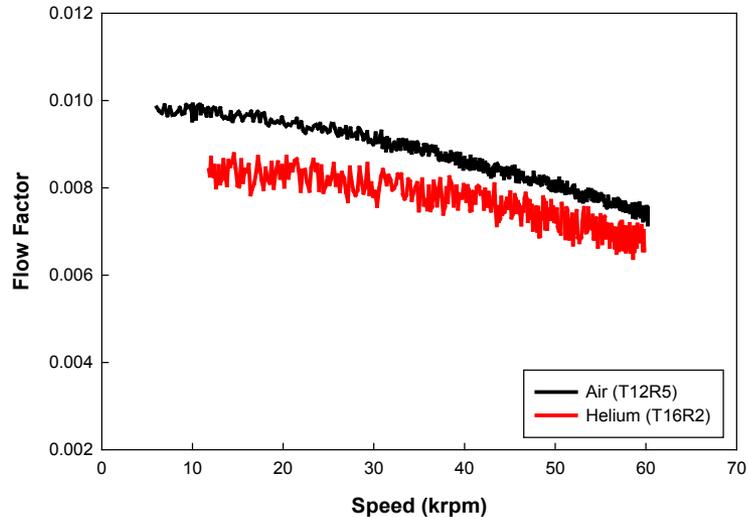
Dynamic Testing of Four Seal Configurations at 100 psig



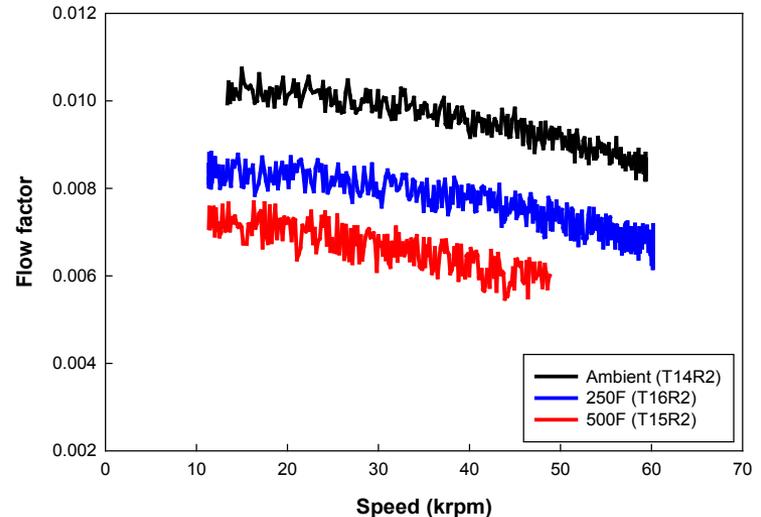
Leakage Increases With Pressure And Decreases With Speed

Comparison Between Air and He

Dynamic Testing with Air and Helium at 70 psi under 250F Temperature



Dynamic Testing with Helium at 70 psi under Different Temperatures

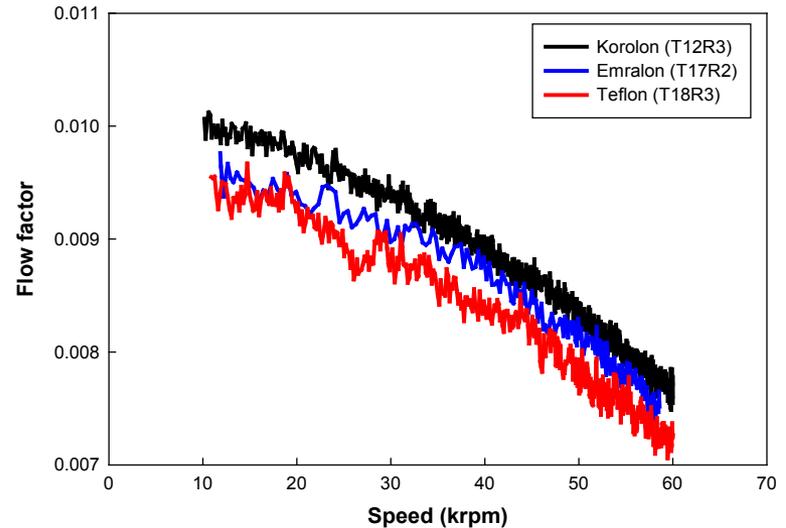


Leakage is Lower for Helium Than Air and Decreases with Temperature and Speed

Lubricating Coatings and Durability

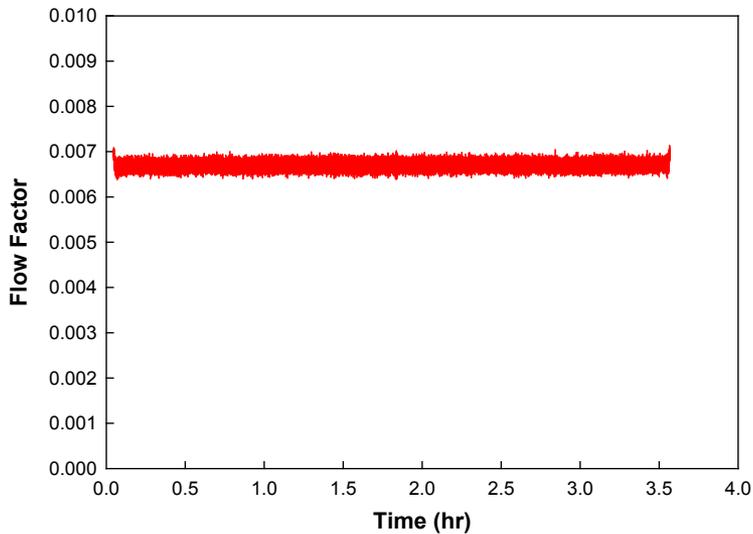
Solid Lubricant Coatings
Reduce Leakage

Dynamic Testing with Air at 70 psig under Ambient Temperature



Durability Testing with Air

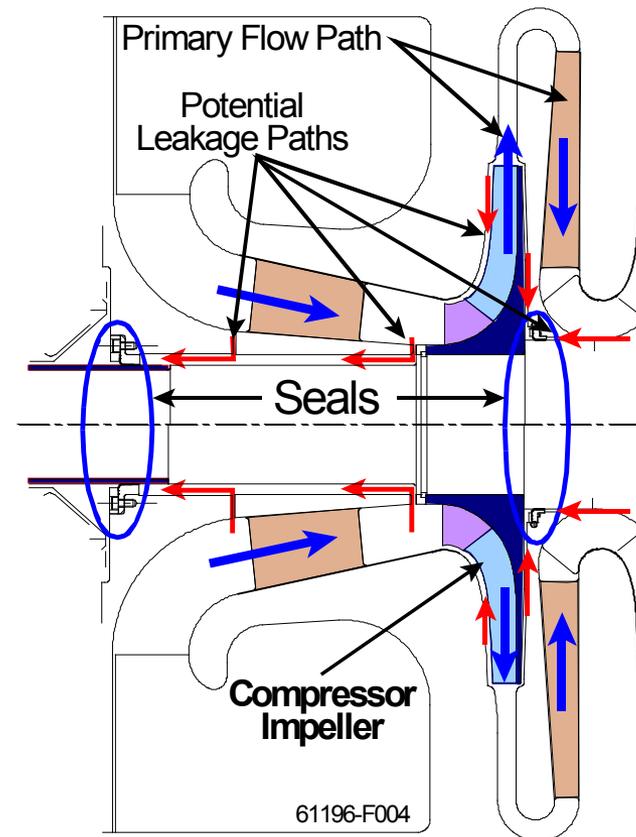
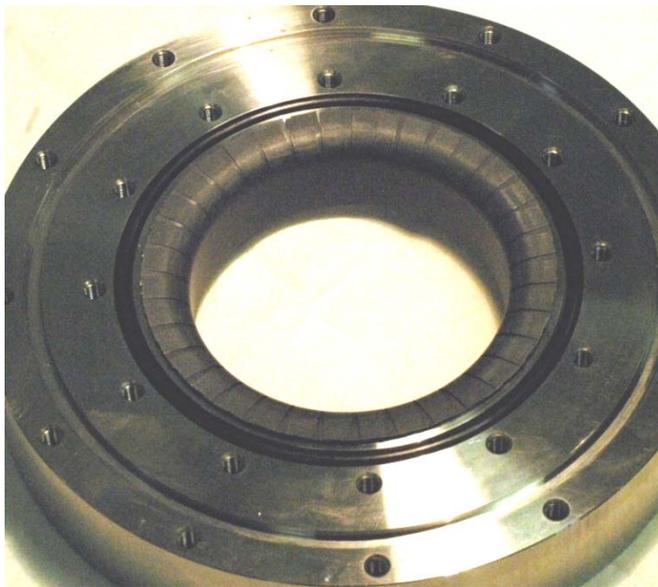
(T21R2: Ambient Temperature, 40 krpm Operating Speed, 50 psi Inlet Pressure)



Seal Behavior During Long-Term Durability Testing with Air

Future Work for FY10

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



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**