High-Temperature Dry Gas Seal (HTDGS) Test Rig

University Turbine Systems Research (UTSR)

Gas Turbine Industrial (GTI) Fellowship Program

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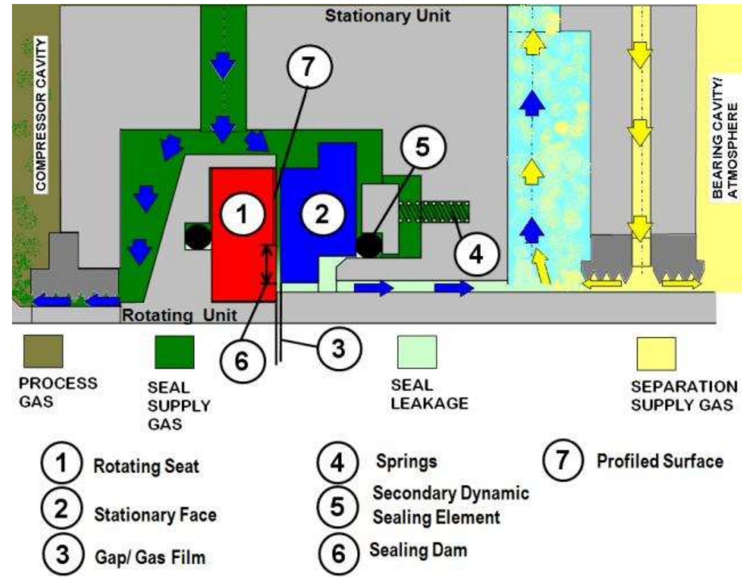
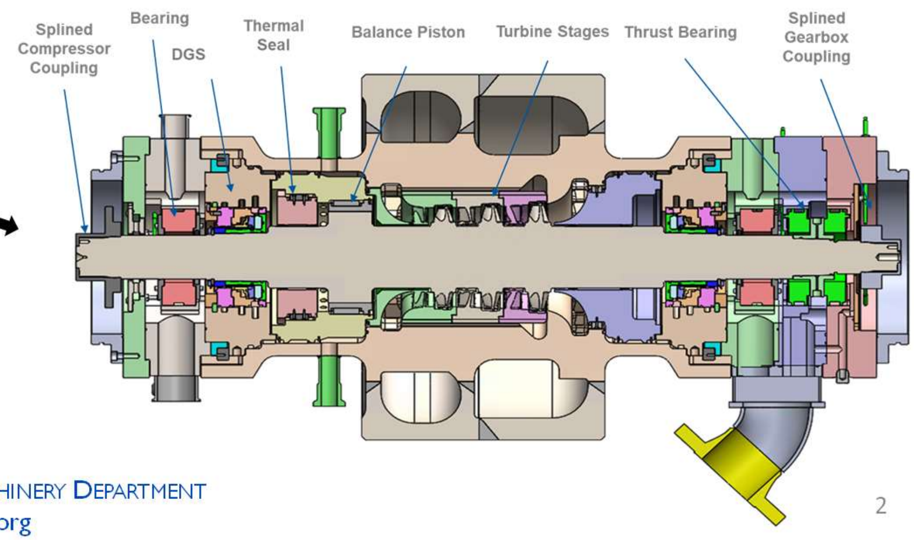
Background

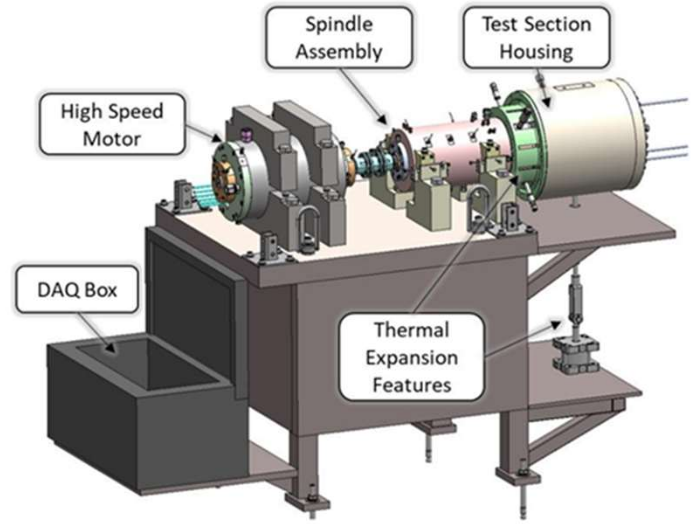
- **Objective:**
  - Test rig capable of testing Dry Gas Seals (DGS) at both high temperatures and pressures (700C, 250 bara)
- **Need:**
  - Higher temperature and pressure requirements in sCO2 turbines
  - Elimination of thermal management system → Higher efficiency

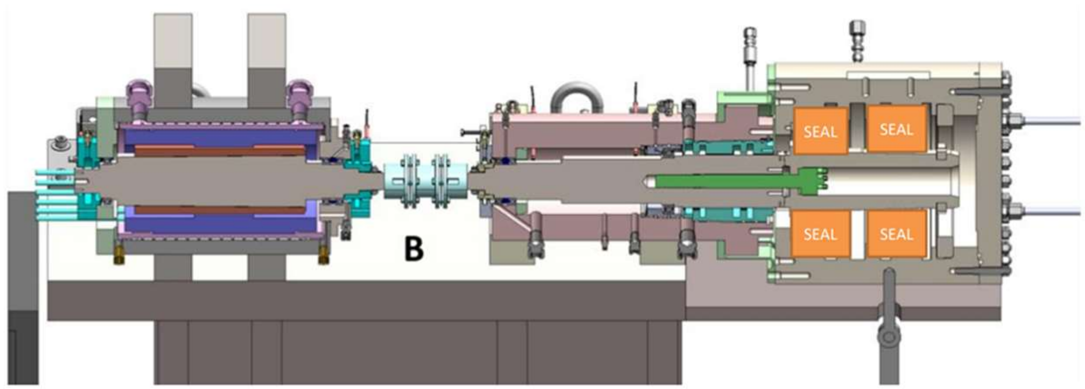




HTDGS Test Rig

- **Goal**:
  - DGS test at 700C and 250 bara
  - Versatility with various seal testing
- **General Layout:**
  - High speed motor assembly:
    - Operating at 21 krpm and 250 kW
  - Spindle assembly:
    - Ground point, thermal management system
  - Test housing assembly:
    - Hirth coupling to accommodate various seal designs
    - Pressure management system
- **Design Challenges:**
  - Thermal growth management
  - Bearing Temperatures
  - ***Pressure management***





End Cap Pressure Analysis

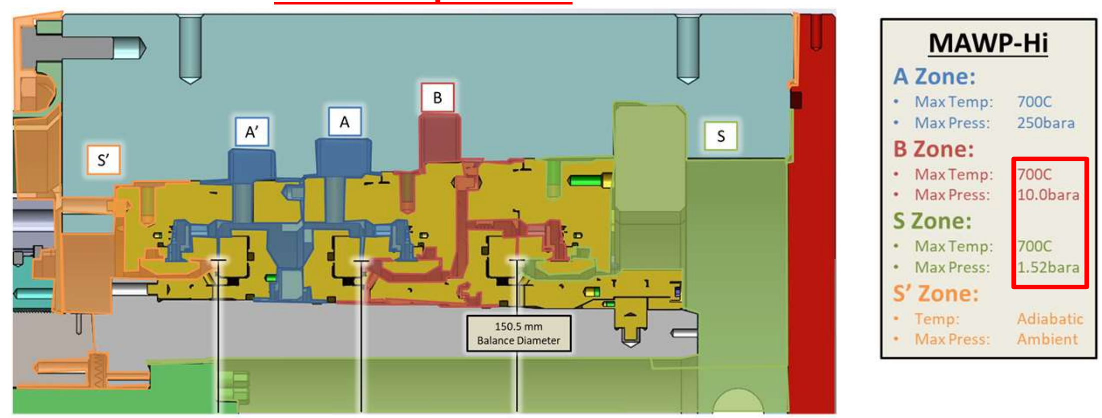
<u>Problem</u>:

- S chamber:
  - Normal Operation: **~1.52 bara**
  - MAWP (Hi-Temp): **~2.5 bara**
  - MAWP (Low-Temp): **~2.67 bara**
- Rapid pressure increase due to high ΔP (B→S)
- Unknown pressure build-up as pressure is relieved

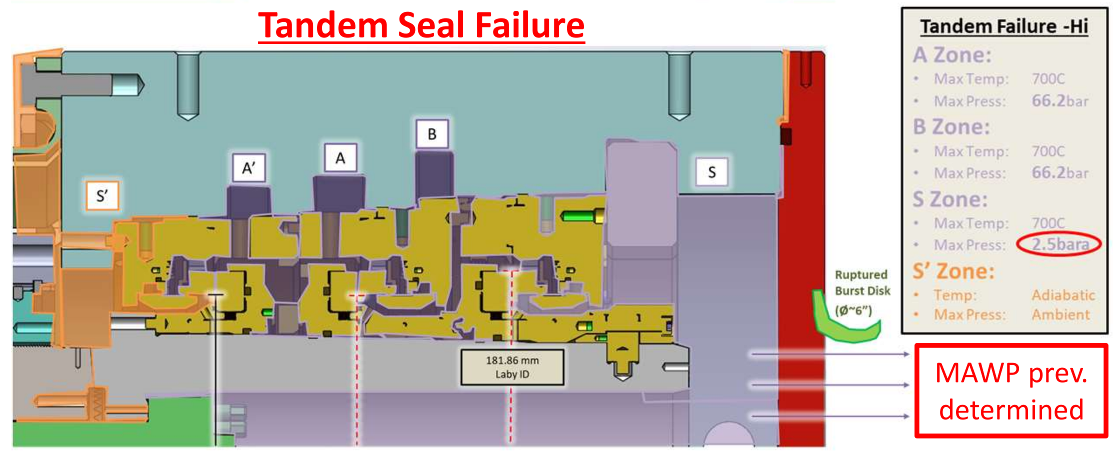
<u>Objective</u>:

- Determine back pressure build-up upon tandem seal failure
- Develop successful pressure relieving strategy (Max Press. < MAWP)
  - Burst disk utilized on end cap

<u>Normal Operation</u>



<u>Tandem Seal Failure</u>



End Cap Pressure Analysis – Transient Model

Objective: Model ruptured burst disk as ***orifice*** flow model and determine pressure in the S chamber

Mass Balance Governing Equations:

$$\frac{dM_{A+B}}{dt} = \dot{m}_{in,ext} - \dot{m}_{B\rightarrow S} \qquad \frac{dM_S}{dt} = \dot{m}_{B\rightarrow S} - \dot{m}_{out}$$

Flow in:

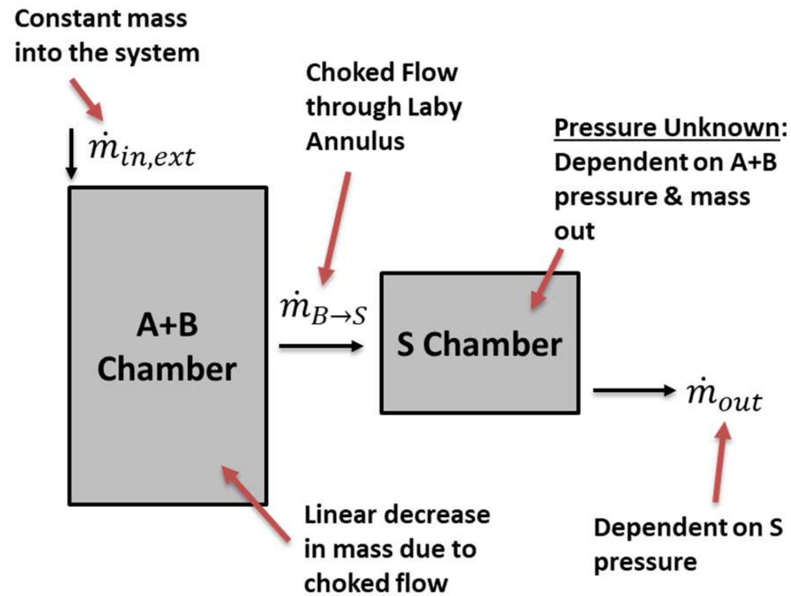
$\dot{m}_{in,ext}$: *Constant CO_2 flow into system*

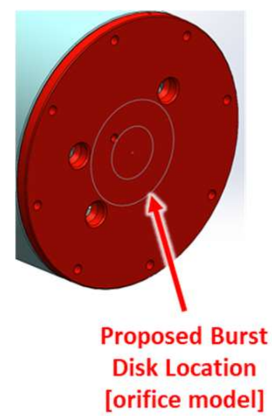
Flow A+B → S

$\dot{m}_{B\rightarrow S} = \rho_{A+B} \cdot v_{SoS} \cdot A_{laby}$: *Choked flow through laby annulus*

Flow S → ambient

$\dot{m}_{out} = C_d \cdot \varepsilon \cdot A_{orif}\sqrt{\frac{2\rho_S \cdot (P_S - P_{atm})}{1-\beta^4}}$: *Flow through orifice (burst disk)*





End Cap Pressure Analysis – Modeling Tool

Pressure Analysis Excel Tool:

- (blue) - Input/ determined via 'Goal Seek'
- (orange) - Input parameters

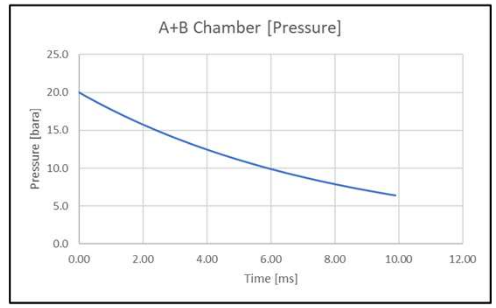
Ambient Conditions			
Description	0	0	Notes
T	700.0	C	Isothermic Temp
P_3	1.000	bara	Ambient Pressure
	100.000	kPa	
	1.00E+05	Pa	

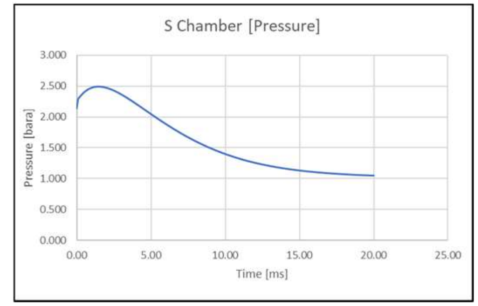
Initial Conditions of S Chamber			
Parameters	Values	Units	Notes
C_d	0.600	-	Burst Disk Cd estimation
$\rho_{2,0}$	1.162	kg/m³	S Chamber initial density
d2	9.9213	in	Upstream diameter
β	0.403	-	Chamber/Orifice diam. ratio
γ	1.182	-	Ratio of specific heats
x	0.532	-	ΔP over upstream pressure
Y	0.355	-	Constant
ε	0.811	-	Expansion Factor
R	0.189	(kJ/kg)/K	Gas Constant/ REFPROP
V2	0.00362	m3	Volume of S Chamber
T	700.0	C	Isothermic Temp
	973.15	K	
$P_{2,0}$	2.137	bara	Initial Pressure at burst (max burst)
	213.7	kPa	
	2.14E+05	Pa	
$Z_{2,0}$	1.000	-	Compressibility Factor/ REFPROP
Initial Mass	0.004203	kg	Calc

A+B to S Chamber Initial Conditions			
Parameters	Values	Units	Notes
P1	20.0	bara	A+B Cavity Pressure
	2.00E+03	kPa	
	2.00E+06	Pa	
v1	468.70	m/s	Speed of sound (choke flow)
V1	0.00218	m3	Volume of A+B Chamber/ CAD
area1	5.75E-04	m²	Laby annulus
$Z_{1,0}$	1.0039	-	Initial Comp. Factor/ REFPROP
Min,ext	0.1159	kg/s	Const./ mass flow into system
	0.023614		
M_0	7	kg	Initial mass

Laby Seal			
	39.37	mils	Calc
Laby Clearance	1	mm	
	1.00E-03	m	
Laby D(ID)	182	mm	HDGS1130-TA1-U-Final (EB Seal Drawing)
	1.82E-01	m	
Laby D(OD)	184	mm	HDGS1130-TA1-U-Final (EB Seal Drawing)
	1.84E-01	m	

Burst Disk			
d3	4.000	in	burst disk diam - (full rupture)
	1.02E-01	m	
Nd	1.00E+00		
A_{orif}	1.26E+01	in²	Orifice Area
	8.11E-03	m²	





Tool Uses:

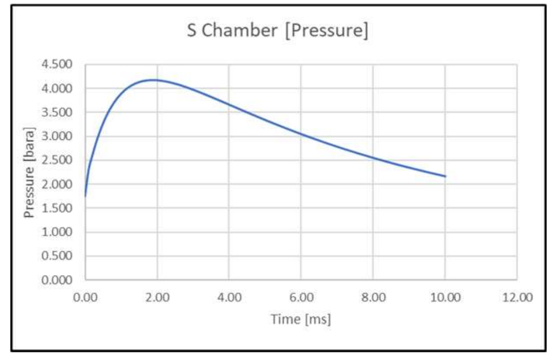
- Transient pressure relief characteristics
- Easily and quickly work through different configurations (i.e. disk size, quantity, input pressure, laby clearance, etc.)
- Allows for more informed decision on pressure management
- Configured for versatile use cases with similar assumptions

End Cap Pressure Analysis – Initial Results

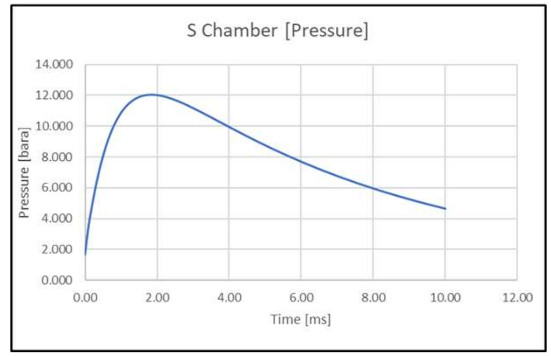
Burst Disk Diameter: 6 in			
Test	**Parameter**	**Value**	**Unit**
Low-Test Point [500C]	A+B Operating Pressure	82	bara
	S Operating Pressure	1.52	bara
	S Burst Pressure	1.747	bara
	Max S Pressure	4.174	bara
Hi-Test Point [700C]	A+B Operating Pressure	250	bara
	S Operating Pressure	1.52	bara
	S Burst Pressure	1.747	bara
	Max S Pressure	12.065	bara

Remember… [MAWP]
Hi: **~2.5 bara**
Low: **~2.67 bara**

Low-Test



Hi-Test



High S chamber pressures results in significant forces on End Cap

Limiting Factors:

- Large laby seal clearance (40 mils) → high mass flow to S chamber
- High pressure ratio A+B → S
- Burst Disk diameter restriction

Proposed Solutions:

- End cap re-design to accommodate increased load
- Incorporate larger burst disk [> 6in]
  - Cons: Increasingly expensive as diameter increases; even more if custom design is required
- Incorporate PSV pressure relief before S chamber reaches maximum pressure
  - Add PSV to relieve pressure in B chamber before secondary seal failure

End Cap Pressure Analysis – Revised Results

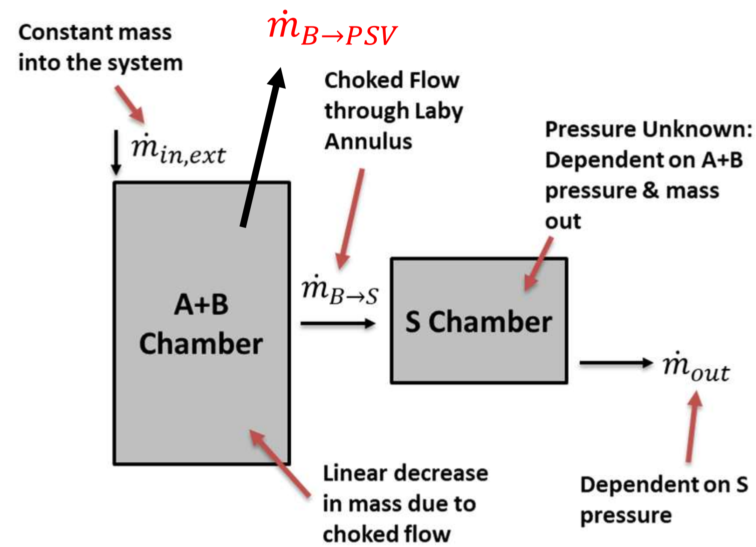
Thus far, model assumes tandem seal failure ∴ high pressure region rapidly builds pressure in S chamber

Implementing PSV into Chamber B:

- Incorporate PSV pressure relief from B chamber (nominally 10 bara)
  - After primary seal failure (A→B), B chamber will build pressure above 10 bara.
  - PSV engages and relieves pressure ***before secondary failure***

Incorporation into model:

- PSV set at specified pressure (estimate 20 bara for model purposes)
- Assume PSV sustains specified pressure in chamber B as pressure is relieved



Burst Disk Diameter: 4* in			
Test	**Parameter**	**Value**	**Unit**
Low-Test Point [500C]	A+B Seal Failure Pressure	20	bara
	S Operating Pressure	1.52	bara
	S Burst Pressure	2.137	bara
	Max S Pressure	2.485	bara
Hi-Test Point [700C]	A+B Seal Failure Pressure	20	bara
	S Operating Pressure	1.52	bara
	S Burst Pressure	2.137*	bara
	Max S Pressure	2.487	bara

****Note:** 4 in burst disk modeled in analysis rather than 6 in*

PSV reduces force on end cap and increases control in pressure relief system

Future Work Recommendations:

- *Implement PSV into test rig P&ID*
- *Determine and incorporate factor of safety into PSV actuation pressure*

Conclusions

- Developed modeling tool for more in depth pressure behavior upon seal failure
  - *Allowed more informed pressure mitigation strategy*
- Successfully prepared test rig for hydrotesting
  - *Parts quoted for machining*
  - *Next steps: Hydrotest the seal housing*
- Progressed the project into preparation to testing phase
  - *Challenges faced in motor spinning, and project management prevented testing being conducted during fellowship timeline*
  - *Next steps: final assembly of test rig*

Thank You

Questions