Low-leakage seals for utility-scale sCO_2 turbines
UTSR-2018

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imagination at work

Outline

- Overview of the program
- Subscale testing Updates
  - Film Stiffness sCO_2 Face Seals
  - Subscale Seal DEMO tests
- Seals Test Rig Development

Overview of Utility-scale sCO_2 Seals Program

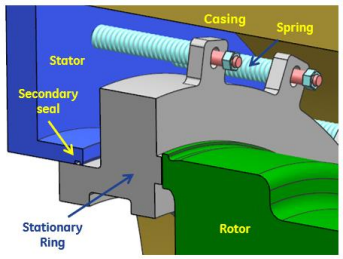
2014		2015				2016				2017				2018				2019		
Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3

Phase 1 Concept Design effort complete

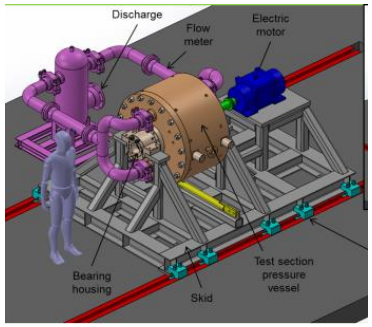
Phase 2 Detail design & testing to attain TRL6

50 MW_e and 450 MW_e Turbine layouts

Face seal concept



sCO_2 test rig Concept



Concept Design TRL 2-3

Air Stiffness Tests

Coatings Tests

Heat Transfer Tests

Subscale demo face seal

Today

sCO_2 Loop & stiffness tests

Full-scale sCO_2 rig design & commissioning

Design & fabrication of full-scale face seals

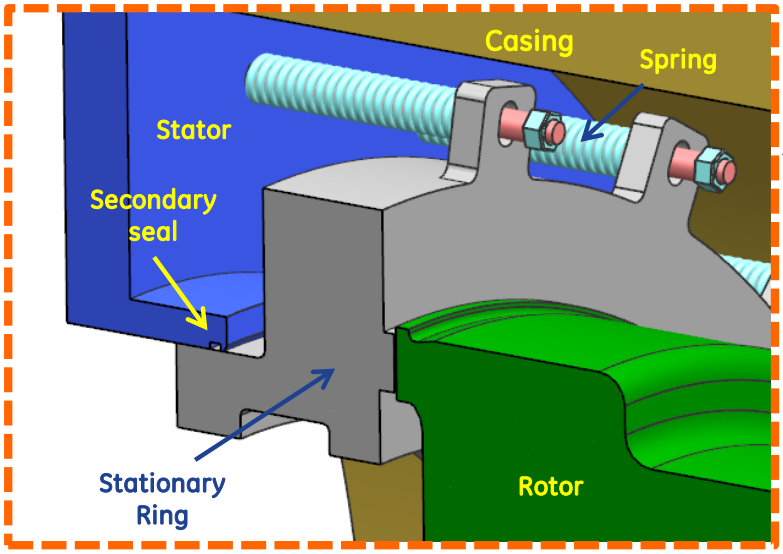
Full-scale Seals Rig Operational

Full-scale Testing

Ready for Field Testing

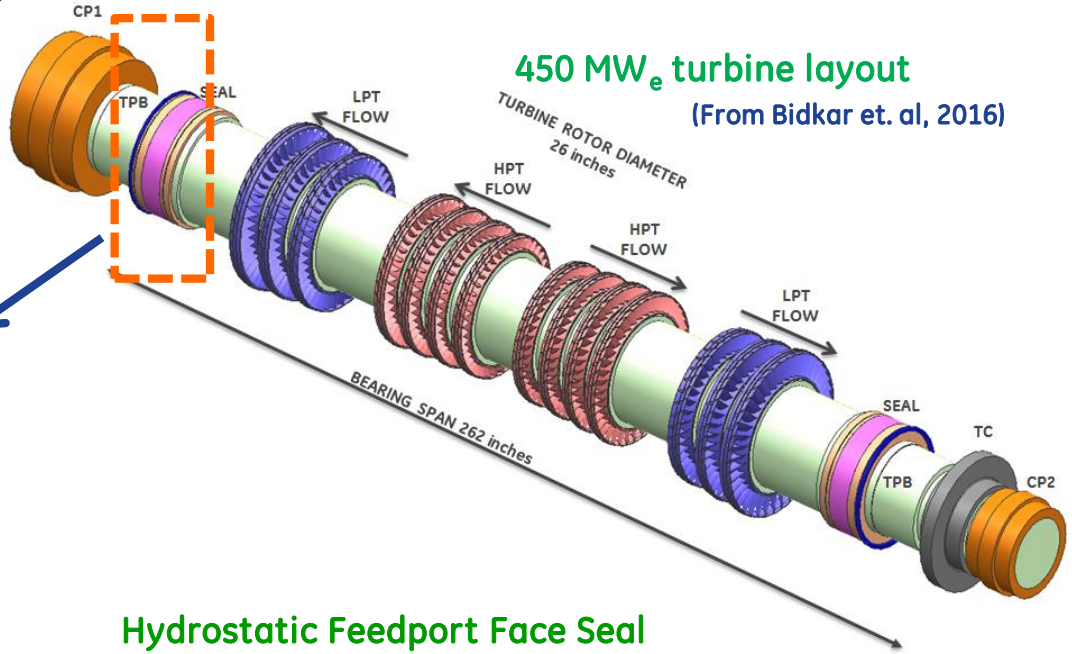
End Seals in sCO_2 turbines

Face Seal for Shaft Ends

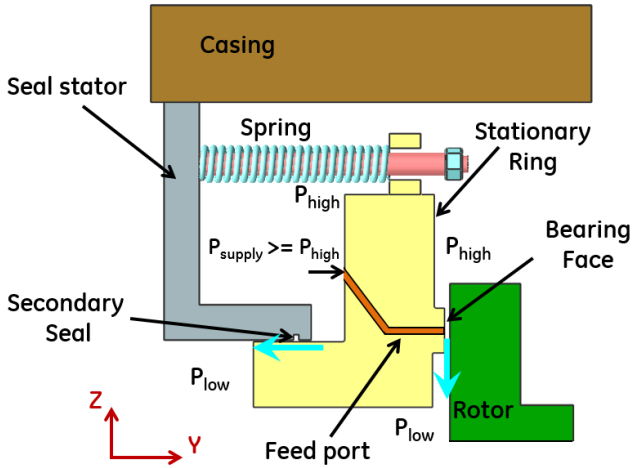


450 MW_e turbine layout

(From Bidkar et. al, 2016)



Hydrostatic Feedport Face Seal

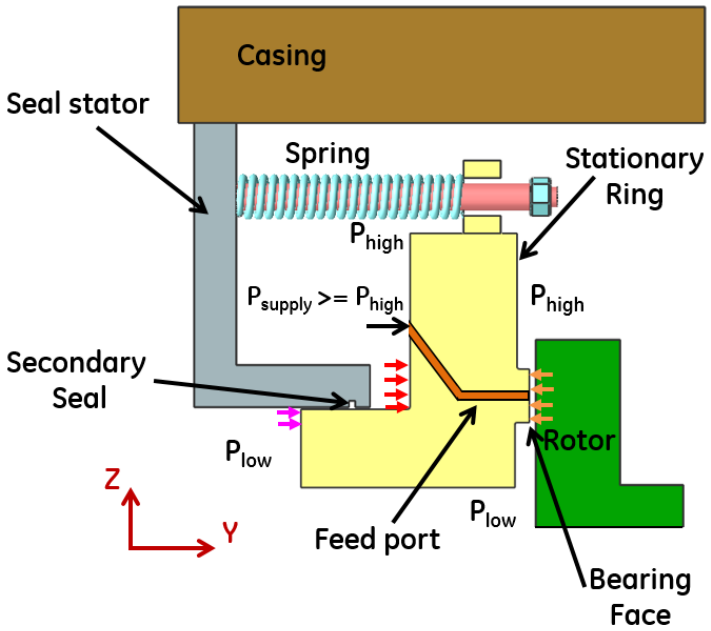


- Face seals are worth ~0.55% points cycle efficiency compared to labyrinth seals
- Face seals needed for utility-scale sCO_2 turbines (24-inch diameter, 1000 psia pressure differential) not readily available
- Two types of seals
  - Hydrodynamic
  - Hydrostatic

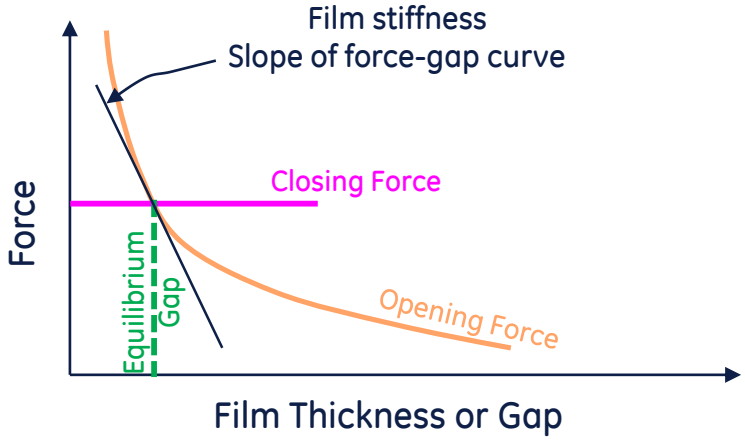
Face seals worth ~0.55% points cycle efficiency for large sCO_2 cycles

Face Seals working principle & Film-stiffness

Hydrostatic Feedport Force Balance



At equilibrium gap,
Opening force = Closing Force



- Seal equilibrium attained after balance of opening & closing forces
- Opening force:
  - Hydrostatic pressurization
  - 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
- sCO_2 working fluid has unique challenges

Film stiffness characterization of seals is important for optimal seal design

Face Seals Film Stiffness Characterization

Need for accurate film-stiffness characterization

Test rig design, fabricate

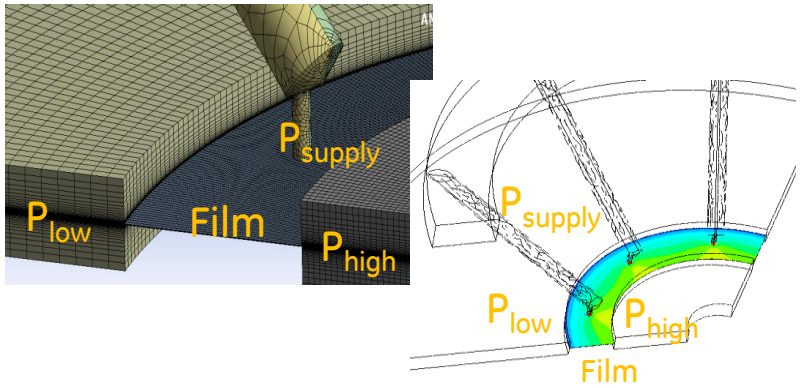
Develop an ANSYS CFX model

Test Rig at GE Research

Force vs. gap test data

Validated CFD Models For Film-stiffness

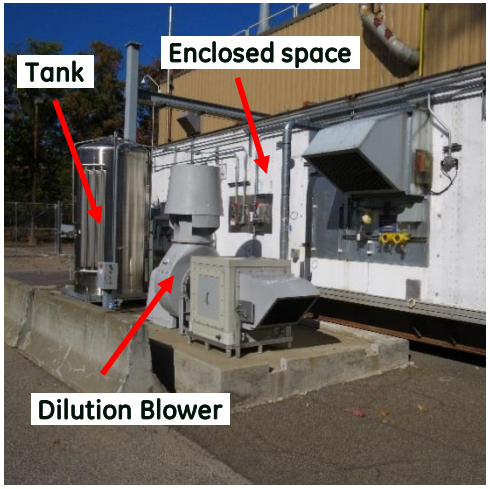
CFD Models

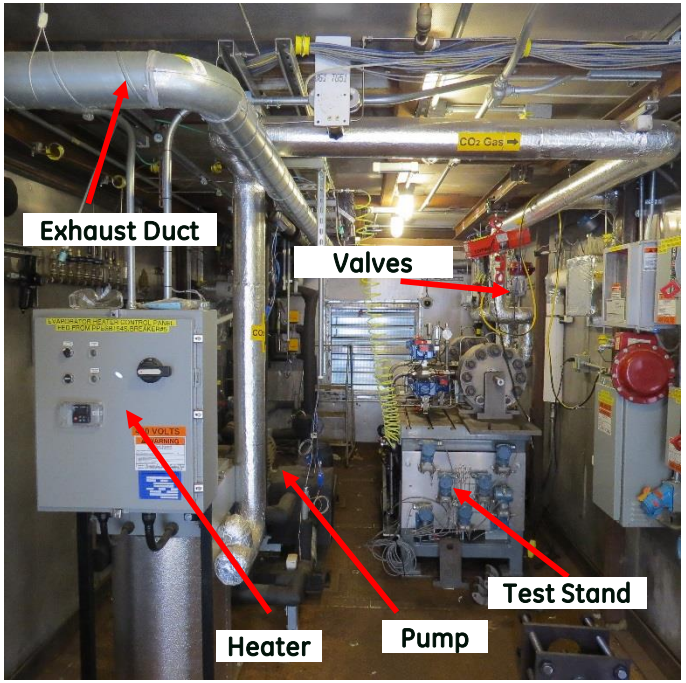


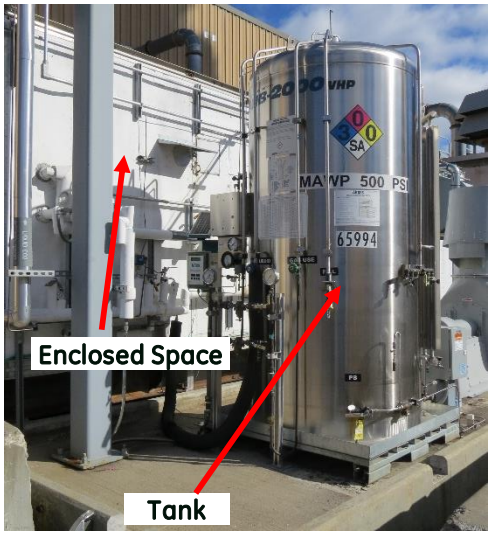
Force vs. gap predictions

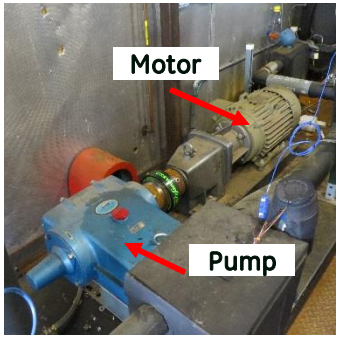
Approach for film-stiffness characterization involved both testing and CFD models

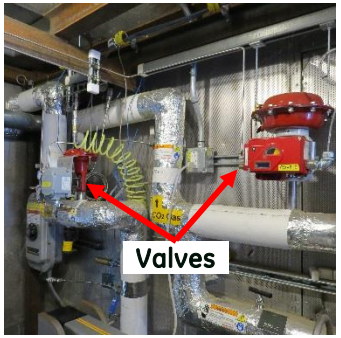
sCO_2 Loop at GE Research







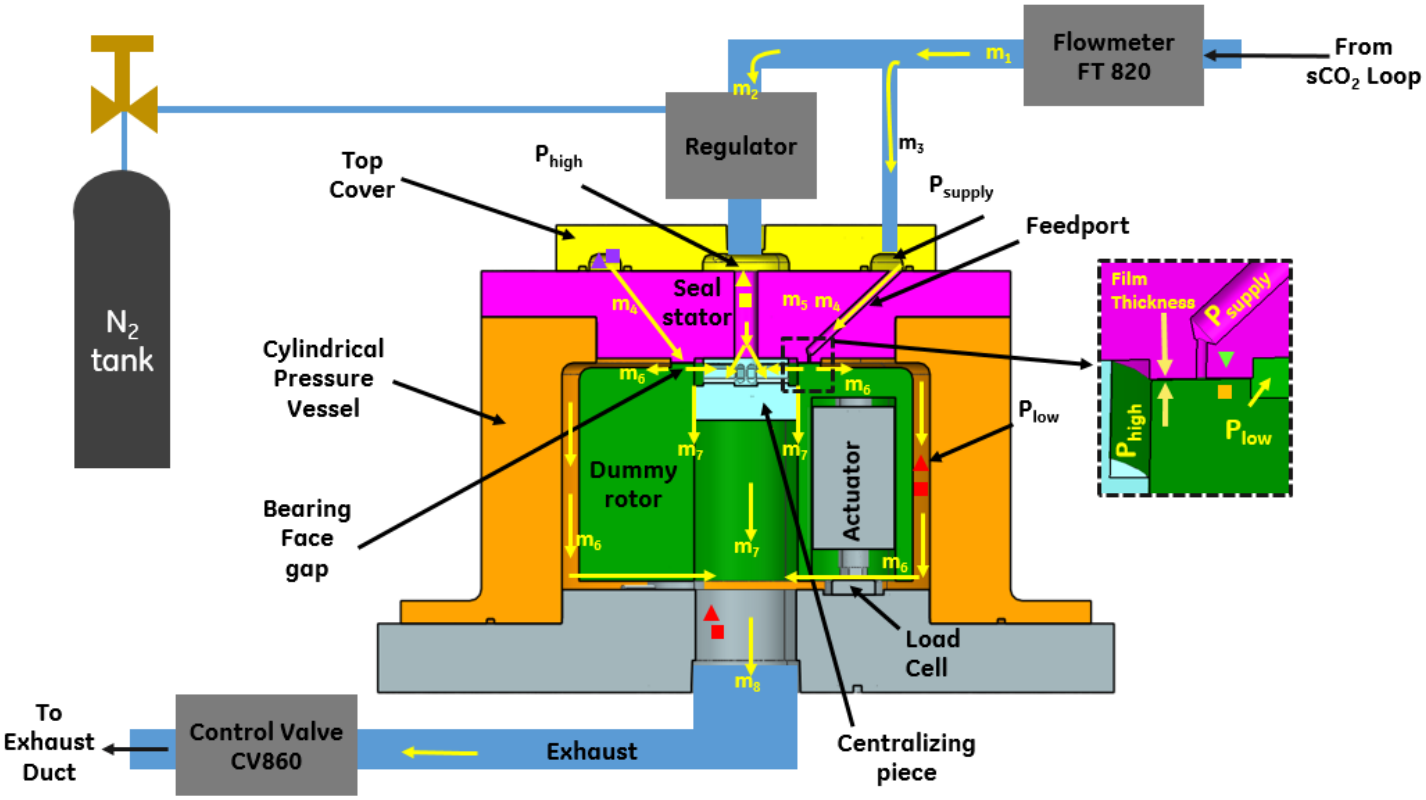




Test Rig for Film-Stiffness Measurement

Test Rig at GE Research

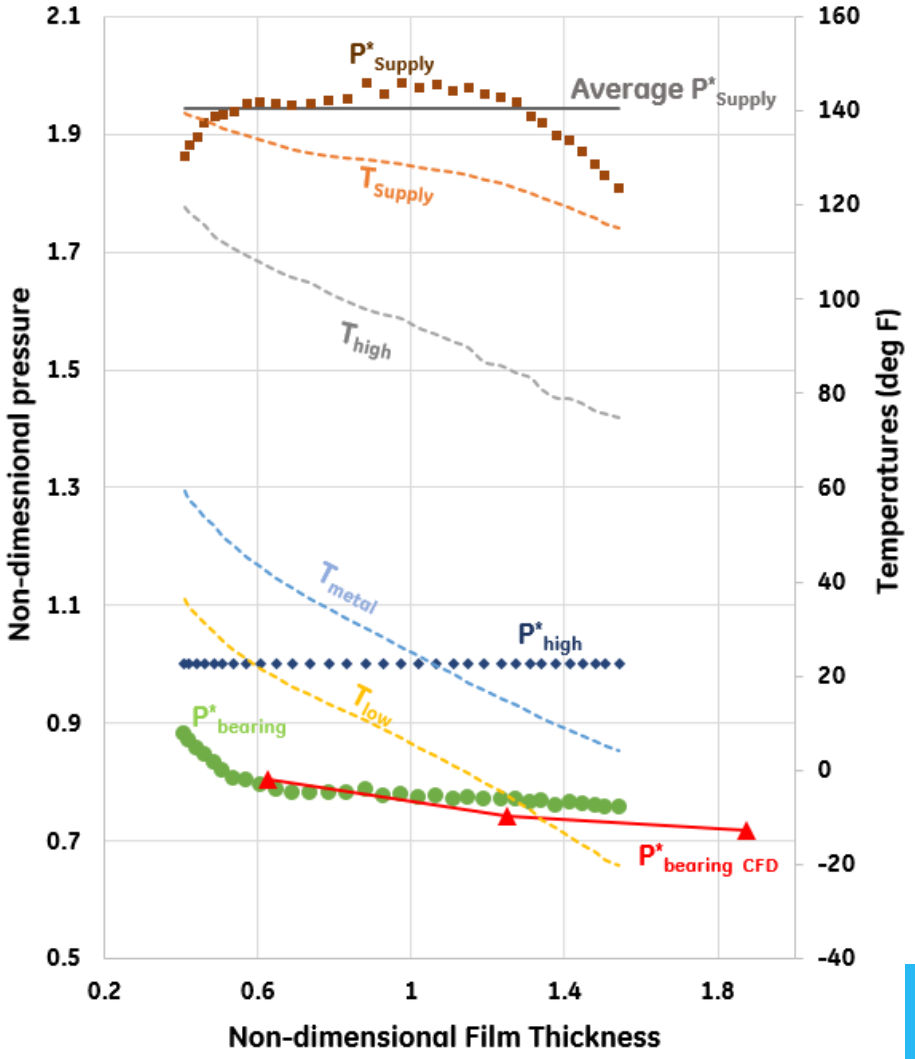
Test rig schematic for film-stiffness characterization



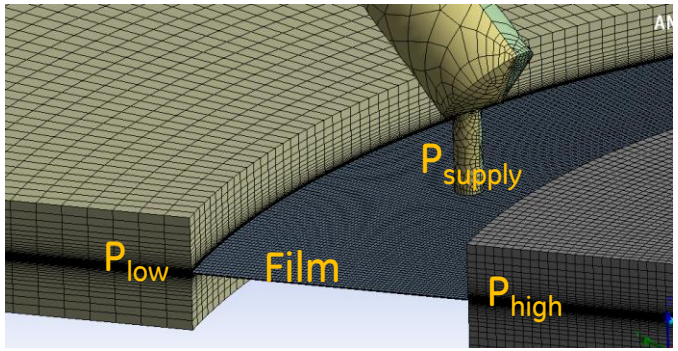
- Test rig simulates flow circuit of a typical hydrostatic seal with pressures P_{high}, P_{low}, P_{supply}
- Stationary rotor & seal stator with adjustable film thickness (with actuators) to measure the opening force (with load cells)
- Test rig can characterize film stiffness for different geometries and different operating pressures

Face Seals sCO_2 Test Data & CFD Results

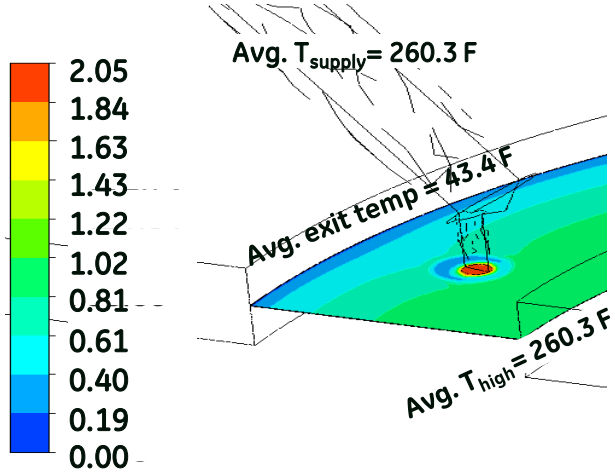
Test Data & CFD predictions
Opening force vs. Film Thickness



CFD Domain



Typical CFD Results: Pressure distribution

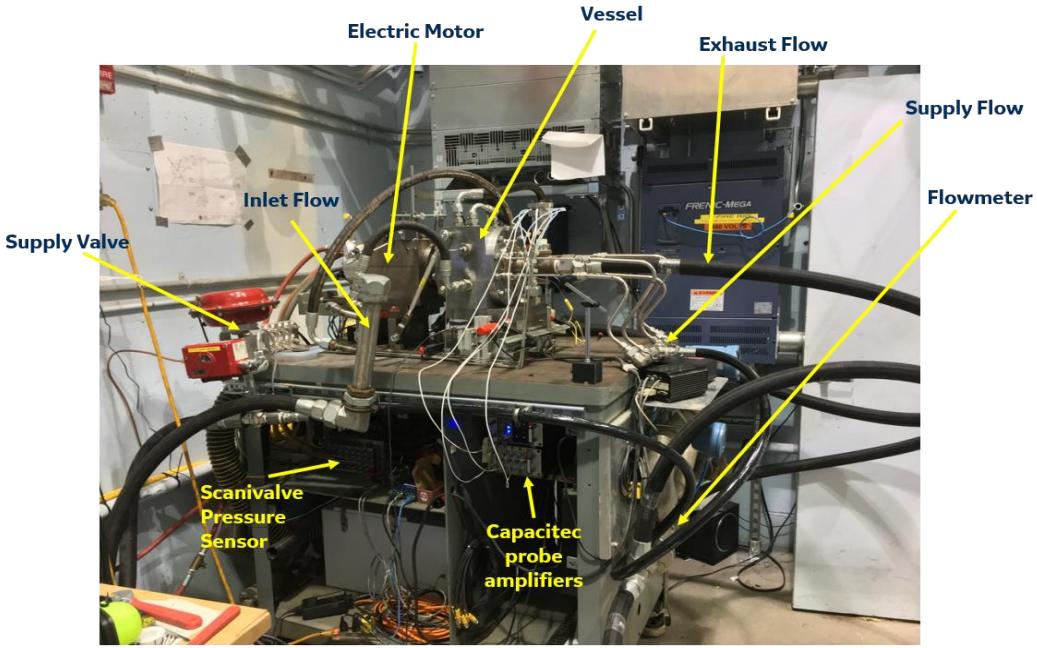


Very good agreement between CFD model & test data for film stiffness predictions

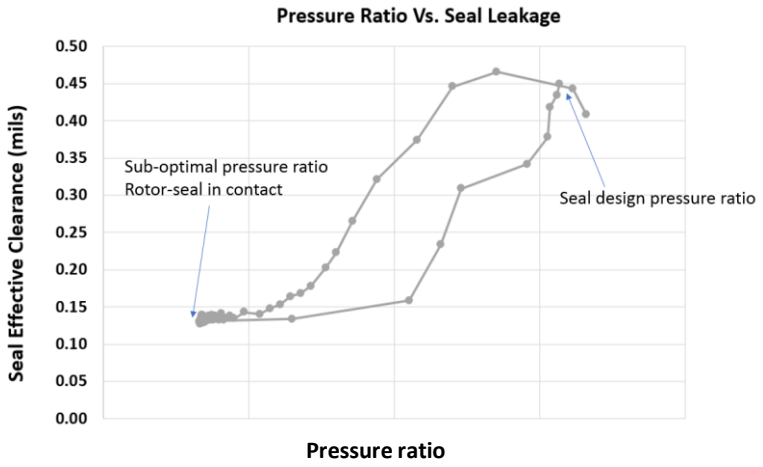
imagination at work

Subscale Seal Tests

Subscale Test Rig at GE



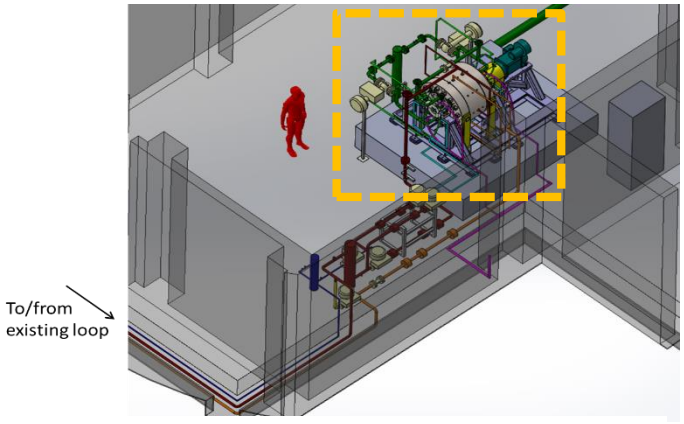
Seal leakage data



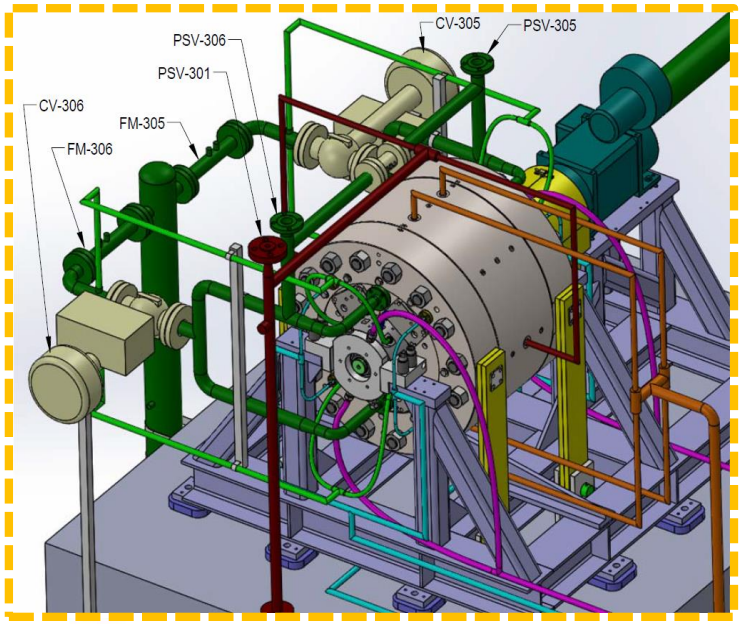
- Seal Design completed with in-house thermal/fluid/mechanical design tools
- Seal Fabrication & test rig modifications completed
- Seal Testing completed on a nominally 5-inch test rig at GE
  - Static & Rotating Flow Tests
  - Pressure & speed sweeps
  - Leakage and temperature-rise data acquired

sCO_2 Seals Test Rig – SwRI

Rig perspective view



Rig CAD model with piping



Picture of Rig (work in progress)

Full-scale Seals test rig design completed & commissioning underway at Southwest Research Institute