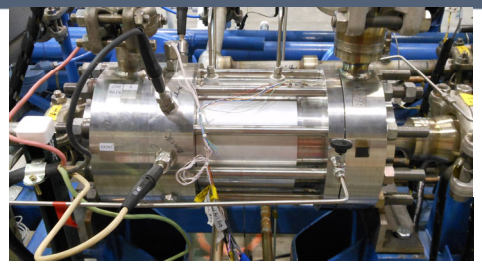
Experimental Testing of a 1MW sCO2 Turbocompressor


Logan Rapp
Sandia National Laboratories
sCO2 Symposium
February 2022

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History of sCO2 research at Sandia National Laboratories

Heat Exchanger Testing

Pressure Fatigue Testing

Turbomachinery Testing

Bearings Testing

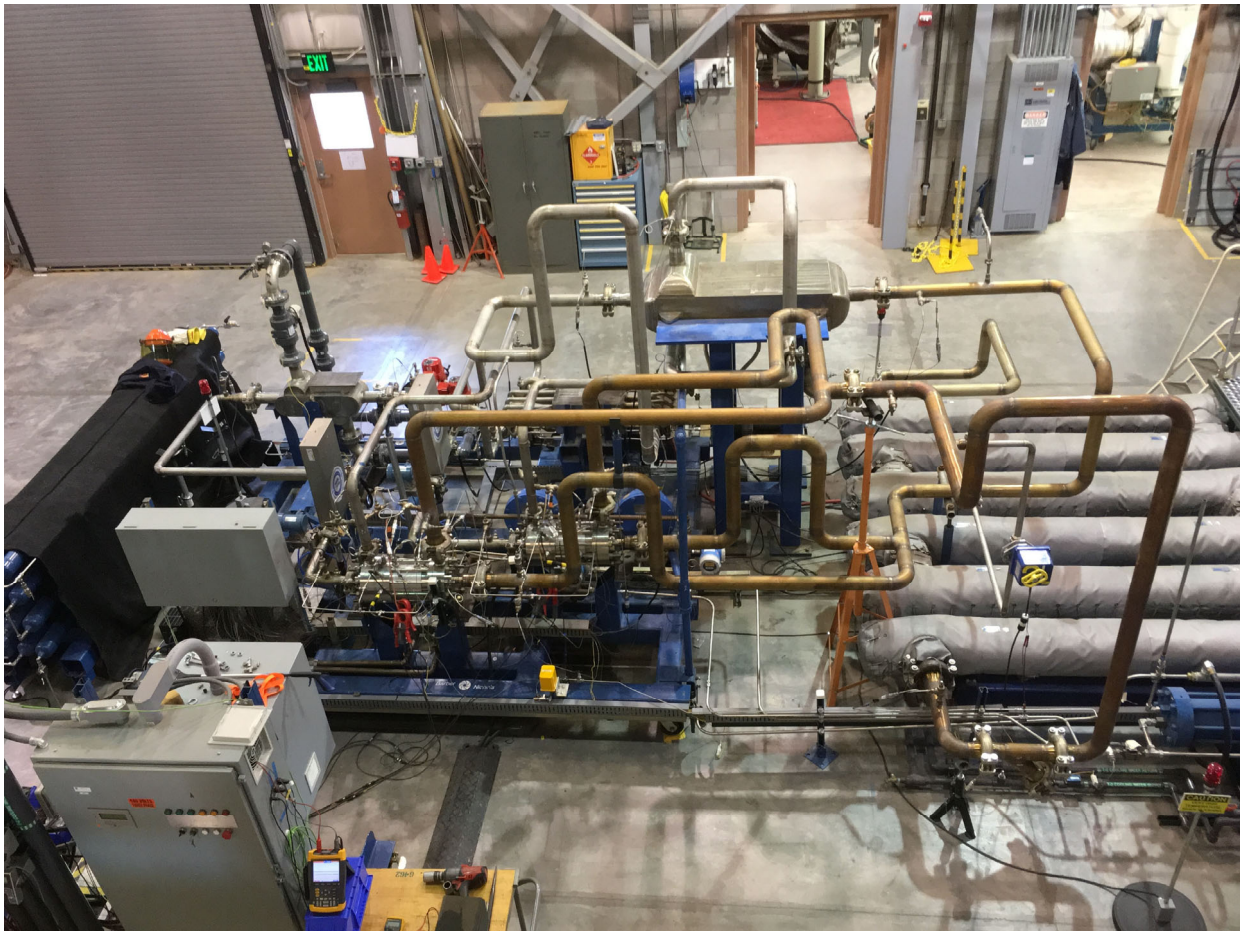
Seals Testing

Recompression Closed Brayton Cycle (RCBC) configuration

Commissioned in 2012

Only experimental sCO2 RCBC ever to have been operated

Many papers and conference proceedings have been published on the data from the RCBC experiments



TurboMachinery Development Platform at SNL

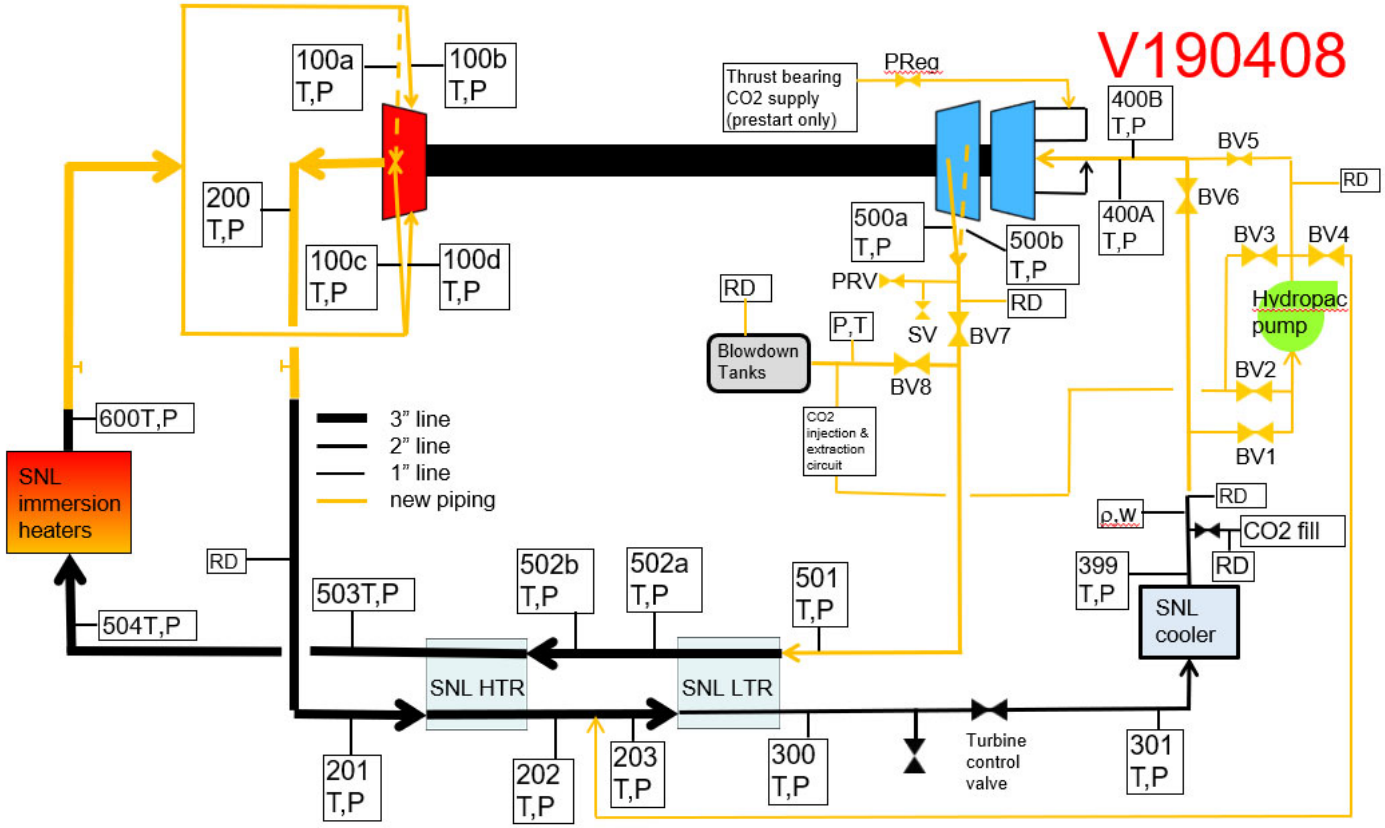
780 kW electric immersion heat

2.3 MW duty High Temp Recuperator

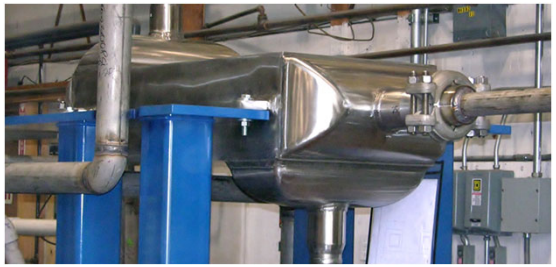
1.6 MW duty Low Temp Recuperator

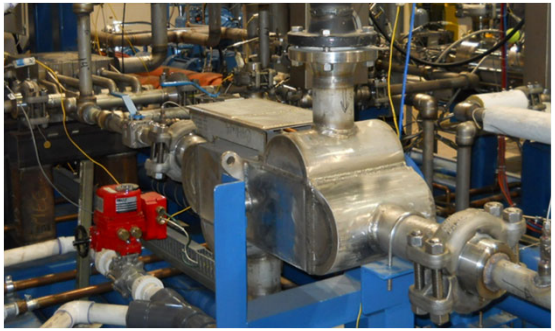
540 kW water/sCO2 cooler

Hydro-Pac Piston compressor pump



TurboMachinery Development Platform at SNL

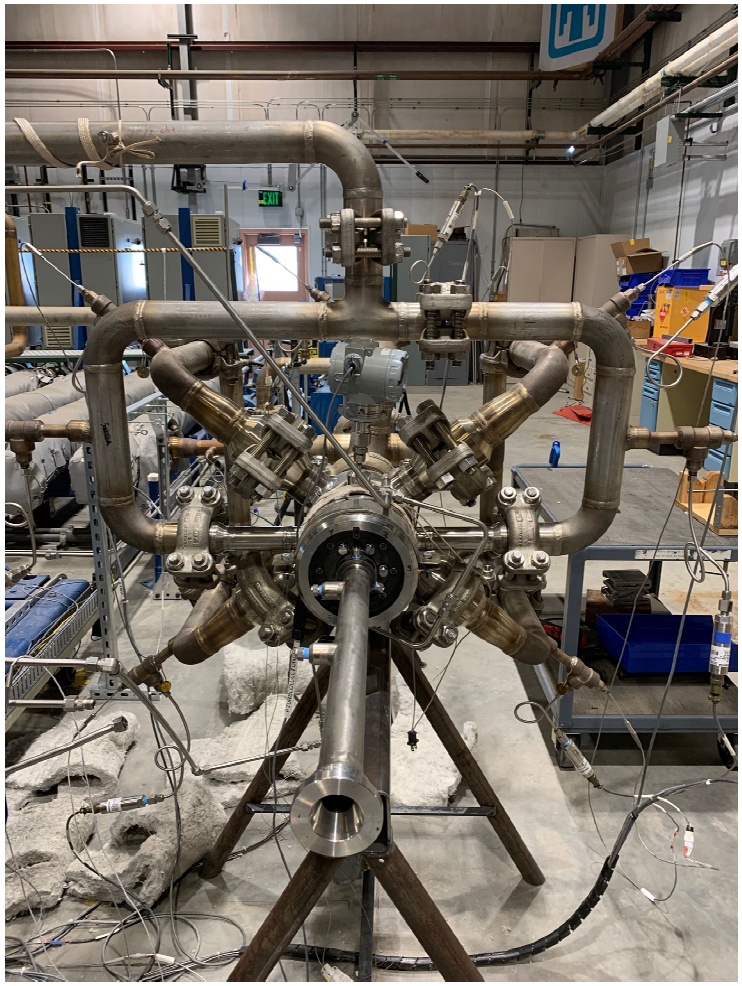


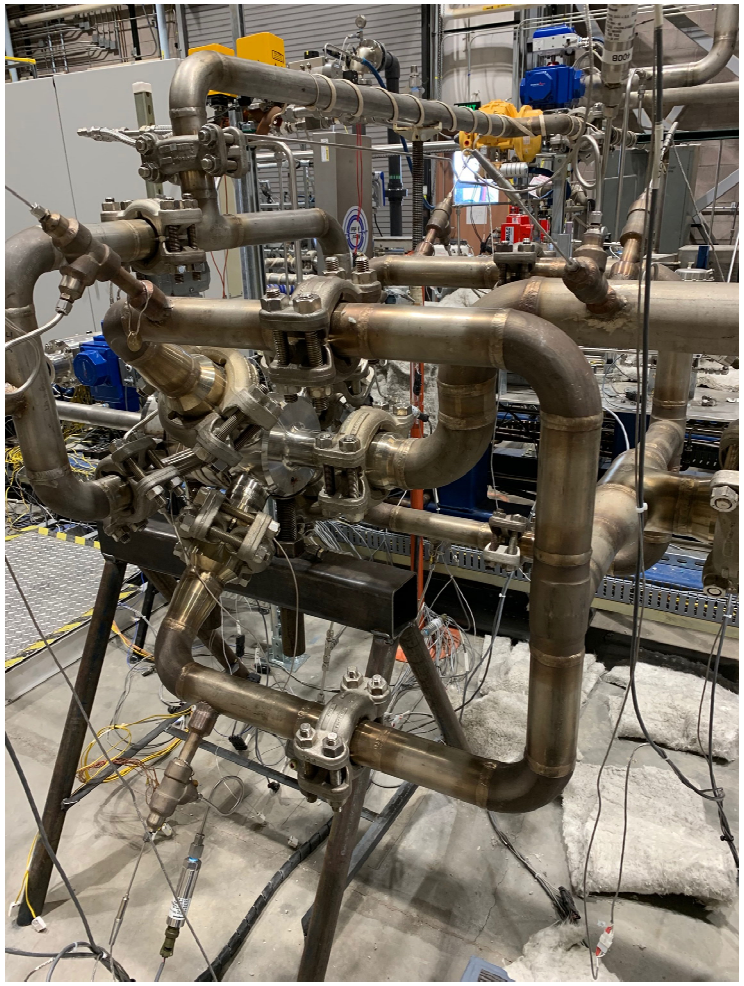


Peregrine Turbine Technologies Turbocompressor

Design Conditions:
- 118,000 RPM
- 750 C Turbine Inlet
- 42.9 MPa compressor discharge

Loop Maximum Conditions:
- 538 C Turbine Inlet (1000 F)
- 17.2 MPa compressor discharge (2500 psi)





Blowdown Start Method

Loop is preconditioned using Hydropac

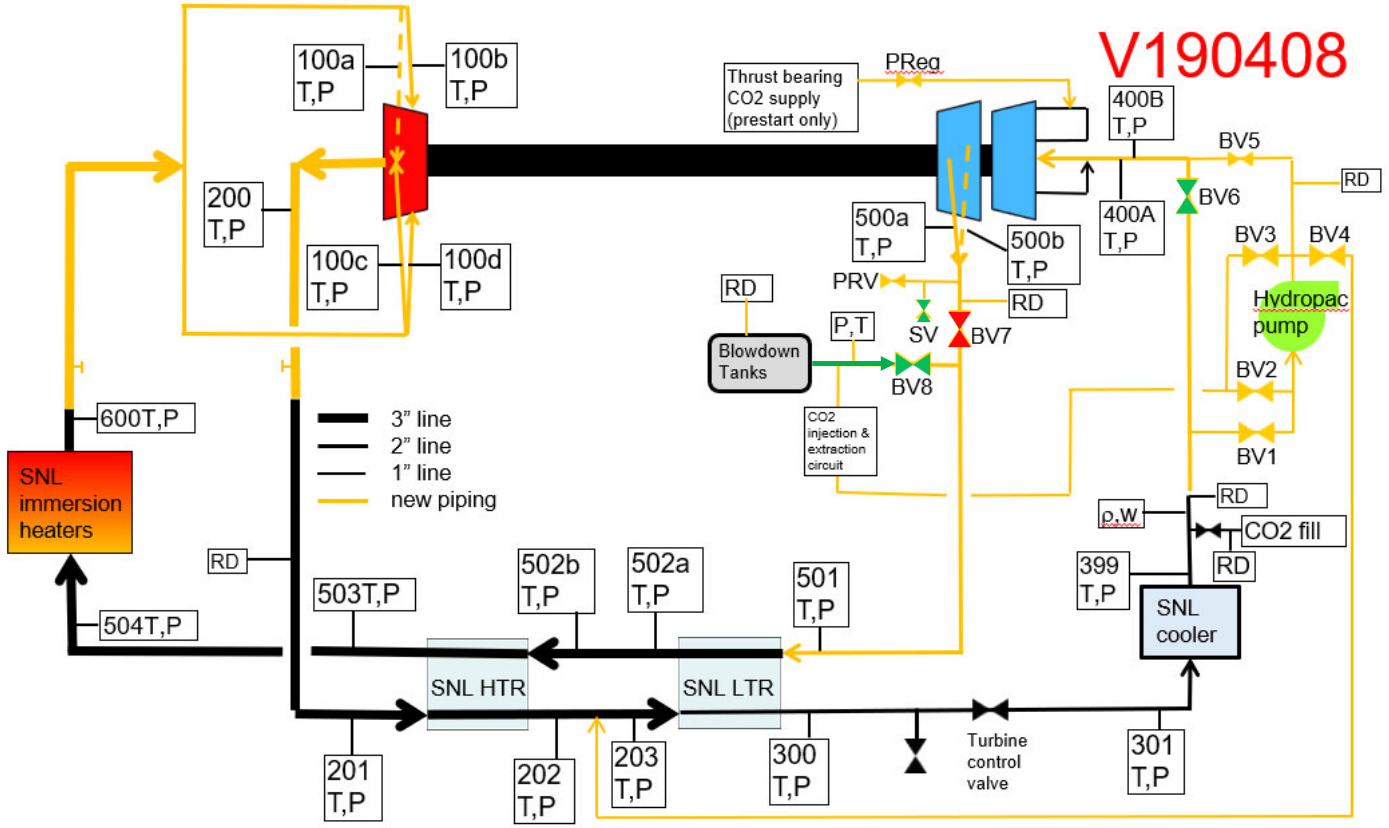
- Compressor inlet above supercritical conditions
- Turbine inlet at approximately target for test

Valve Positions

- BV7 is closed
- BV8 and SV are opened

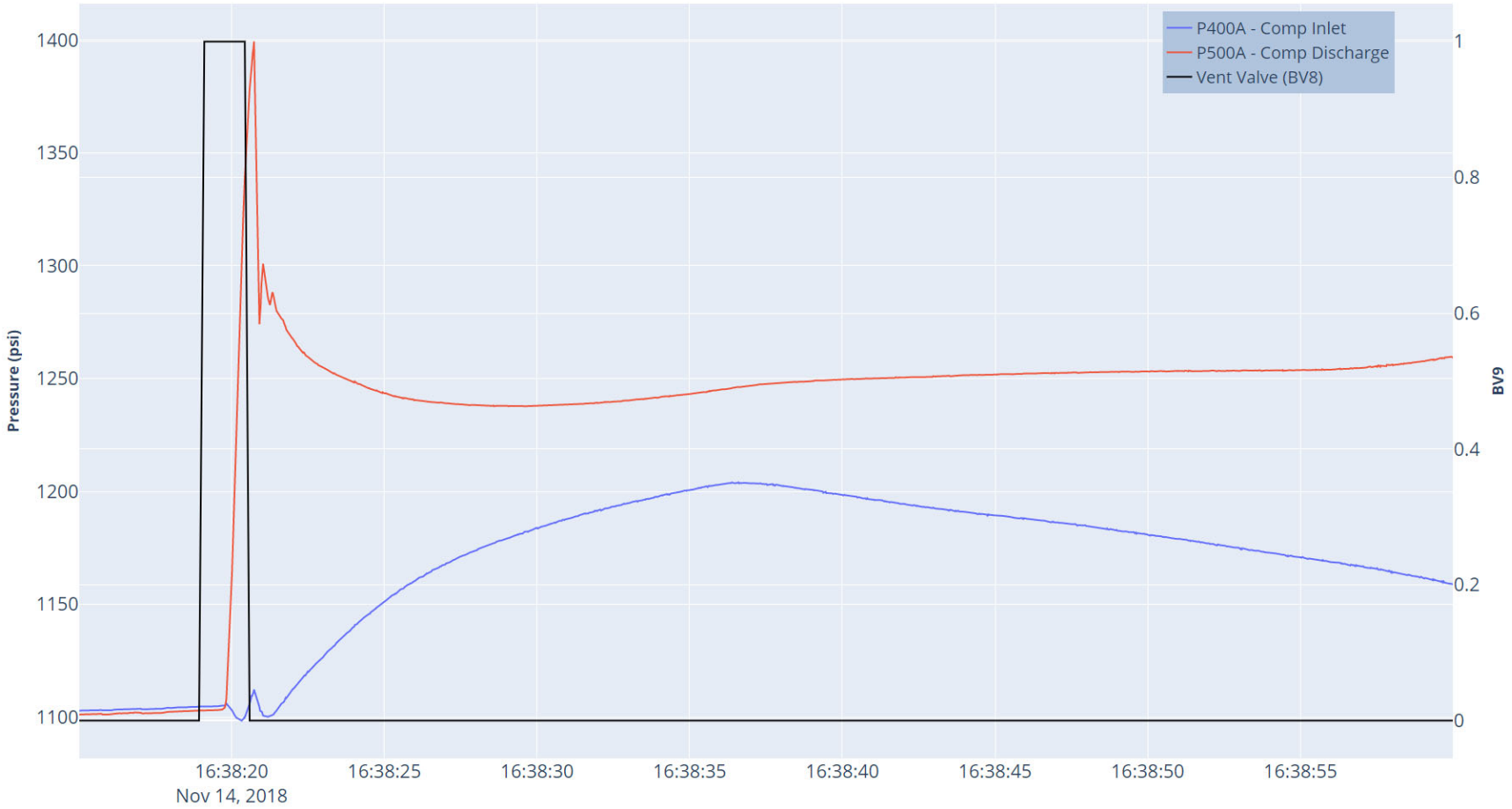
Once P500A –P501 > dP_min:

- BV7 is opened and BV8 and SV are closed



Blowdown start

1750 psi blowdown pressure,
Valve open for ~2 seconds



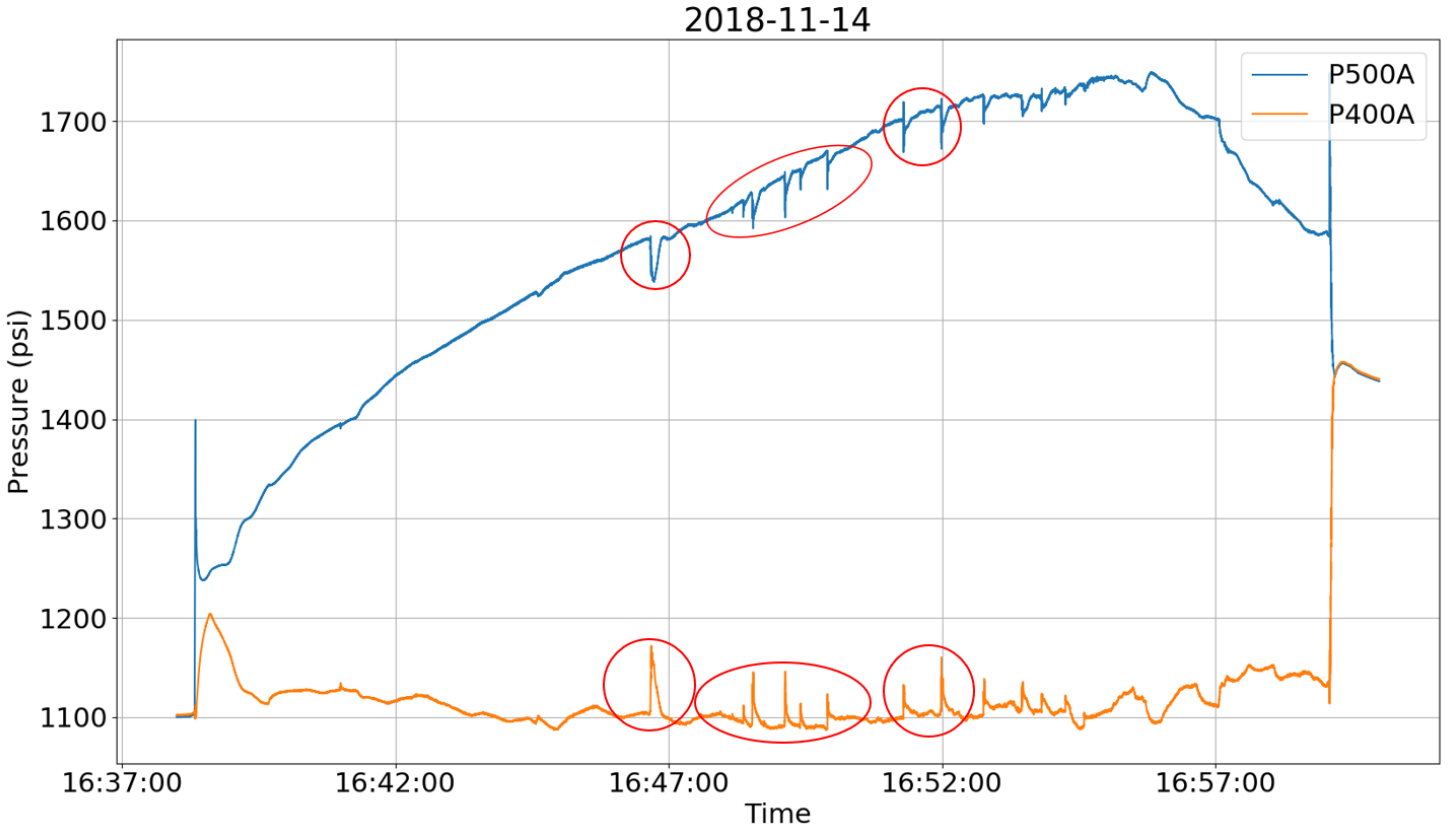
Summary of tests with blowdown start

Test Number	Test Date	Test Duration	TIT (°F)	Compressor Discharge Pressure (psi)	Max PR	
1	8/9/2018	00:00:32	225	1240	1.2	First spin
2	10/10/2018	00:18:40	420	1400	1.25	Turbine touched shroud, not enough back pressure
3	11/14/2018	00:20:46	645	1750	1.59	Valve supplying thrust bearing didn't actuate – did not achieve thrust balance. Added prox probe after this test
4	3/1/2019	00:03:32	610	1460	1.26	Aft bearing failure
5	3/6/2019	00:08:23	530	1510	1.3	Changed start procedure- still had aft bearing failure
6	4/4/2019	00:03:18	530	1510	1.28	Aft bearing failure
7	5/7/2019	8:05:44	570	1475	1.27	No failures – achieved thrust balance and performed controlled shut down after ~8 hours
8	7/10/2019	N/A	N/A	N/A	N/A	Possible build error – rotor hit/broke prox probe on start attempt.
9	10/3/2019	8:19:40	830	2050	1.75	No problems
10	10/4/2019	7:55:42	985	2000	1.89	No problems
11	10/22/2019	7:54:07	985	2030	1.72	No problems
12	10/23/2019	4:53:13	985	2000	1.75	No problems
13	11/11/2019	10:09:33	985	2000	1.74	No problems
14	11/12/2019	10:13:40	985	2050	1.75	No problems
15	11/13/2019	10:29:11	985	2050	1.73	Forward bearing failure and filter collapse – lead time on filter was ~4 months
16	3/4/2020	0:21:36	775	2000	1.67	Forward bearing failure
17	3/11/2020	0:53:14	810	2000	1.75	Forward bearing failure
18	4/21/2020	1:25:05	780	2000	1.65	New feature added for bearing retention – Forward bearing failure
19	5/7/2020	0:02:47	550	1500	1.2	Aft bearing failure

Bearing Issues

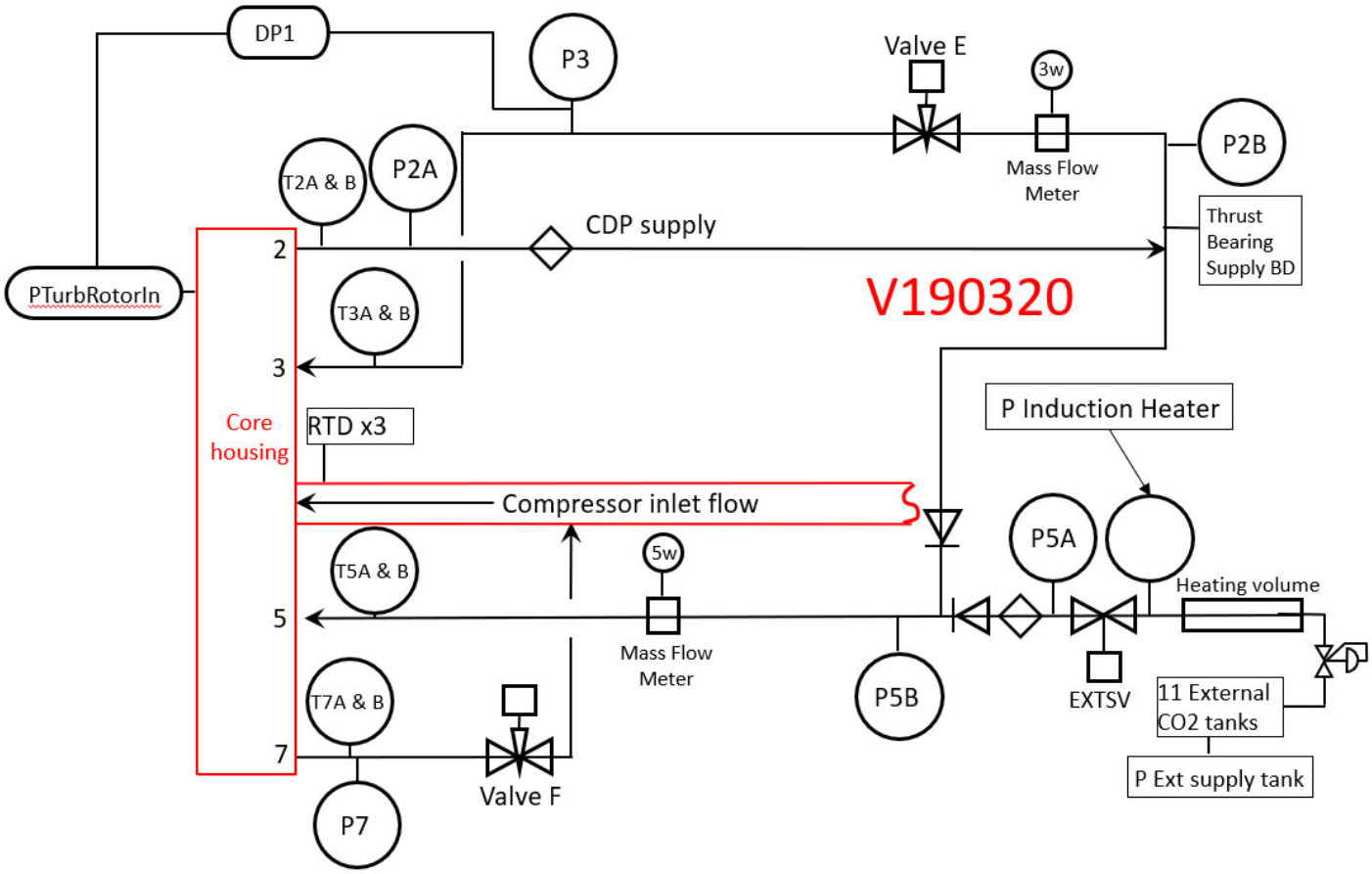
In Tests #1-3, both the thrust bearing and the radial bearings experienced rubs/failures

Spikes in pressure indicate thrust bearing rubs

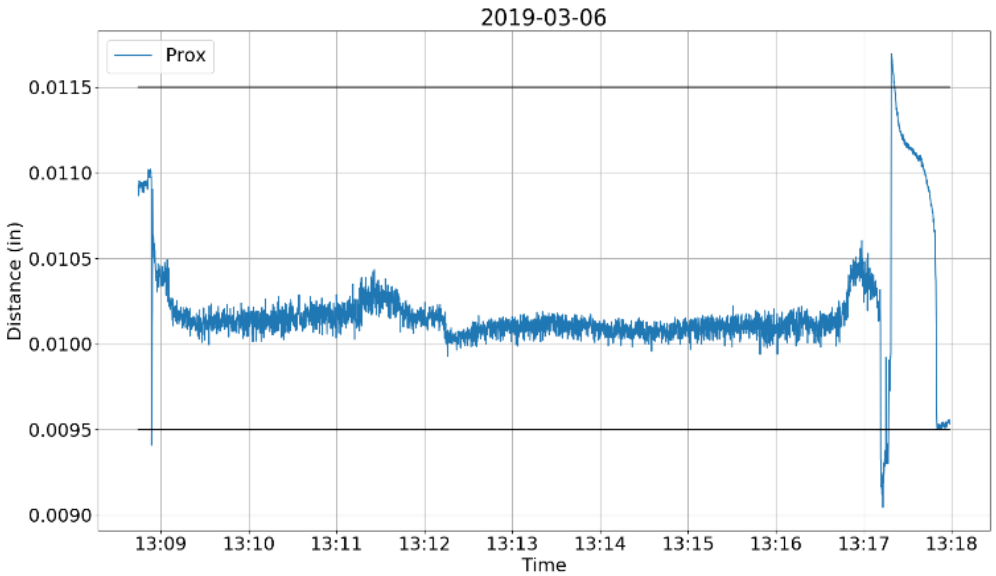


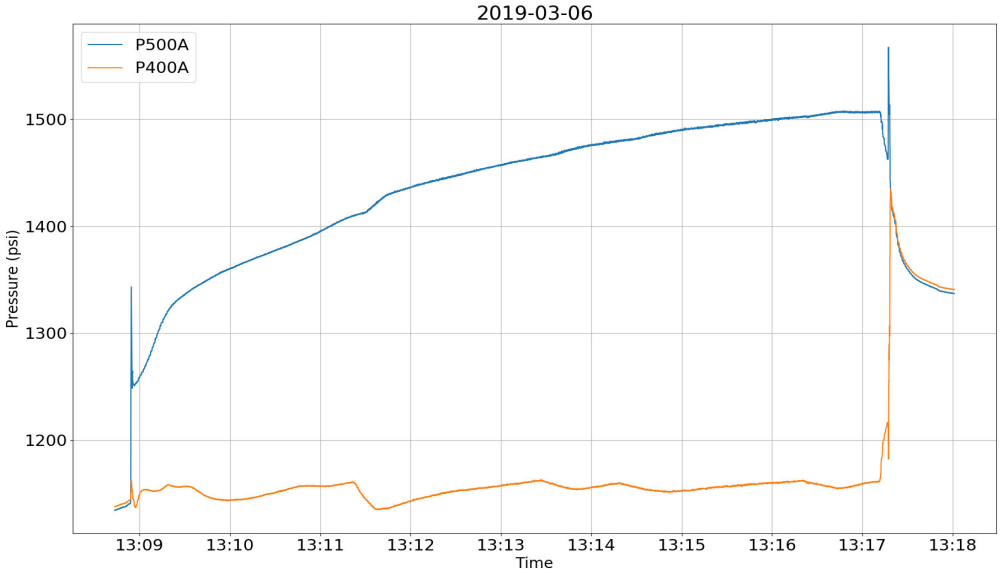
Secondary Flows

Valve F regulates venting pressure on aft side of thrust disk rotor – acts as balance piston



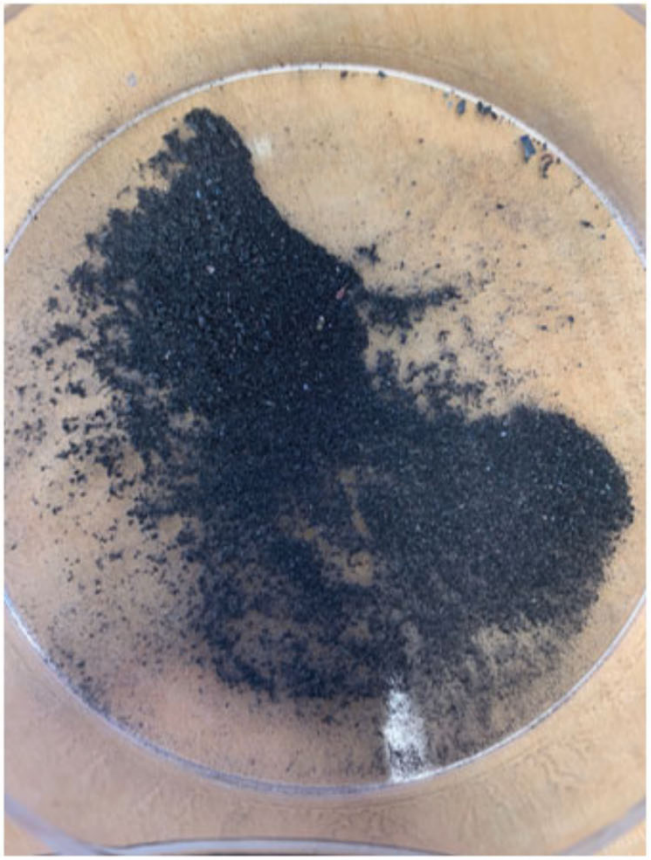
Thrust bearing issue resolved





By adjusting Valve F and the TCV the force on the rotor was balanced.

Filter Collapse



~2/3rds Common Stainless Steel, ~1/3rd Aluminum and Silicon, small percentages of Ca, Cu, Na, K, Ti.

- Indicates material is likely coming from stainless steel piping or recuperators
- Aluminum and silicon source unknown

- Accumulation of material has been significantly less than previously
- Perhaps bearing failures were causing accumulation?

Radial Bearing Issues

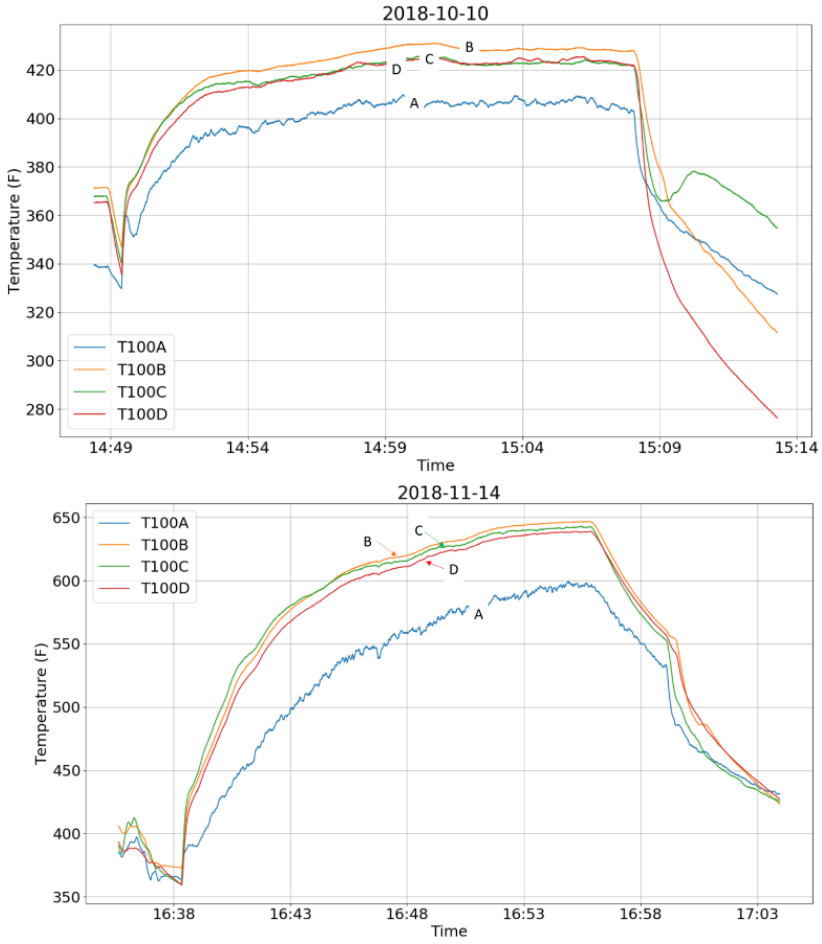
Persistent issues with radial bearings

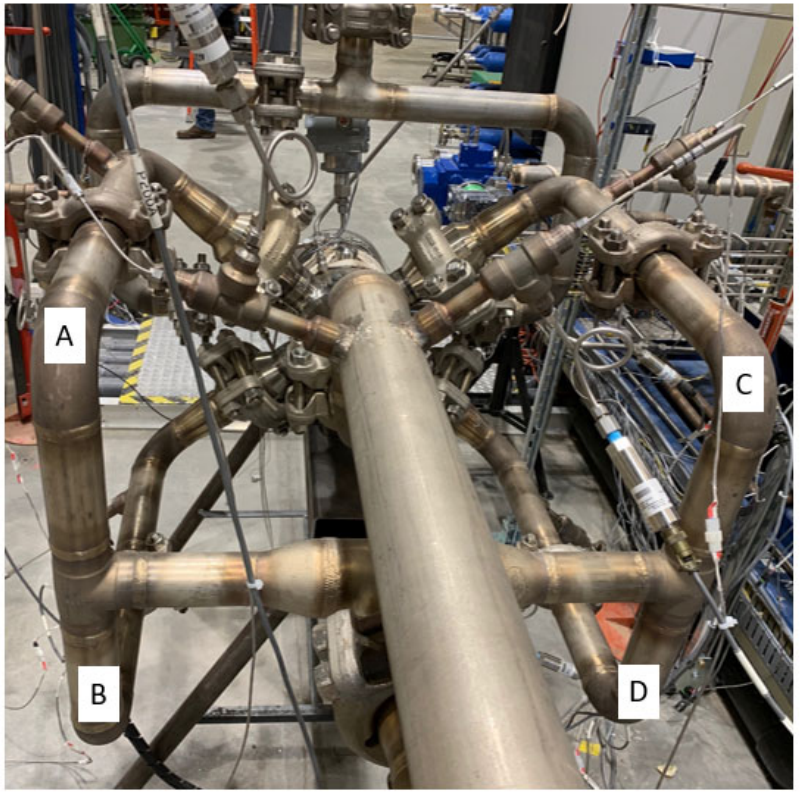
- Initially with forward bearing, seems to be fixed with retaining feature
- Still issues with aft bearing

Possible causes of failure:

- Blowdown start?
- Critical speed causing rotor instability?
- Radial load caused by non-uniform turbine inlet conditions?
    - Resolved with instrumentation

Turbine Inlets



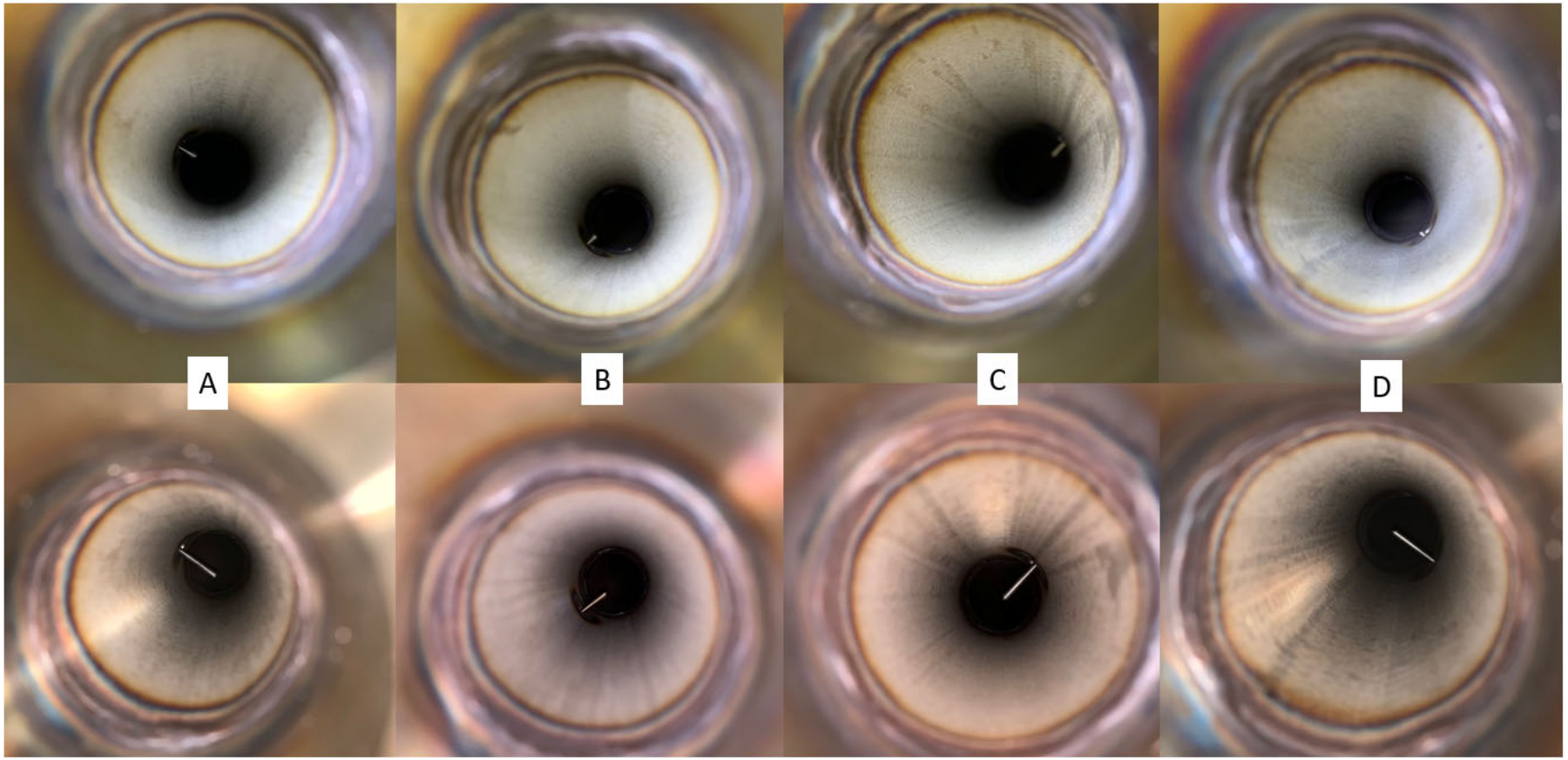


Leg “A” was consistently lower temperature than the other 3

Original and New Turbine Inlet RTD insertions

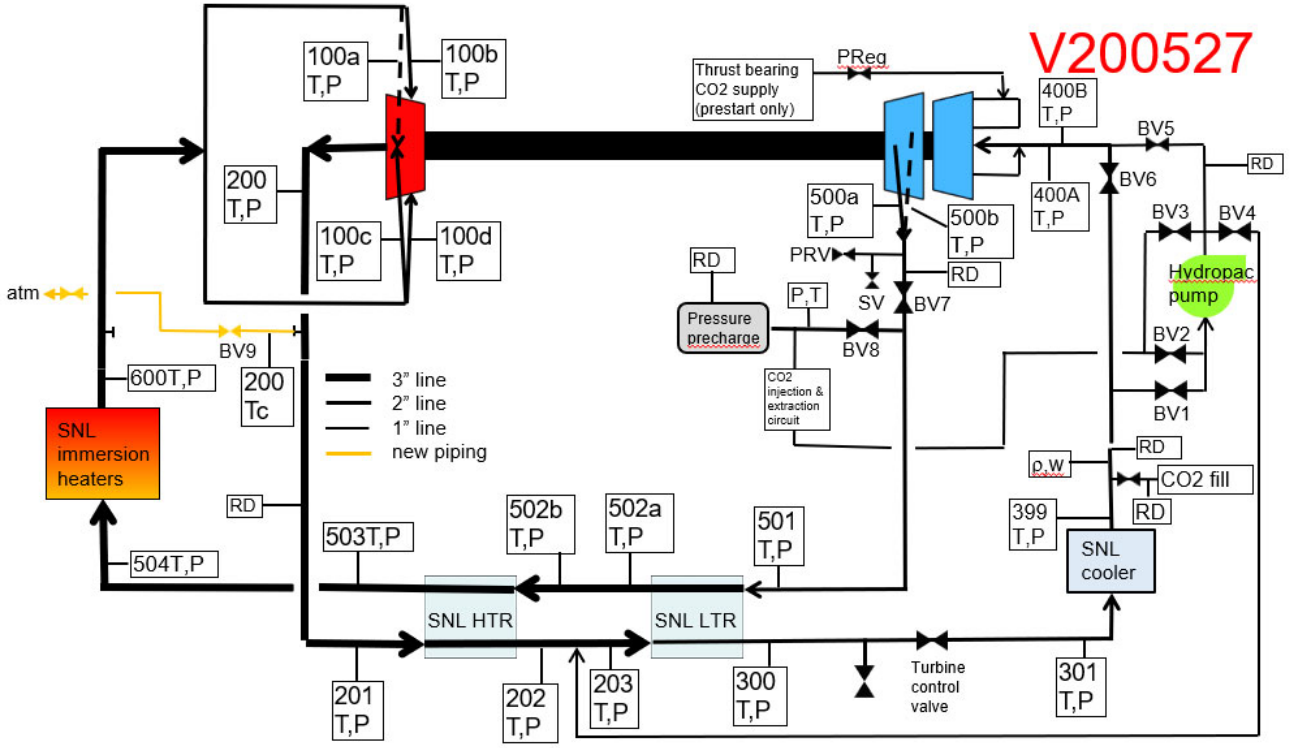
Original

New

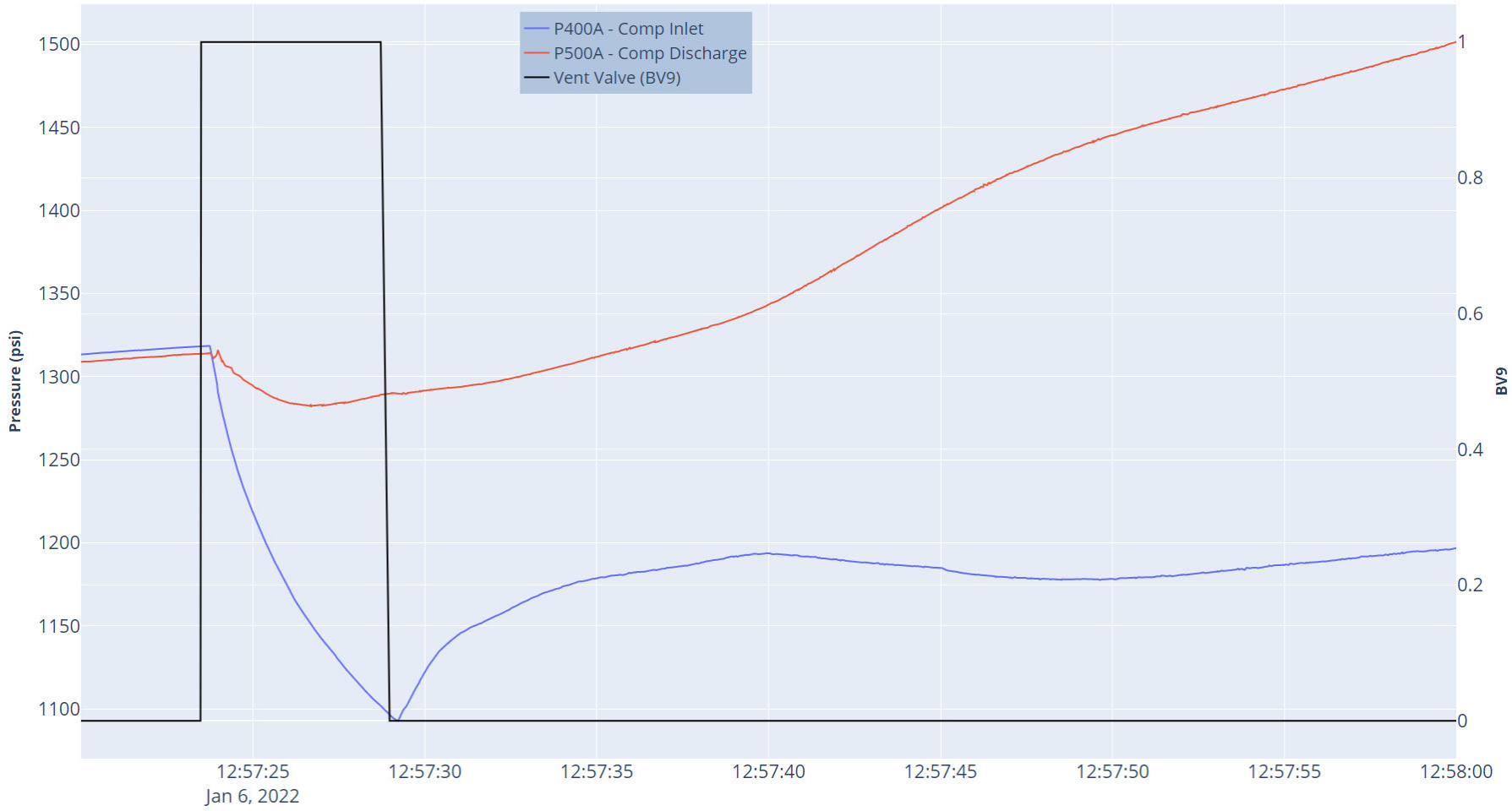


Vent Start

- Fill loop to higher pressure than desire during operation
- Open BV9 (downstream of turbine) an vent to atmosphere
- Close valve once compressor inlet pressure ≤ 1100 psi



Vent Start


P400A - Comp Inlet
P500A - Comp Discharge
Vent Valve (BV9)
Pressure (psi)
1500
1450
1400
1350
1300
1250
1200
1150
1100
BV9
1
0.8
0.6
0.4
0.2
0
12:57:25
Jan 6, 2022
12:57:30
12:57:35
12:57:40
12:57:45
12:57:50
12:57:55
12:58:00

Testing summary with vent start

- 52 test performed
- 431.5 total operating time
  - 330.5 on single set of bearings over 32 tests
  - Operated a single test for 56.5 hours
- Aft bearing issues have persisted

Next Steps

Continue troubleshooting bearing issues, might be issue related to critical speed?

Run sensitivity tests of turbocompressor performance with compressor inlet conditions

Construct loop to reach ~750C and ~250bar, test turbocompressor closer to full design conditions.

- Will depend on funding support

Thank you