Low-leakage seals for utility-scale sCO_2 turbines DE-FE24007

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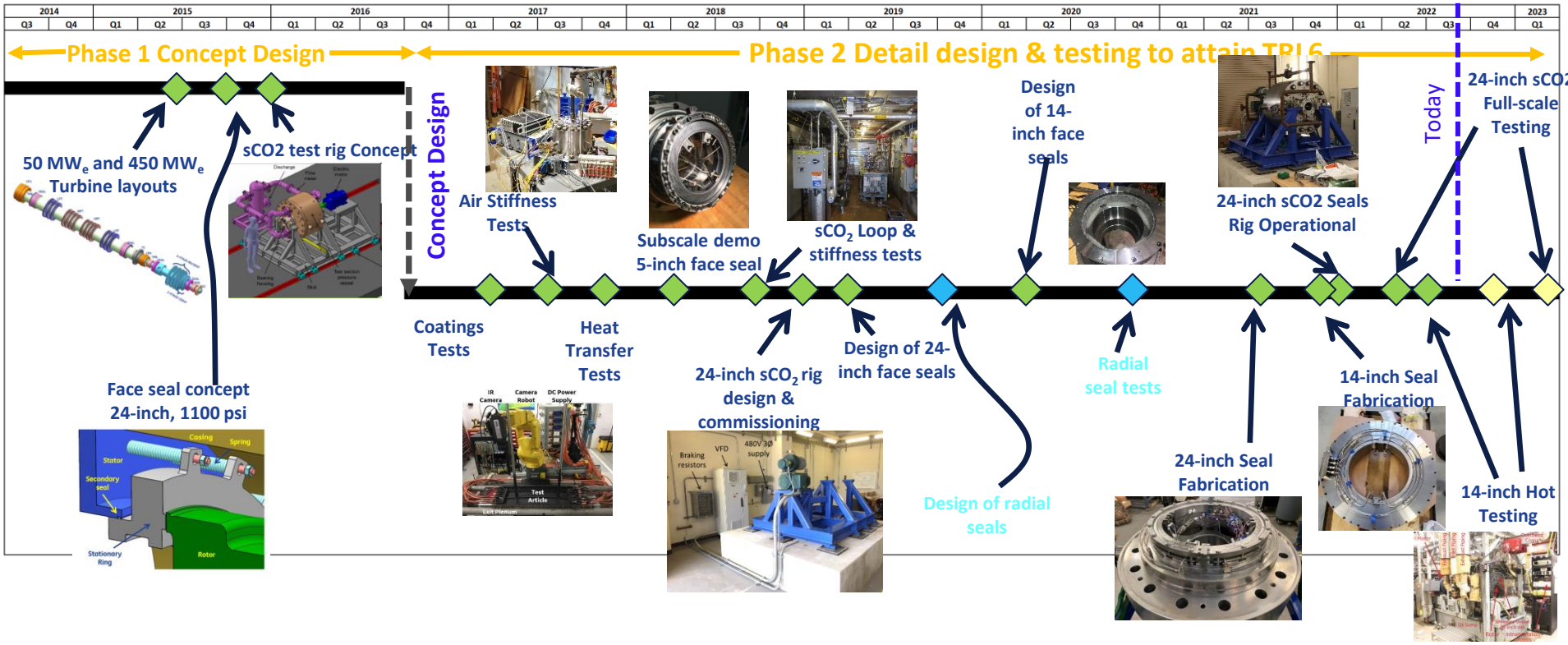
imagination at work

Outline

- Program Overview
- Recap of subscale testing (2017-2020)
- 14-inch Seal Fabrication/Testing (2020-2022)
- 24-inch Seal Fabrication/Testing (2020-2022)
- Summary of Next Steps

Overview of Utility-scale sCO_2 Seals Program



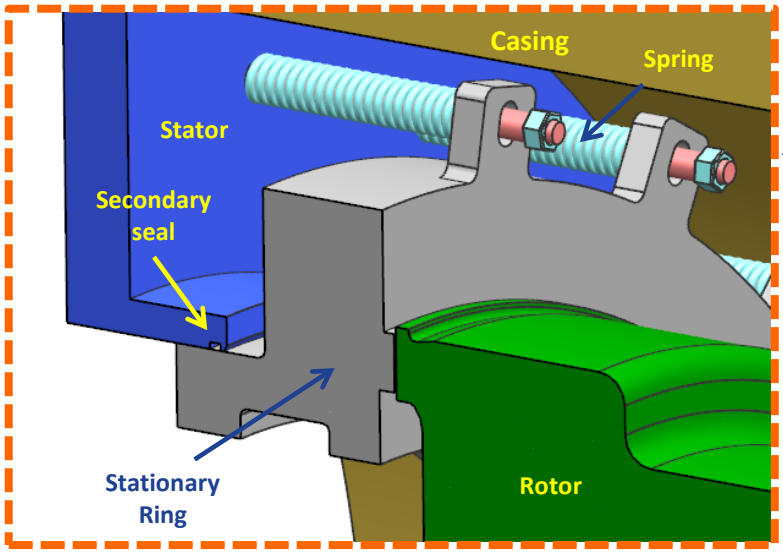
Objective: Develop film-riding seals for large sCO_2 turbines with TRL5/6 tests

GE Public Class 1

imagination at work

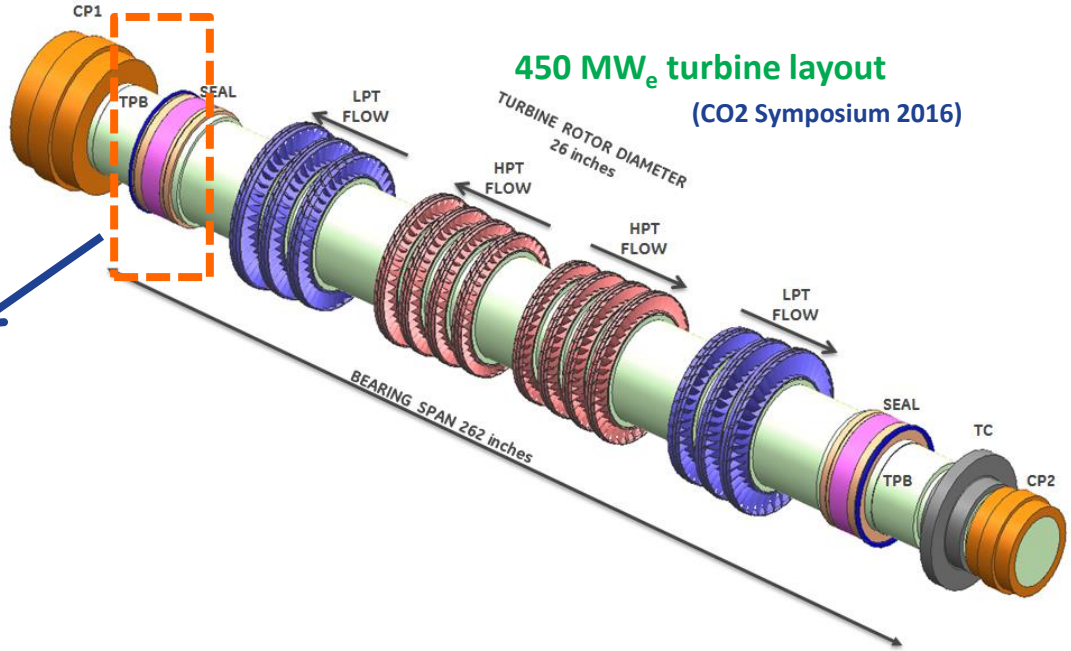
End Seals in sCO_2 turbines

Face Seal for Shaft Ends



450 MW_e turbine layout

(CO2 Symposium 2016)

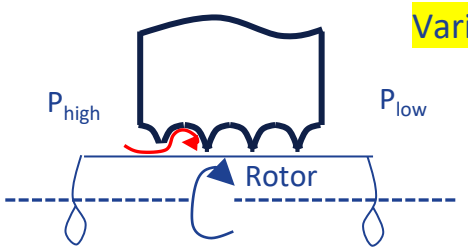


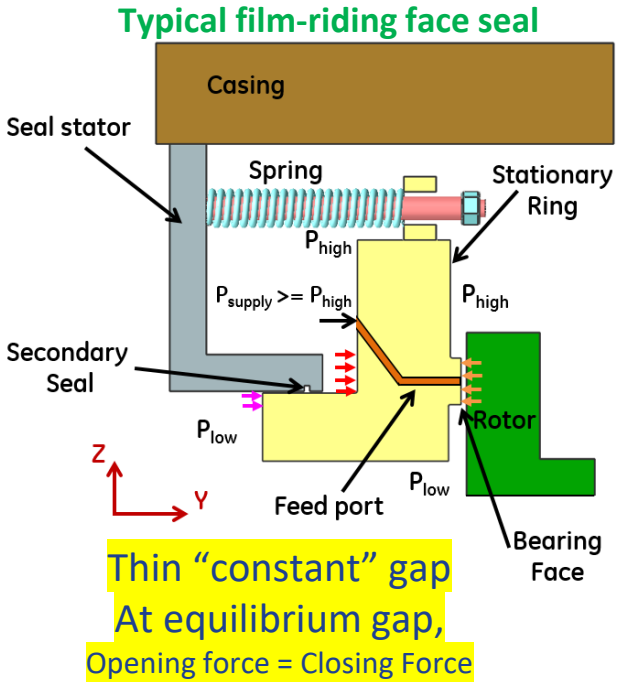
- Face seals are worth ~0.55% points cycle efficiency compared to labyrinth seals
- Face seals needed for utility-scale sCO_2 turbines (24-inch diameter, 1000 psia pressure differential) not readily available

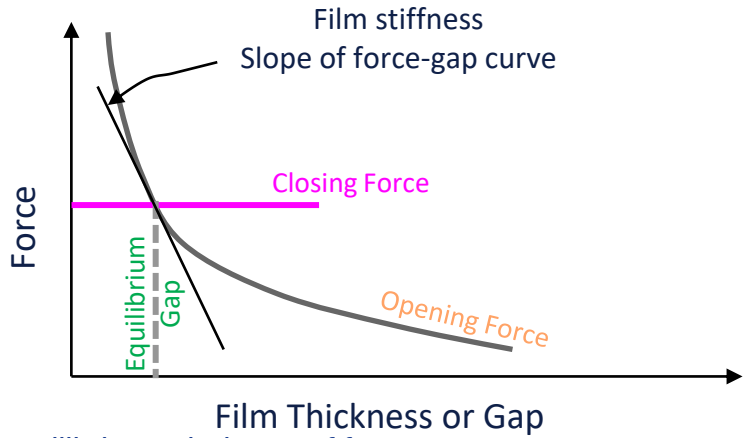
Face seals worth ~0.55% points cycle efficiency for large sCO_2 cycles

Seal Working Principle

Film-riding Seals working principle



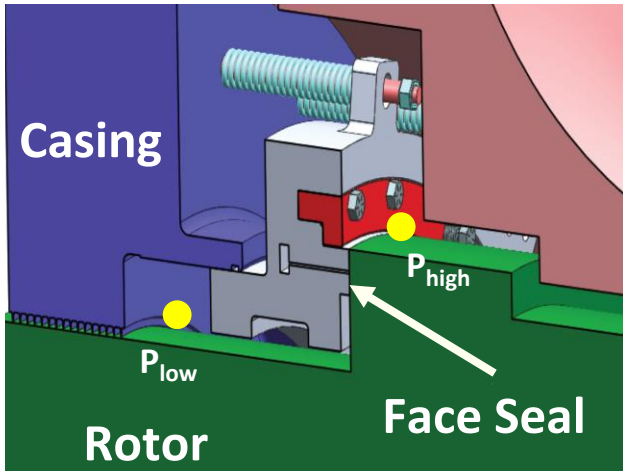


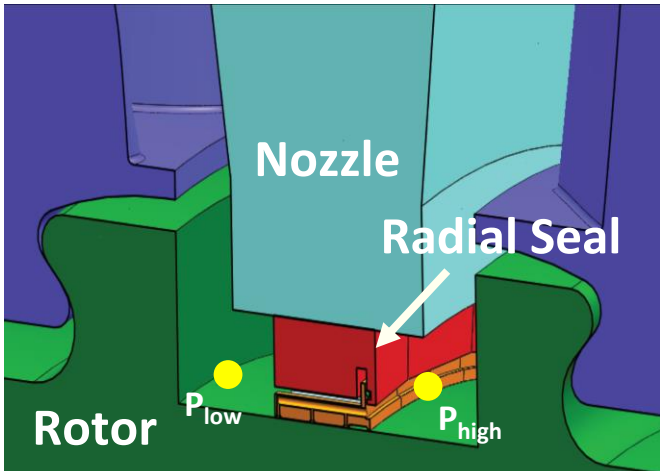


- Seal equilibrium – balance of forces
- Opening force
  - Hydrostatic pressurization/hydrodynamic grooves
  - Positive film stiffness; force increases with reducing film thickness
- Film stiffness
  - Needed for faithful dynamic tracking against inertia, friction, pressure
  - Loss can lead to seal rubs and seal failure
- sCO2 working fluid has unique challenges

Film-riding seals operate with very thin films (0.0003 to 0.002 inch) separating the rotor & seal

Face Seals and Radial Seals





- Film & sealing on axial face
- Need to withstand rotor-stator axial motion

- Film & sealing on radial face
- Need to withstand rotor-stator radial motion

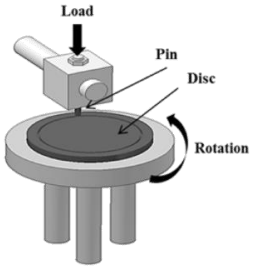
Both types of seals are important depending on sealing location, size envelope & operating condition requirements

Quick Re-cap of Testing (2017-2020)

Summary of Tests (2017-2020)

Room temp Pin-on-disk Coatings tests

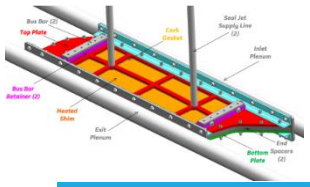
TRL2 test

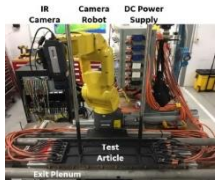


CrC/CrN, AlTiN(Mo,W)S2, DLCs identified as optimal coatings

Room temp Static Flow tests to measure Heat Transfer Coeff. (IGTI 2018)

TRL2 test

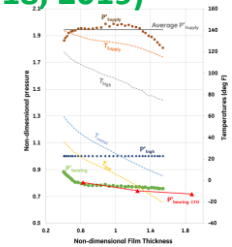




Measured HTCs with scaled experiments

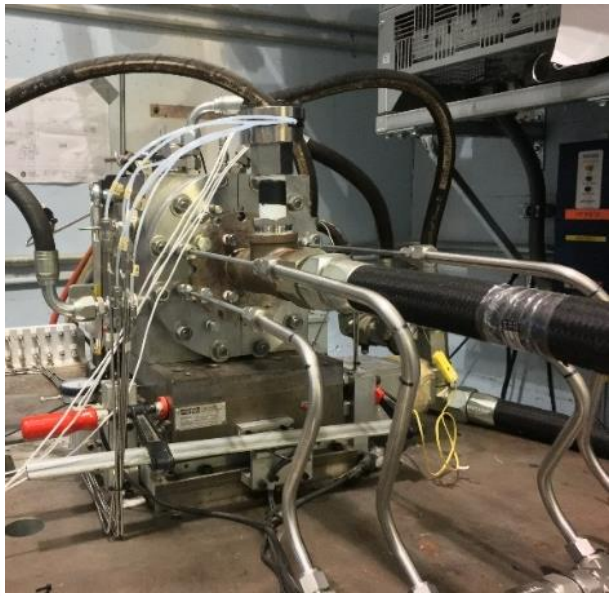
3-inch diameter, Static Medium temp tests with sCO2

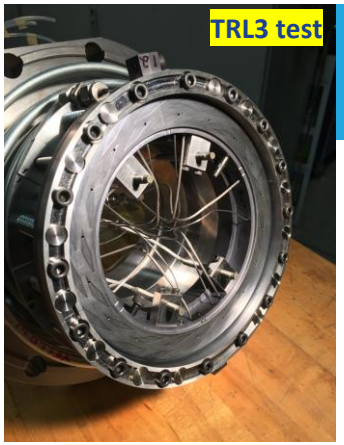
TRL2 test (IGTI 2018, 2019)



Hydrostatic lift with sCO2, match with CFD

5-inch diameter, Rotating Room Temp tests with Air





Split **Face** Seal demo in air

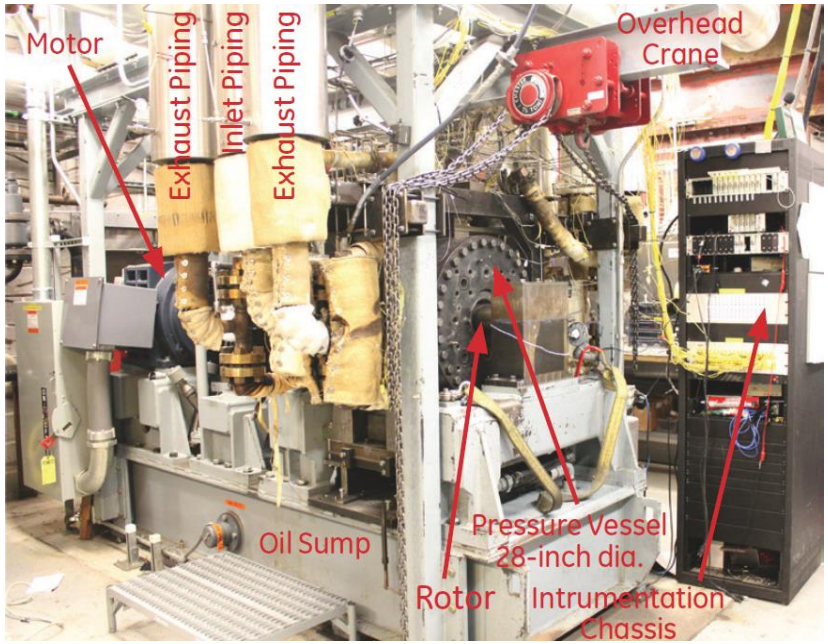
Radial Seal demo in air

14-inch Seal Testing (2020-2022)

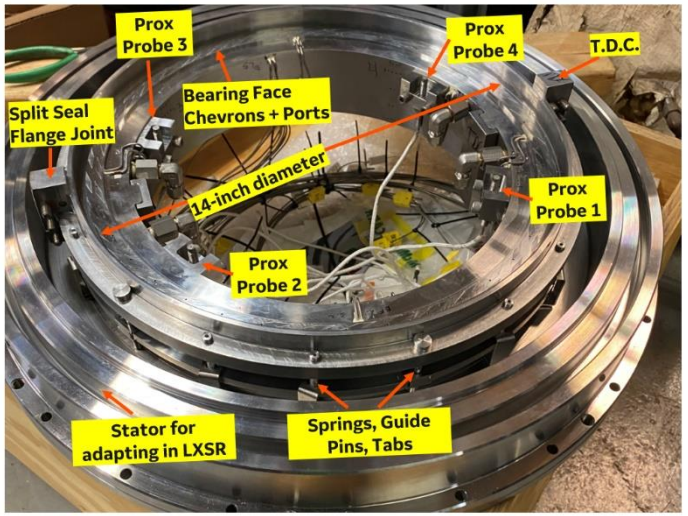
TRL 4/5

14-inch Seal Tests in GE Rig

GE 14-inch Test Rig

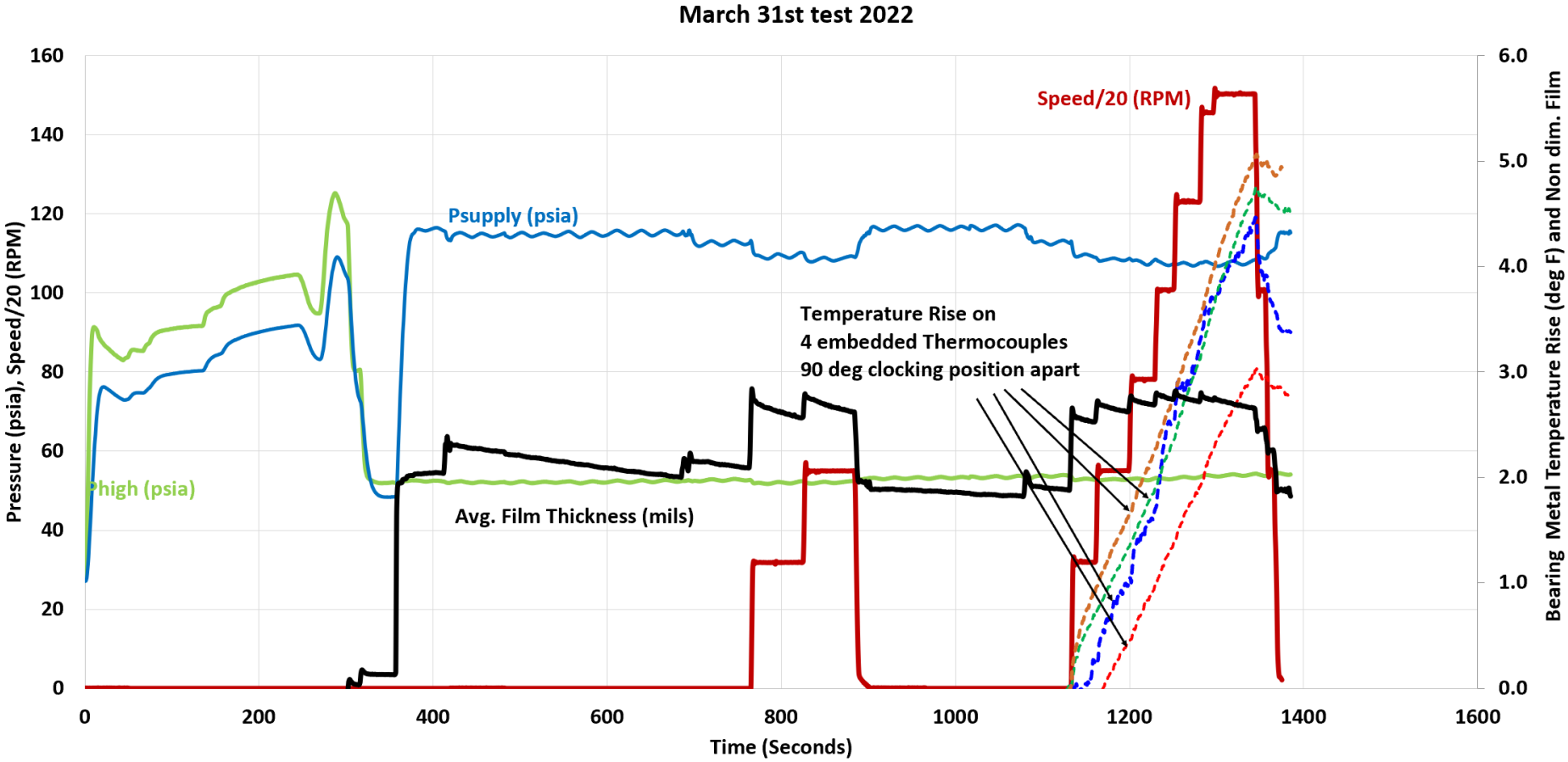


14-inch Face Seal



- Seal Fabrication Apr 2020 – Aug 2021
- 14-inch seal tests started Dec 2021
- Non-rotating Tests Dec2021- March 2022
- Rotating Tests Apr 2022- June 2022

Successful 14-inch Rotating Tests



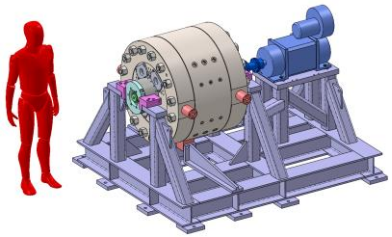
- Rotating tests show 2-3 x 10^{-3} non-dimensional film thickness
- Speeds tested up to 5200 rpm, 350 F inlet air
- Windage temperature rise ~ 5 degrees for this test
- Overall successful test for split-face technology with small operating gaps, on its way to TRL4/5

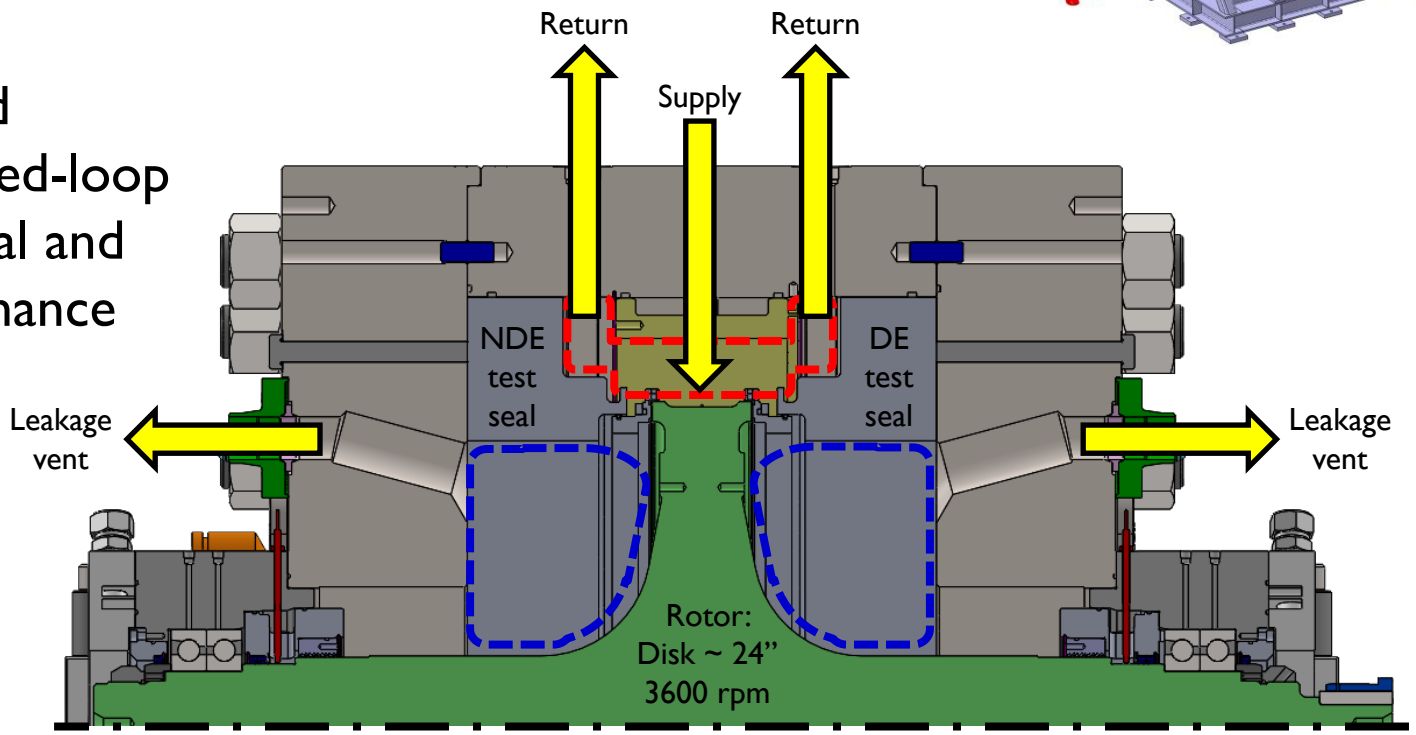
24-inch sCO_2 Seal Testing (2020-2022)

TRL 5/6

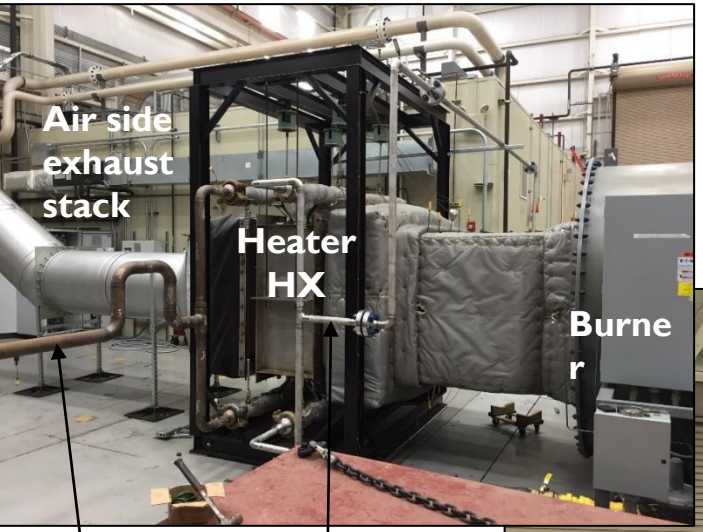
Test rig overview

- Back-to-back seal arrangement
- Thrust balanced
- Open- and closed-loop
- Measure thermal and leakage performance





Conditions:
75 bar, 400°F max
1-10 bar



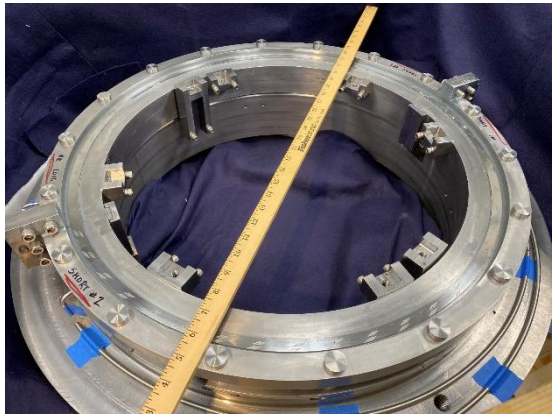
From pump

To rig

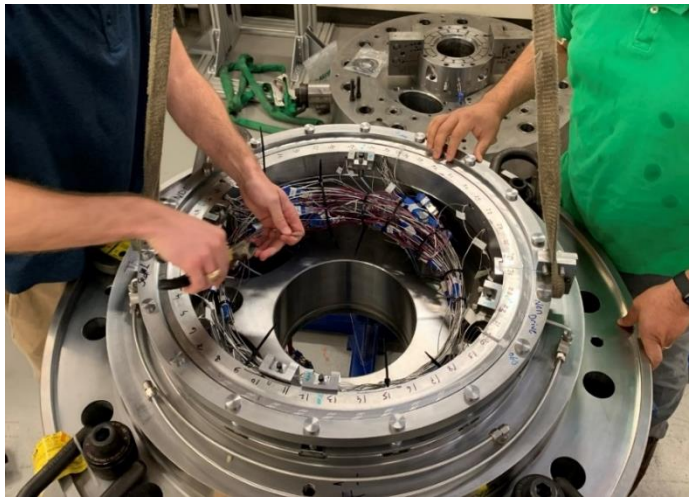
Stainless piping: upstream of rig / from heater
Painted CS piping: downstream of rig

Seal Fabrication Timeline

Seal Fabrication Jan 2021



Seals delivered to SwRI in Seal instrumented Aug 2022



24-inch seal Assembly Aug-Oct 2021

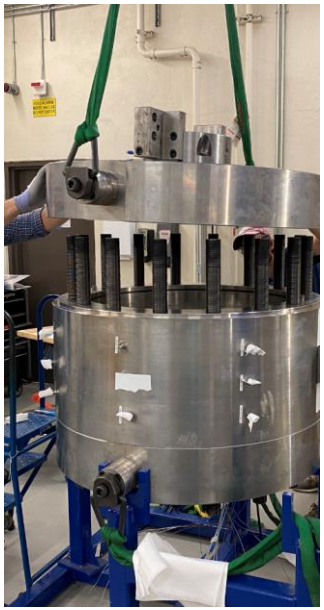
1. Seal assembled

2. Seal attached to end cap

3. End Cap Assembly

4. PV Center Piece Assembly

5. Second End Cap (without seal)



6. Test Rig ready for second seal

24-inch seal assembly – large equipment
Seals assembled and ready for testing Oct 2021

Test Rig Infrastructure Timeline

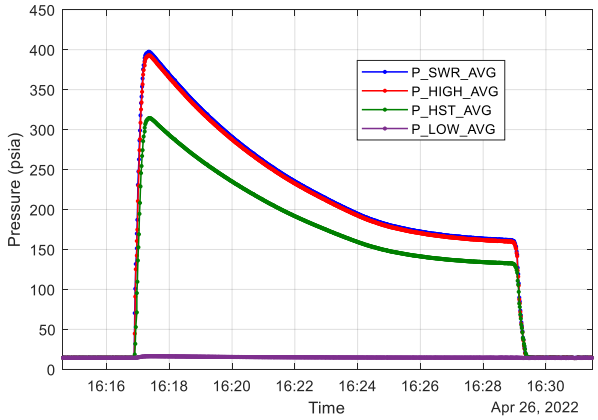
New sCO2 Seals Rig at SwRI
2016 – 2020

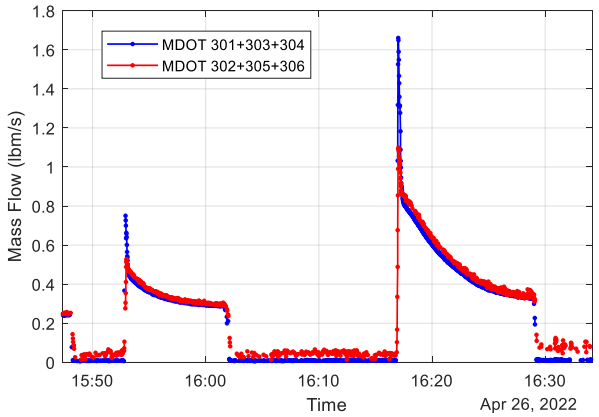
Cryostar Fill Pump Infrastructure
2020-2021

- Rig commissioned – end of year 2020
- Needed a larger Fill Pump
  - Repurpose a prior DOE pump, 2 tanks & new construction near Bldg. 278
  - 2020 – construction
  - 2021 – electrical VFD/sensor issues resolved with MW generator rental
  - 2021 – Dry Gas Seal on Pump failed (weather exposure). Issue resolved Dec 2021

Low-medium pressure blow-down tests (Dec 2021- Apr 2022)

- Blow down tests from ~250 psi and ~450 psi
- Pressure drop over time due to flow leaking through seals
- Flow measurements are consistent: mass conservation
- Exercised flow through upstream cavity and hydrostatic supply

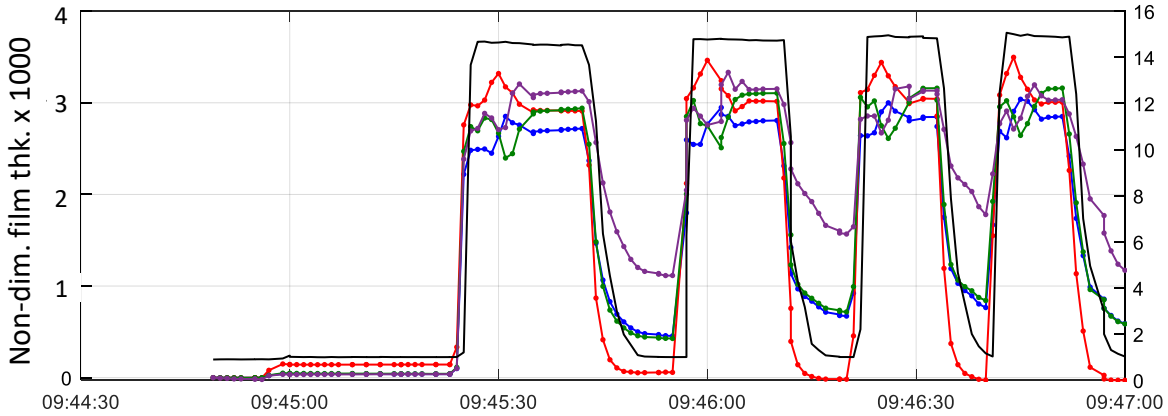


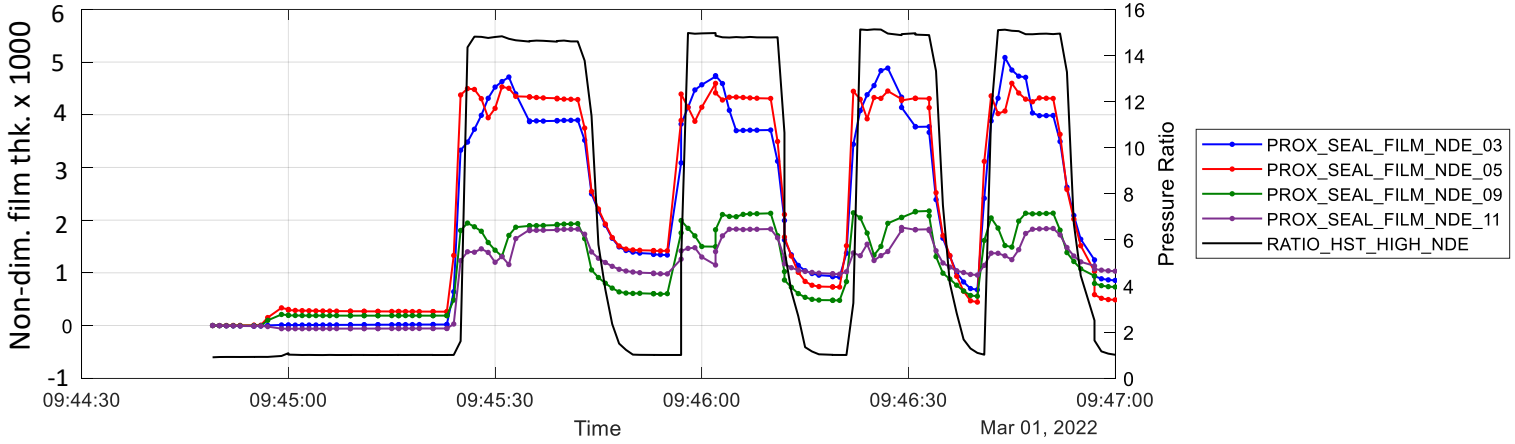


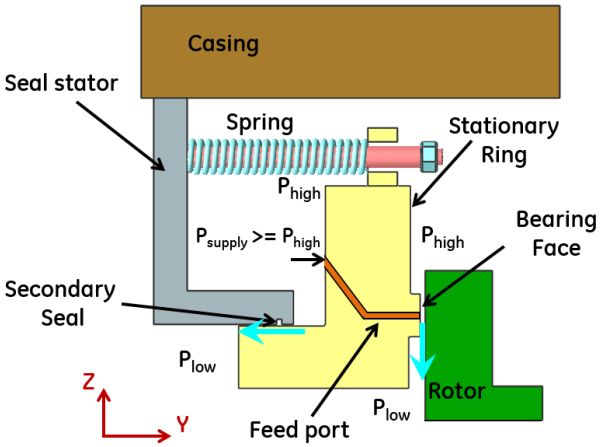
Seal lift-off demonstrated (non-rotating tests)

Shaft HAND rotation possible

Test B, 250 psi…….March 1st 2022 data



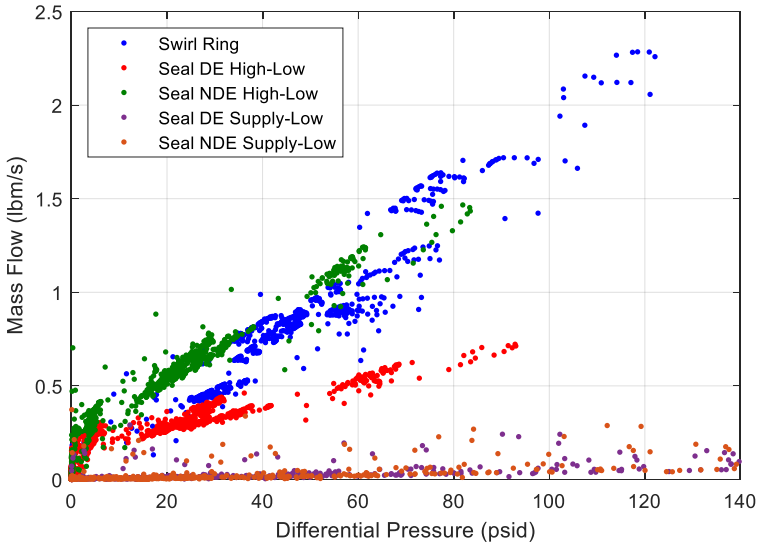




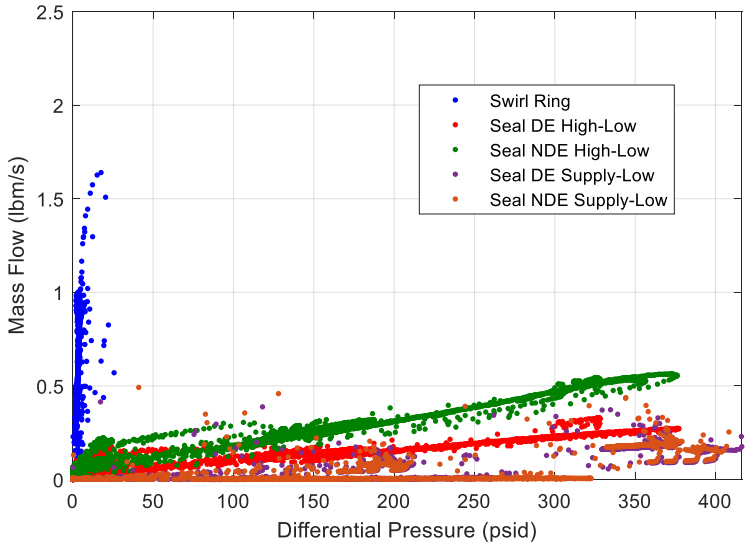
Non. Dimensional film thickness ~ 2 to 4 x 10^{-3} with P_{supply} only

New piston ring seals leak less than original

3/1/22: Original



4/26/22: New



- Piston ring swapped Apr 8th to 10th
- Testing Apr 26th shows order of magnitude leakage improvement
- Metallic piston ring did not work well
- Apr 26th data is an enabler for longer duration tests, rotating tests

Summary & Next Steps

Summary & Next Steps

- 14-inch seal tests
  - Complete tests at higher temperatures & speeds (expected Dec 2022)

- 24-inch seal tests
  - Swapped piston ring – enabler for lower leakage and longer duration tests
  - Low-pressure non-rotating tests (longer duration) – Oct/Nov 2022
  - Rotating tests Dec 2022 -Jan 2023