Hydraulically Controlled Mechanical Seal for Reactor Coolant Pump

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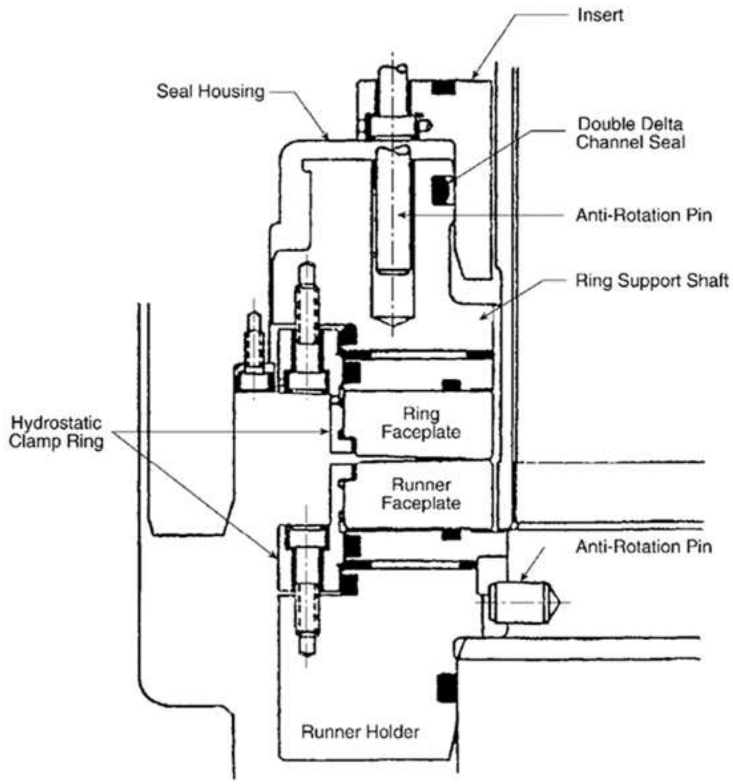
The Westinghouse #1 RCP Seal



Ring is pre-coned for full film lubrication.

- 410 Stainless Steel face holder
- Aluminum Oxide or Silicon Nitride face
- Pressurized at **15.5 MPa** at OD, 0.48 MPa at ID (2250 to 70 psi)
- Seal injection system cools water to ~66 ℃ (150 ℉)
- Nominal leakage rate = **11.36 L/min** (3.0 gpm)

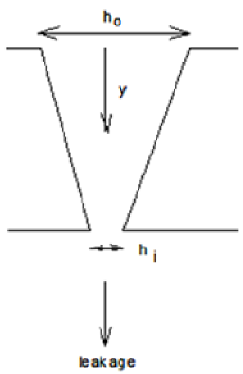
Abnormal Leakage Rates

- Undesirable high or low leakage rate.
- Common causes:
  - Electrophoresis (Chemical Deposition)
  - Pump Transients
  - Temperature and Pressure Excursions
- Can require reactor shutdown in extreme cases.

Controllable Seals – a Potential Solution

- Limited mitigation options has motivated interest in a method of active control of leakage rate.
- Previous controllable seals – two methods:
  - Control the closing force
  - Control the opening force by controlling face geometry (especially the coning!)
- Controlling coning is preferred for stability.
- Based on $h_i \sim \delta$ where h_i is the film thickness at the ID and δ is the coning.

Coning

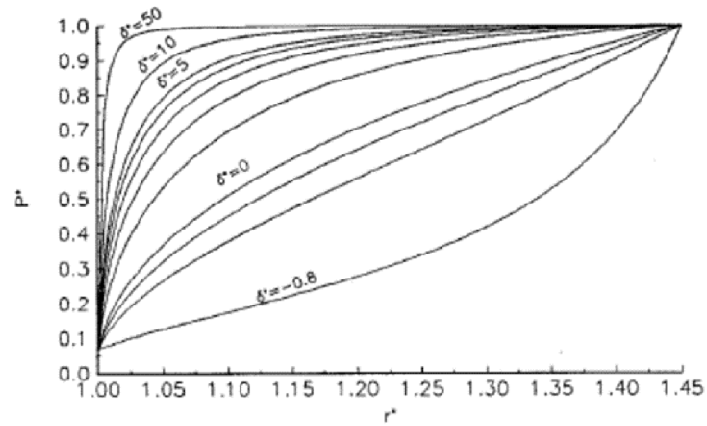


Example of Positive Coning

$$\delta = h_o - h_i$$

Coning is normally developed by:

- Mechanical Deformation
- Thermal Deformation
- Pre-Coning

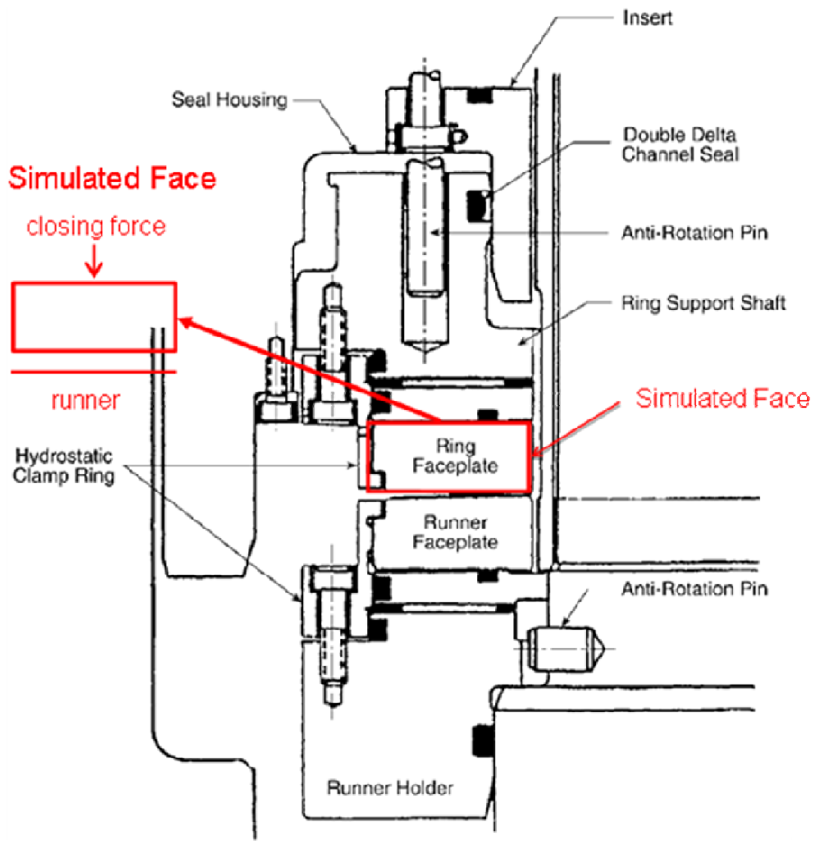


- larger δ/h_i – more bowed out the profile & larger area under curve
- area ~ opening force = closing force
- each curve – given value of closing force
- for a given closing force,
  δ/h_i = constant
  or $h_i \sim \delta$

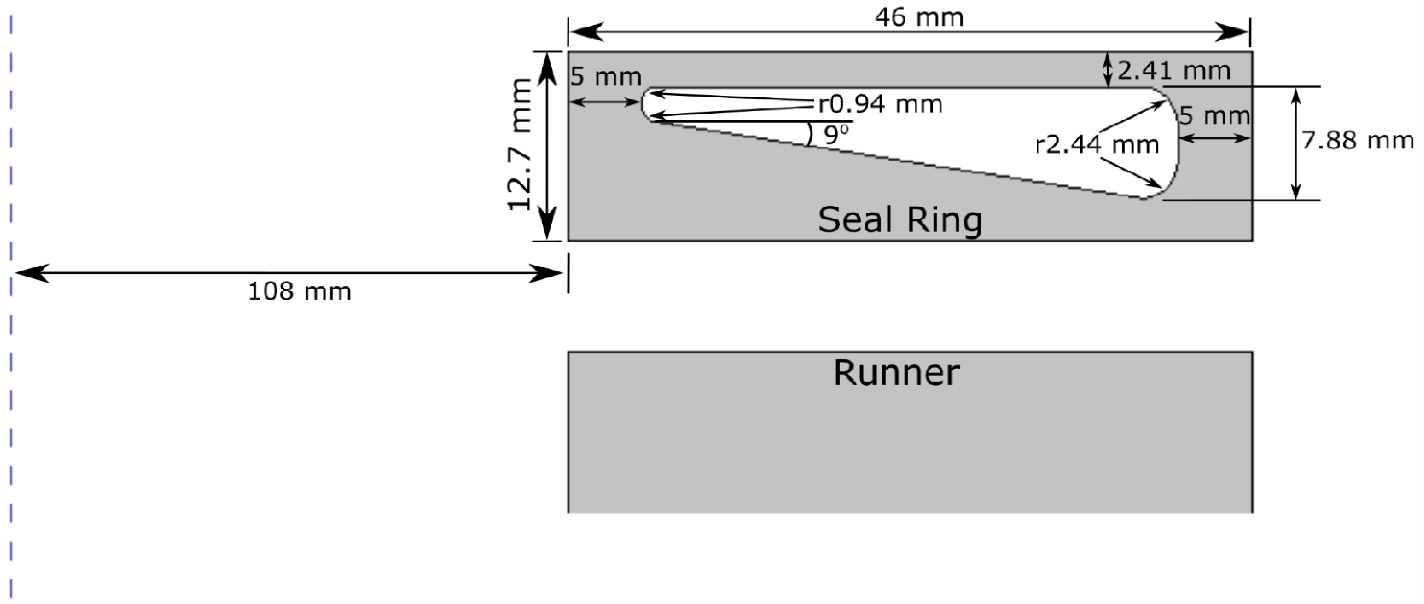
Proposed Controllable Seal for RCP

- Proposed seal face uses hydraulically pressurized internal cavity for active control of coning to adjust leakage rate.
- Proposed seal face is drop-in replacement for existing Westinghouse #1 seal face.
- Numerical models created to predict approximate performance.

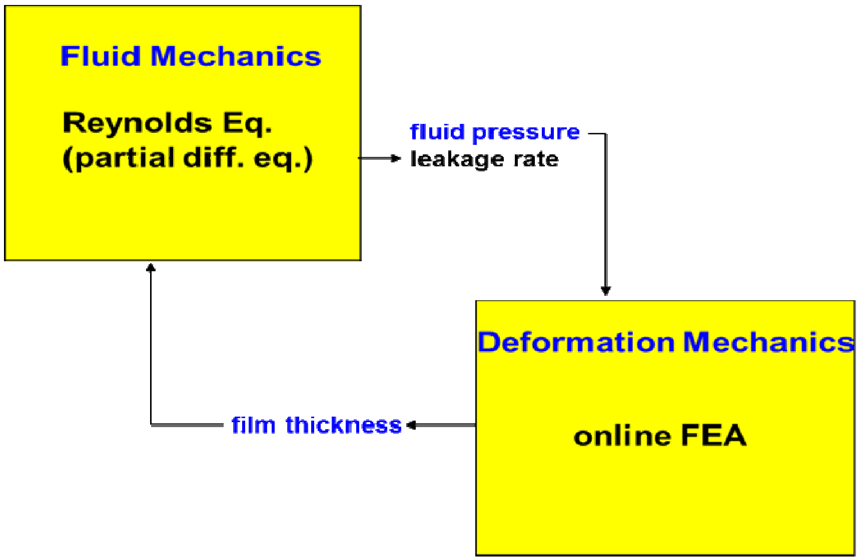
The Modeled Face



Hydraulically Controlled Seal Geometry



Seal Behavior & Numerical Model Components

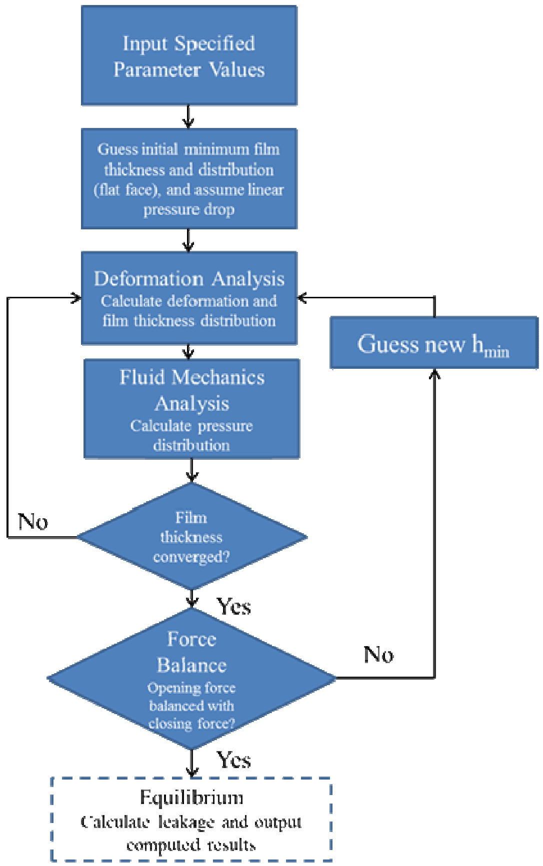


Iterative computational procedure required

Numerical Modeling

- Model couples deformation and fluid mechanics in face gap
- Fluid mechanics solved numerically using Reynolds Equation in Python
- Deformation solved using finite element analysis (ABAQUS)
- Solve iteratively until converged solution is reached

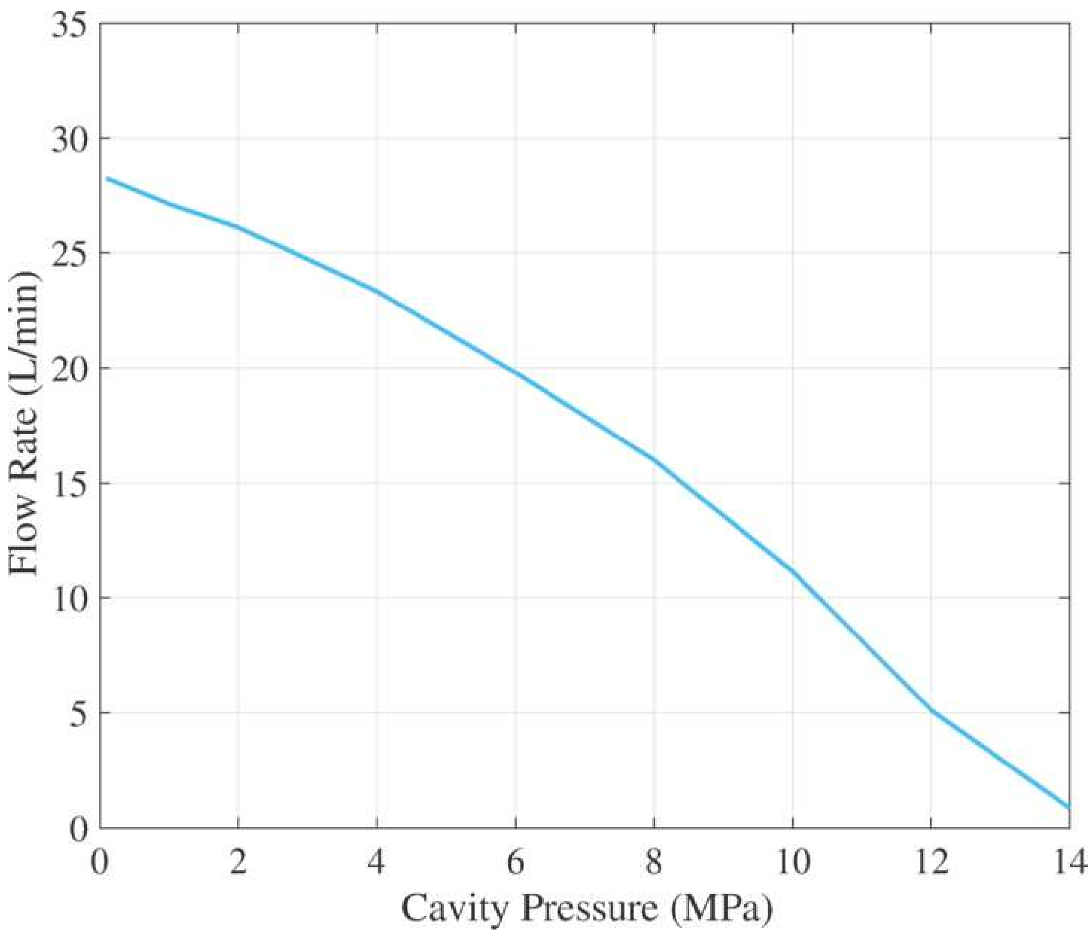
Computational Procedure



Types of Results of Simulations

- Varying leakage rate
  - Set nominal closing force.
  - Vary control pressures.
  - Compute leakage.
- Restoring nominal leakage rate
  - Perturb closing force from nominal value.
  - Compute leakage (“uncontrolled leakage”).
  - Change control pressures until nominal leakage is obtained.

Varying Leakage

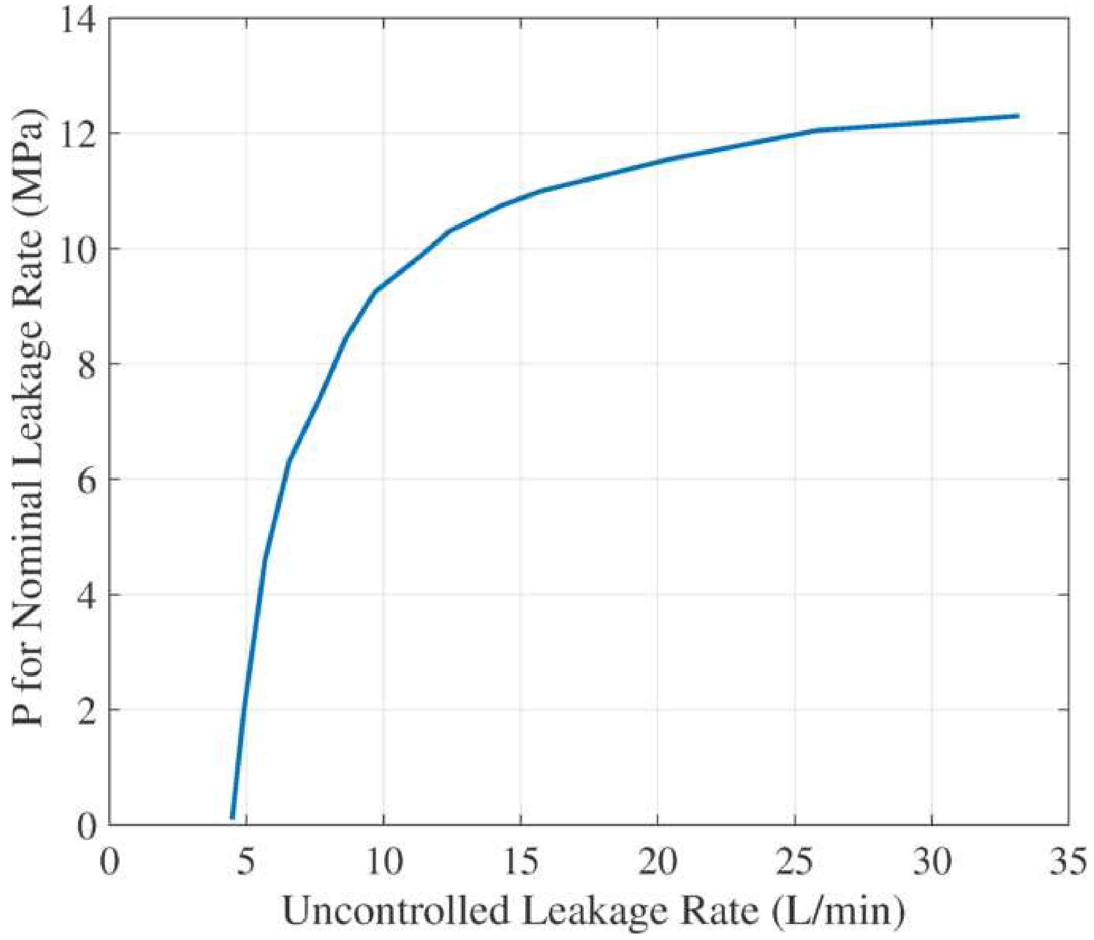


Cavity Pressure		Leakage, 9.0 cavity base, $\theta_1 = 80, \theta_2 = 200$	
MPa	PSI	L/min	GPM
0.1	14.5	28.24	7.46
1	145	27.13	7.17
2	290	26.12	6.90
4	580	23.33	6.16
6	870	19.80	5.23
8	1160	16.00	4.23
10	1450	11.15	2.95
12	1740	5.12	1.35
14	2031	0.86	0.23

Restoring Nominal Leakage Rate (Table)

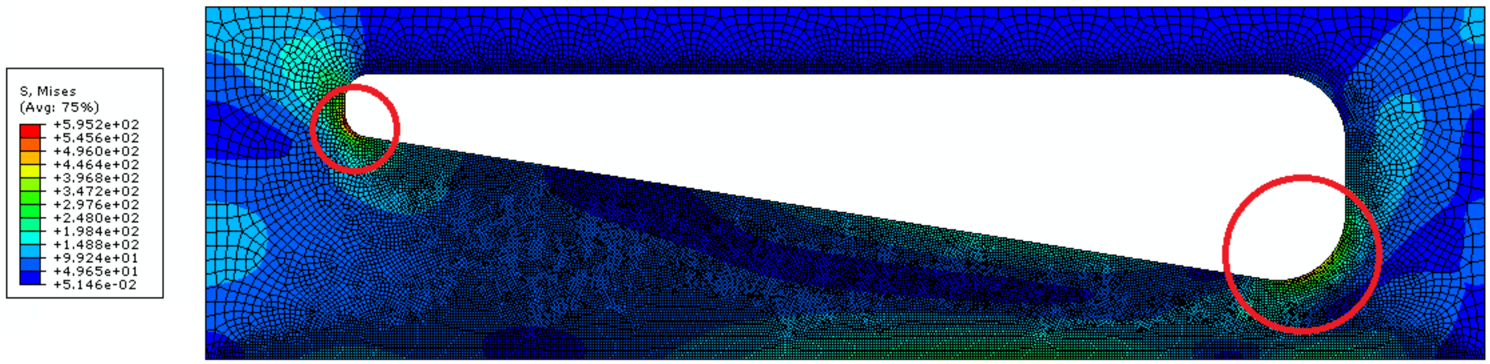
	Cavity Pressure		Corrected Leakage		Uncorrected Leakage, P = 9.875 MPa	
Fclose (MN)	MPa	PSI	Q (L/min)	Q (gpm)	Q (L/min)	Q (gpm)
0.450	12.3	1784.0	11.48	3.03	33.18	8.77
0.460	12.05	1747.7	11.50	3.04	25.81	6.81
0.470	11.55	1675.2	11.25	2.97	20.43	5.40
0.480	11.0	1595.4	11.31	2.99	15.76	4.16
0.485	10.75	1559.2	11.25	2.97	14.32	3.78
0.490	10.3	1493.9	11.25	2.97	12.40	3.28
0.495	9.875	1432.2	11.36	3.00	11.36	3.00
0.500	9.25	1341.6	11.33	2.99	9.69	2.56
0.505	8.45	1225.6	11.30	2.99	8.63	2.28
0.510	7.4	1073.3	11.33	2.99	7.67	2.03
0.515	6.3	913.7	11.37	3.00	6.55	1.73
0.520	4.6	667.2	11.19	2.96	5.68	1.50
0.525	2.0	290.1	11.26	2.97	4.91	1.30
0.528	0.1	14.5	11.32	2.99	4.48	1.18

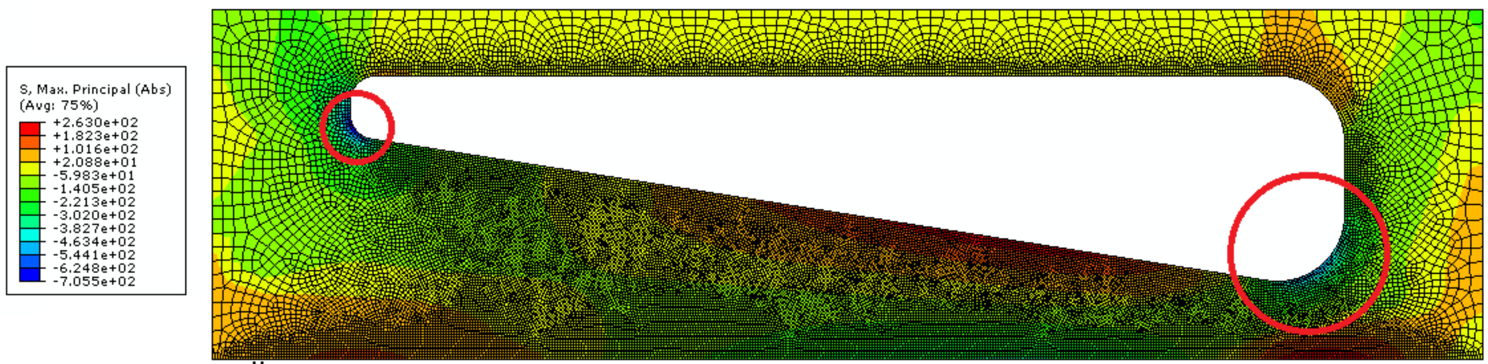
Restoring Nominal Leakage Rate (Plot)



Stress Distribution of Uncorrected Flow

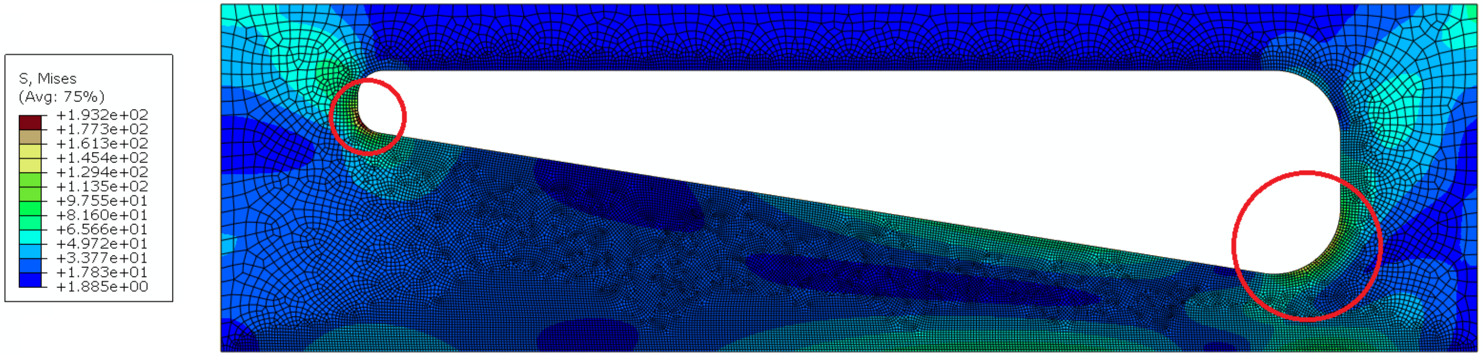
- Maximum von Mises stress =595 MPa
- Yield strength of 410 stainless steel = 1005 MPa
- Maximum von Mises stress is compressive, circled in red.

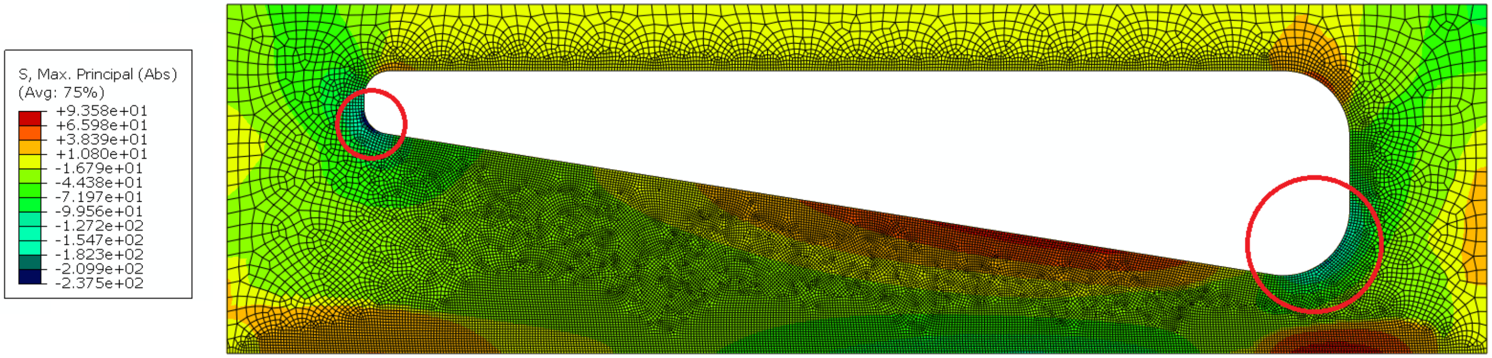




Stress Distribution of Corrected Flow

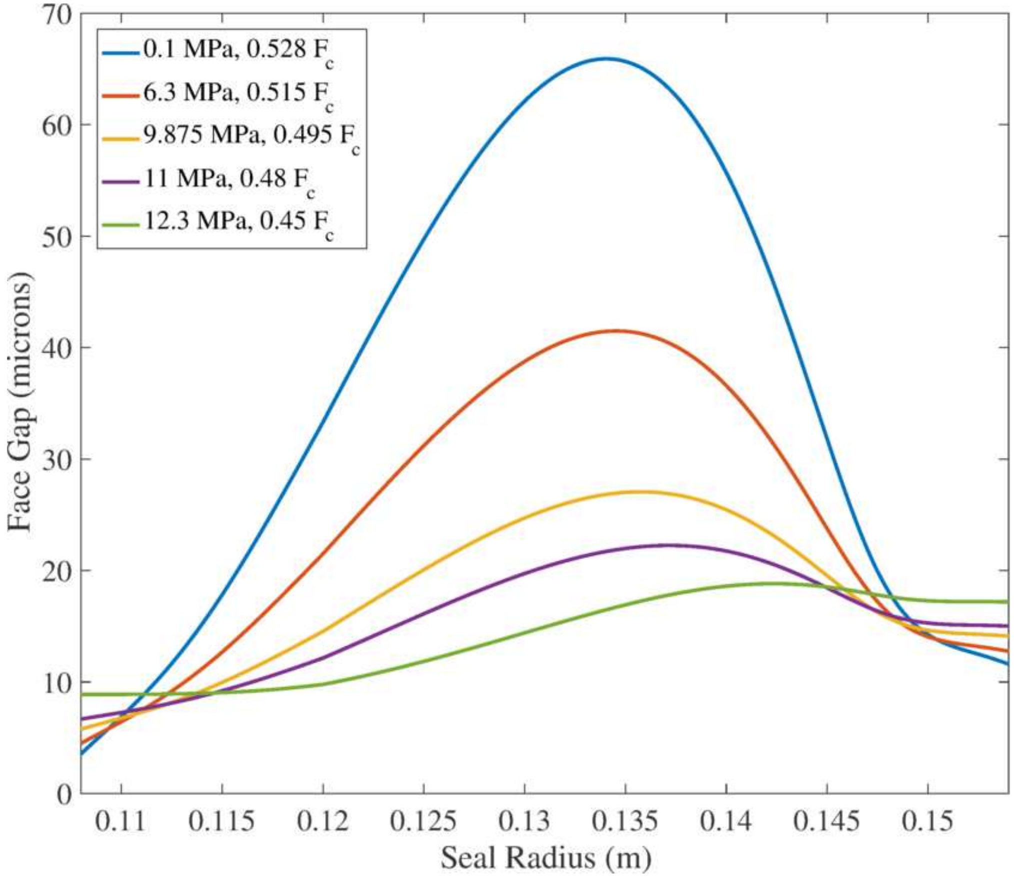
- Maximum von Mises stress =193 MPa
- Yield strength of 410 stainless steel = 1005 MPa
- Maximum von Mises stress is compressive, circled in red.





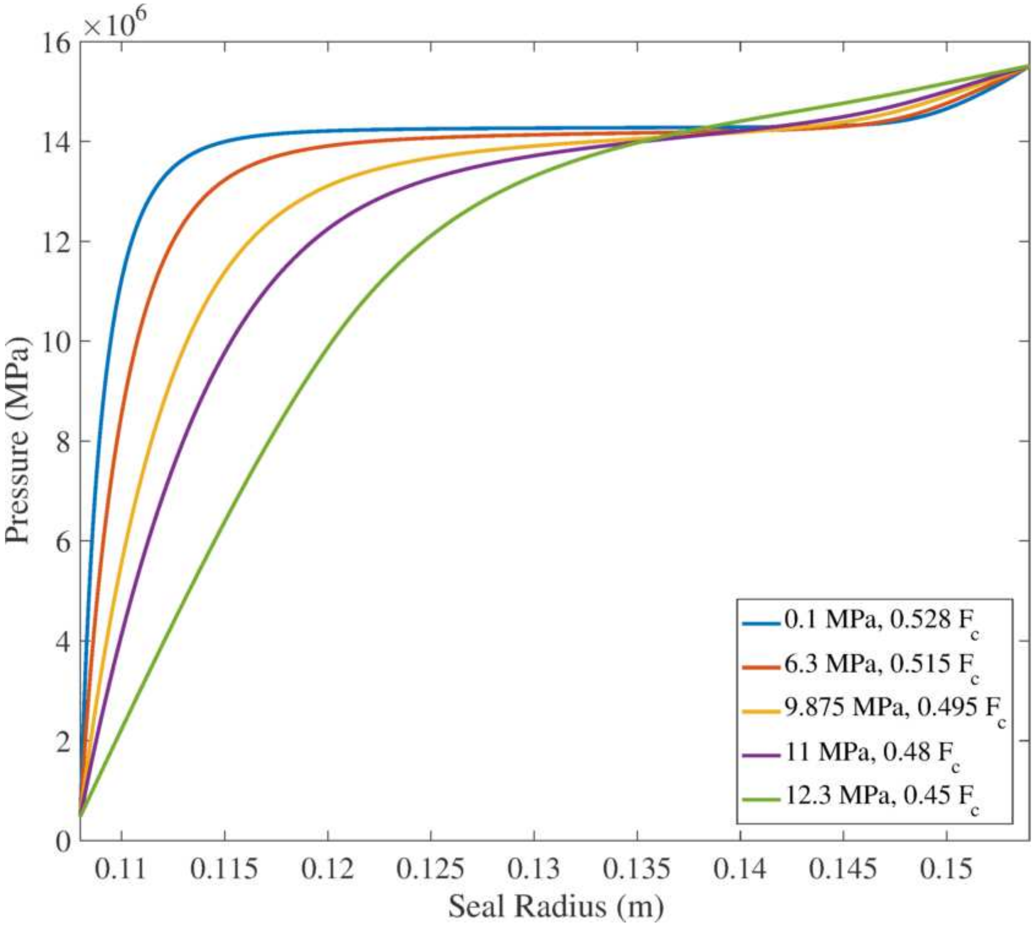
Face Deformation

- Face deformation for selected corrected flow rates. Cavity pressures to correct for closing force given in legend.



Pressure Distribution

- Pressure distributions for selected corrected flow rates. Cavity pressures to correct for closing force given in legend.



Conclusions from Simulation

- Hydraulically controlled seal has control range of 28.7 L/min (7.6 gpm) of abnormal leakage rate correction.
- The seal provides sufficient active control to address many abnormal leakage rate scenarios.