Lawrence Livermore National Laboratory

Prototyping and Testing of the Rotating Target FerroFluidic Seal

Jeff Gronberg, Ryan Abbott, Owen Alford, Craig Brooksby, Ed Cook, Pat Duffy, Jay Javedani, Nick Killington, Tom Piggott

Sep 5, 2012 - PosiPol 2012

Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551

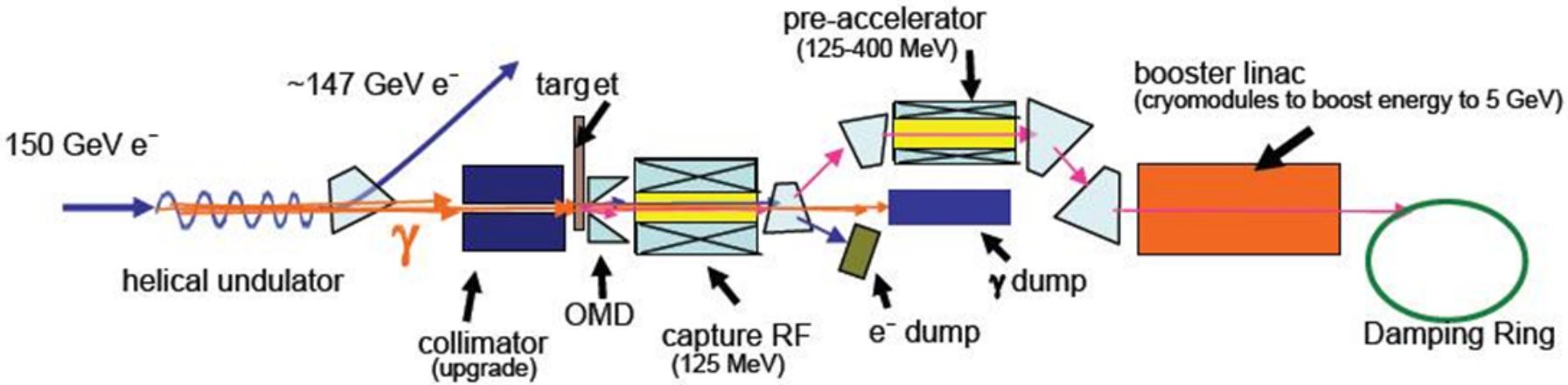
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

UCRL-XXXX-12345

The photon beam from the helical undulators presents challenges for the target and capture magnet

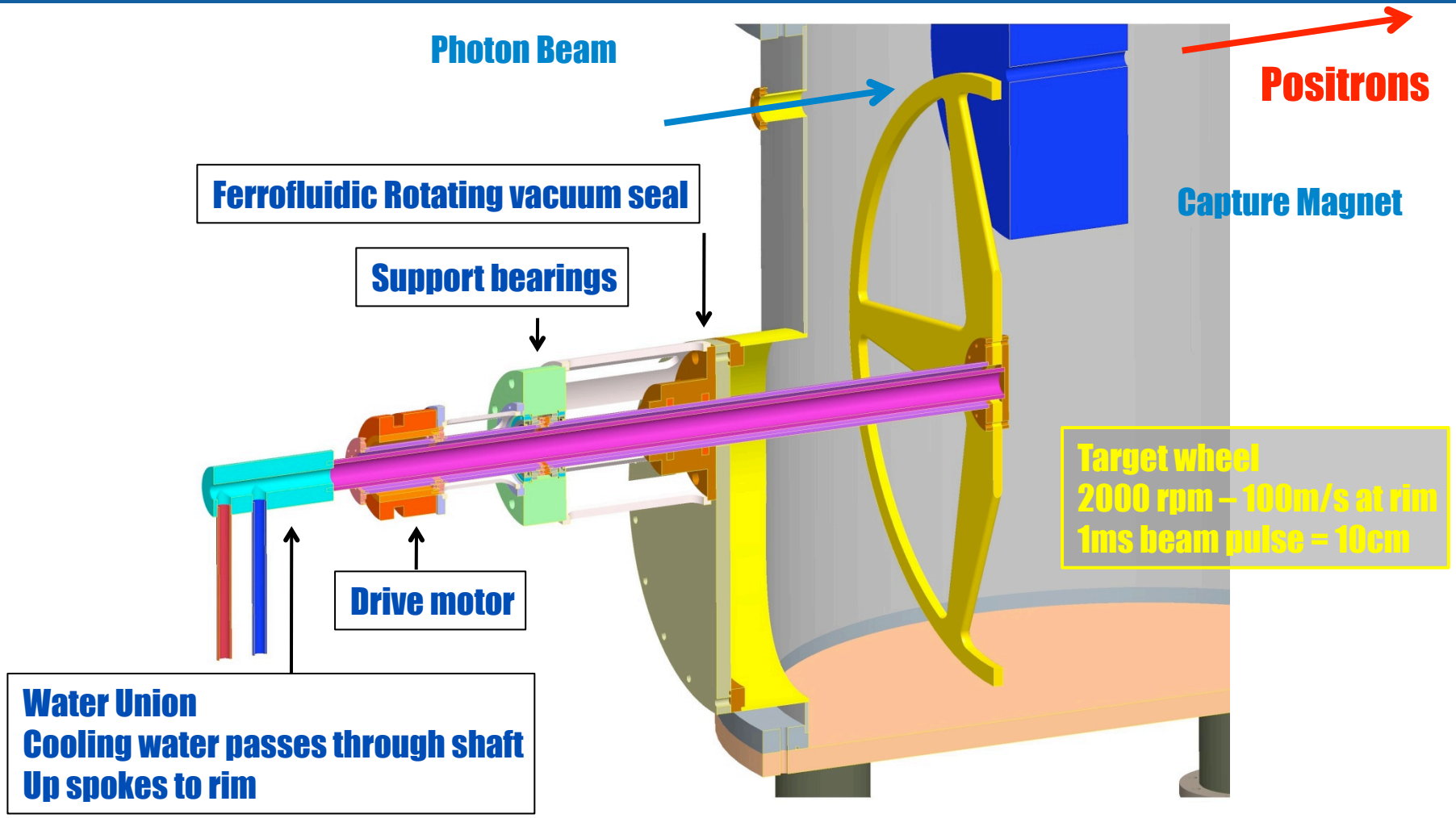
Helical undulator to generate a circularly polarized photon beam

Optical Matching Device to get high capture efficiency

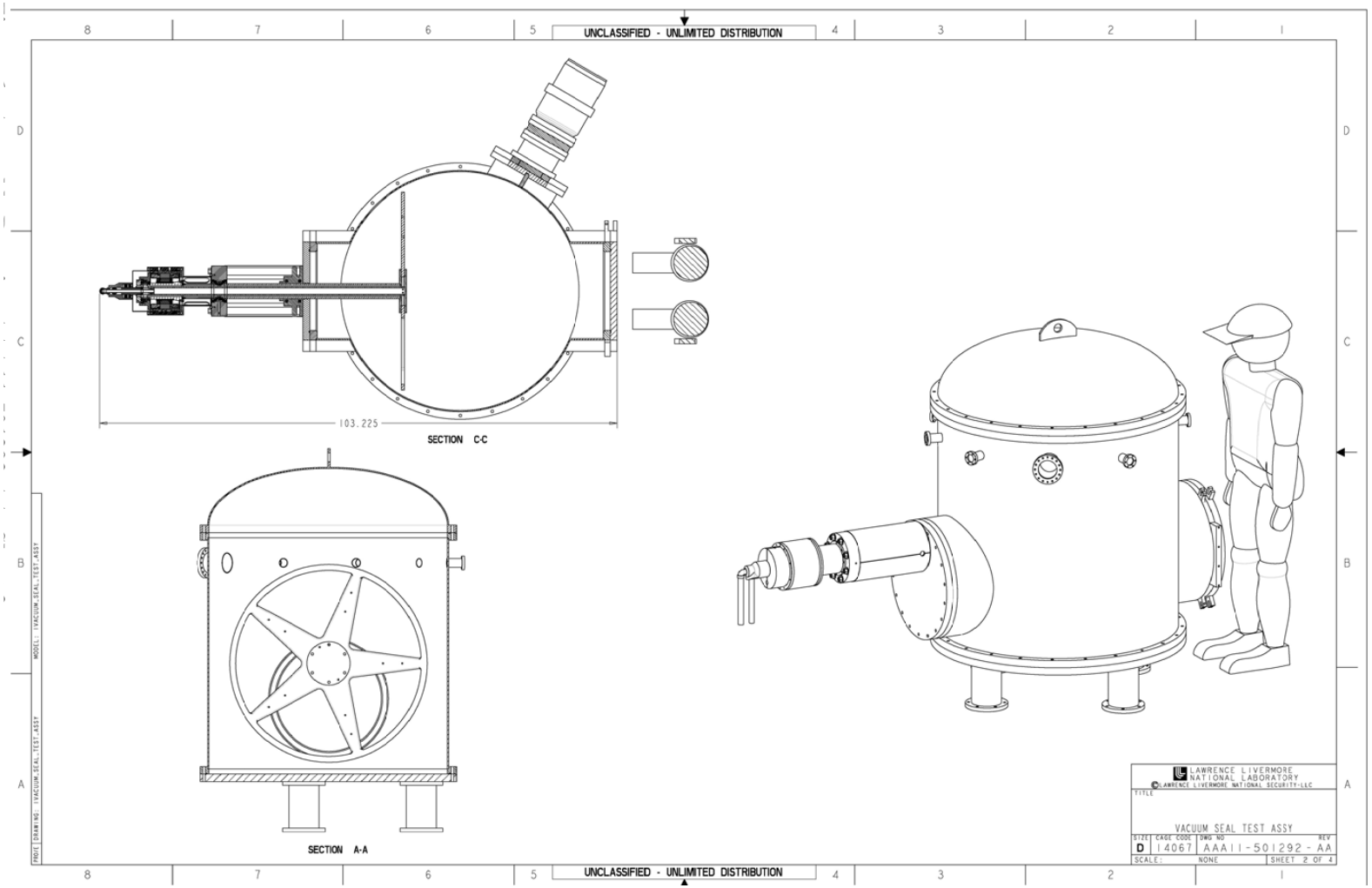


Rotating target to smear out the long 1ms pulse

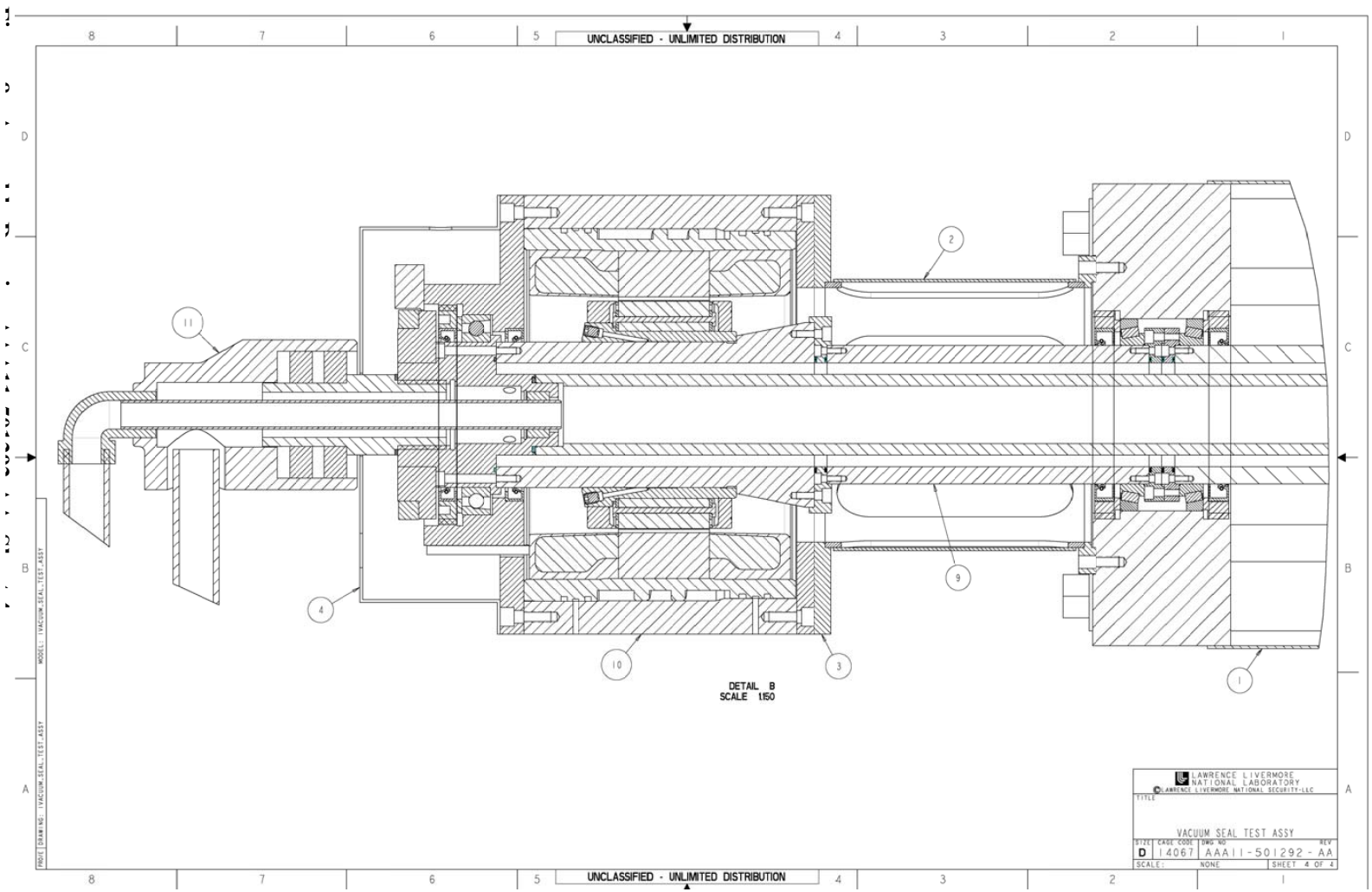
We are doing design and prototyping of the rotating shaft seal and the capture magnet



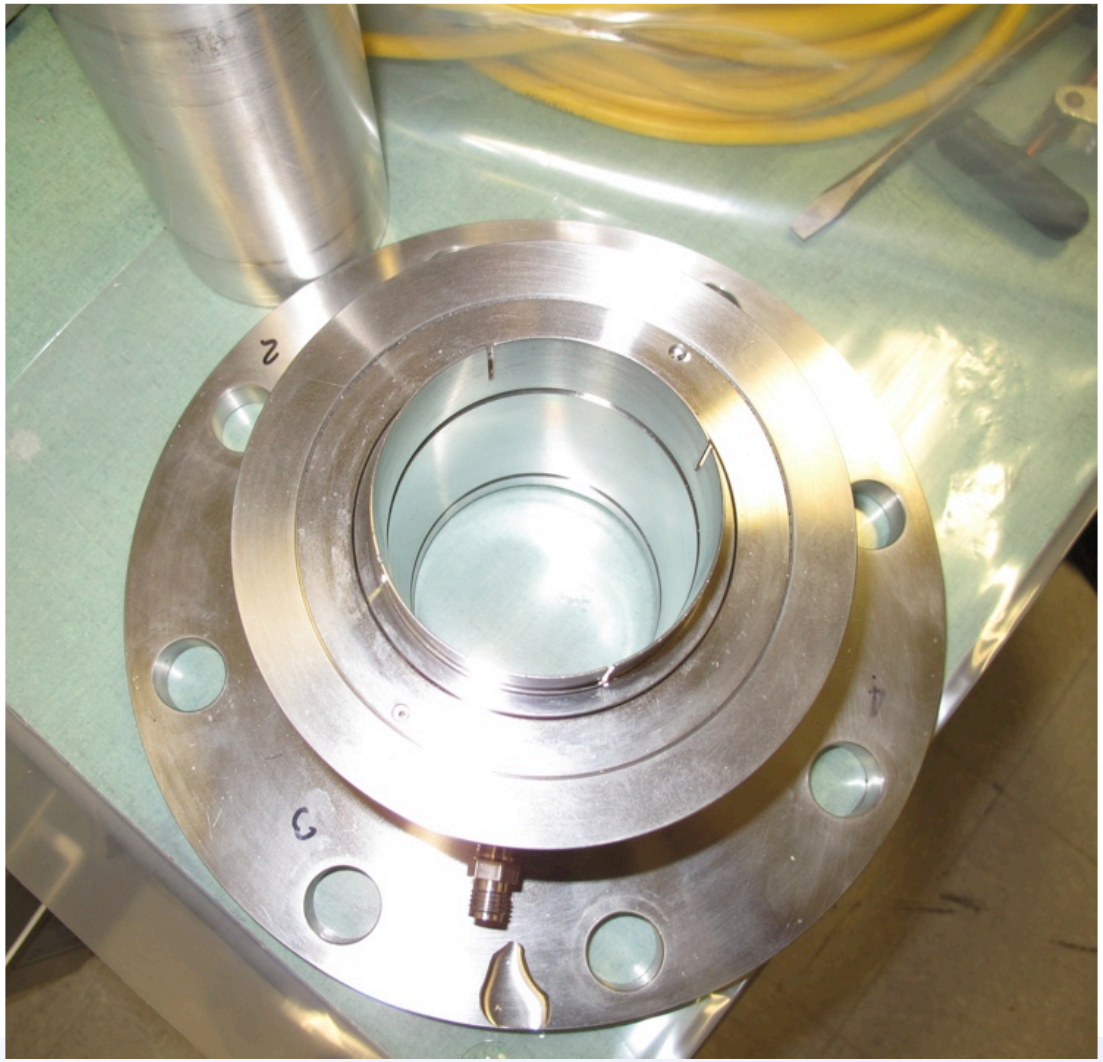
We have created a prototype of the rotating shaft with the ferro-fluidic vacuum seal



Drive motor and rotating cooling water coupling mount directly on the shaft



We started testing of the Rigaku Ferro-fluidic Seal for outgassing when it arrived



- A magnetic fluid is held between the inner and outer ring by permanent magnets
- There is significant torque and heat dissipation
- The ferrofluid can be expected to outgas

We modified an existing outgassing test stand to test the ferro-fluidic seals

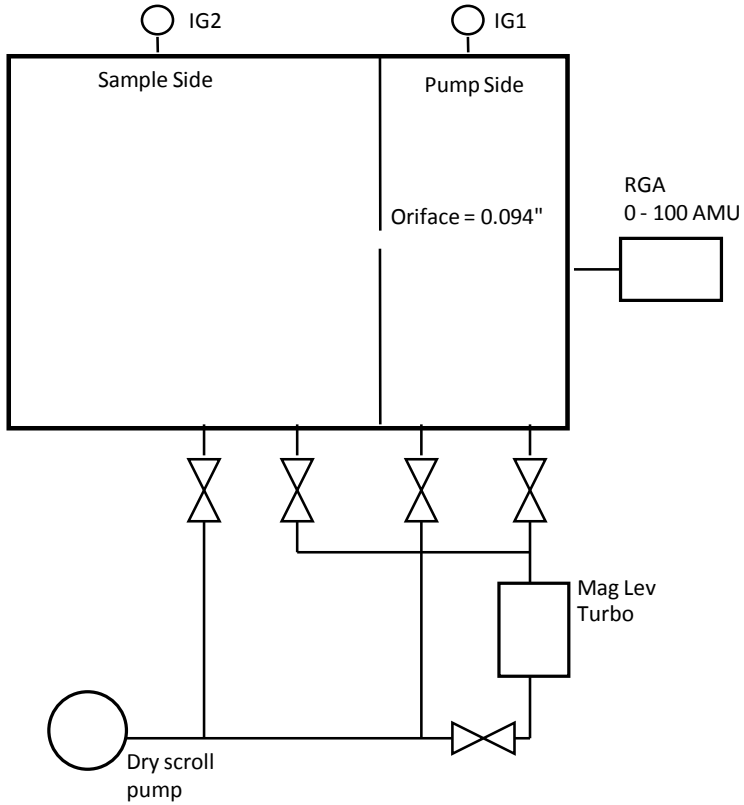
Vacuum Sciences and Engineering Lab Outgassing Measurement Test Stand

Sample Side Volume = 216 Cu. in.

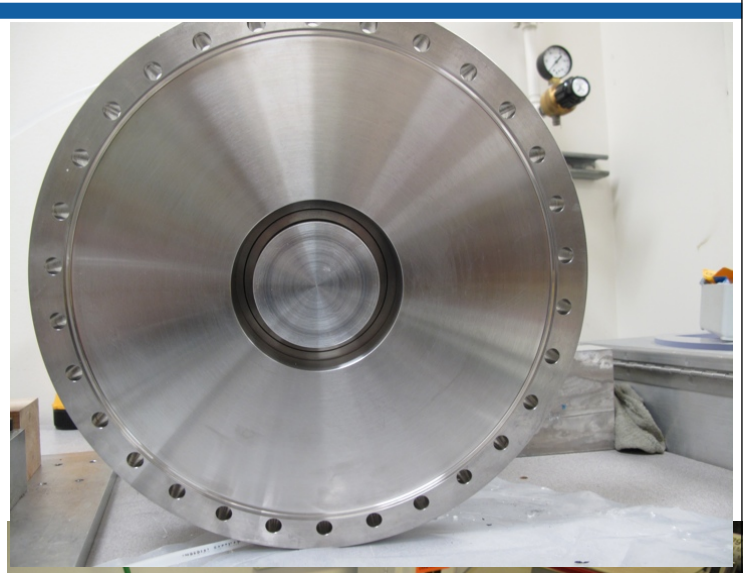
Sample Side Surface Area = 5,575 cm^2

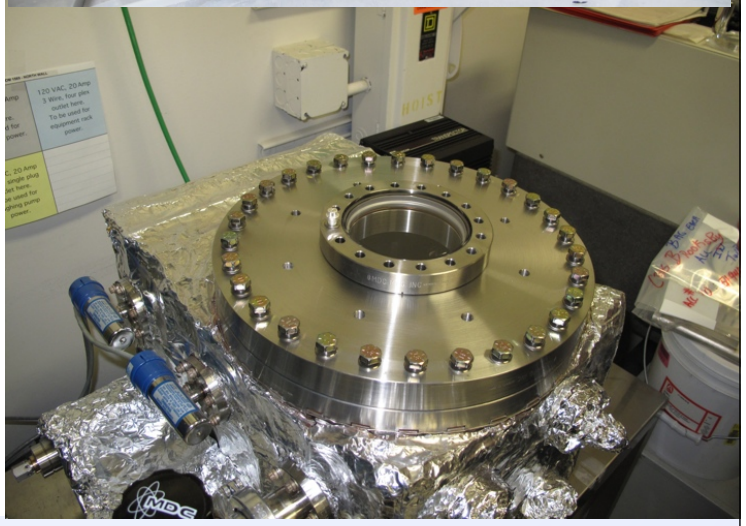
Conductance = 0.52 L/s for air at 20C

$Q = C(P_{IG2} - P_{IG1})$



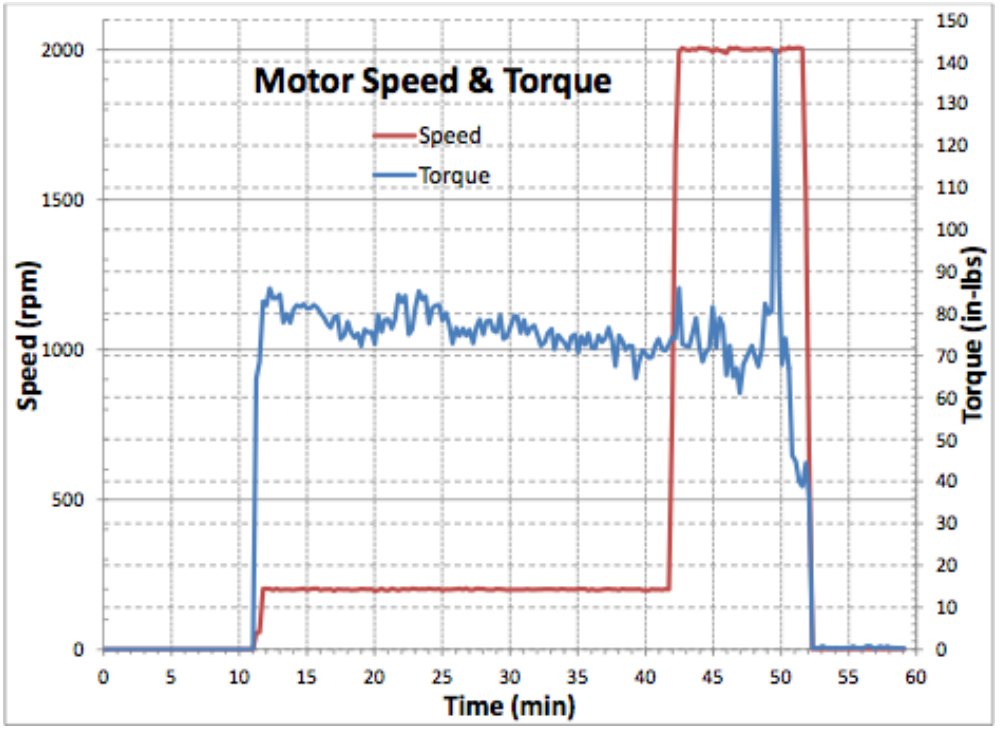
The test stand allows us to rotate the seal up to 2000 RPM with pressure and outgassing measurements





October 3rd, 2011 we did our first full test of the Rigaku seal

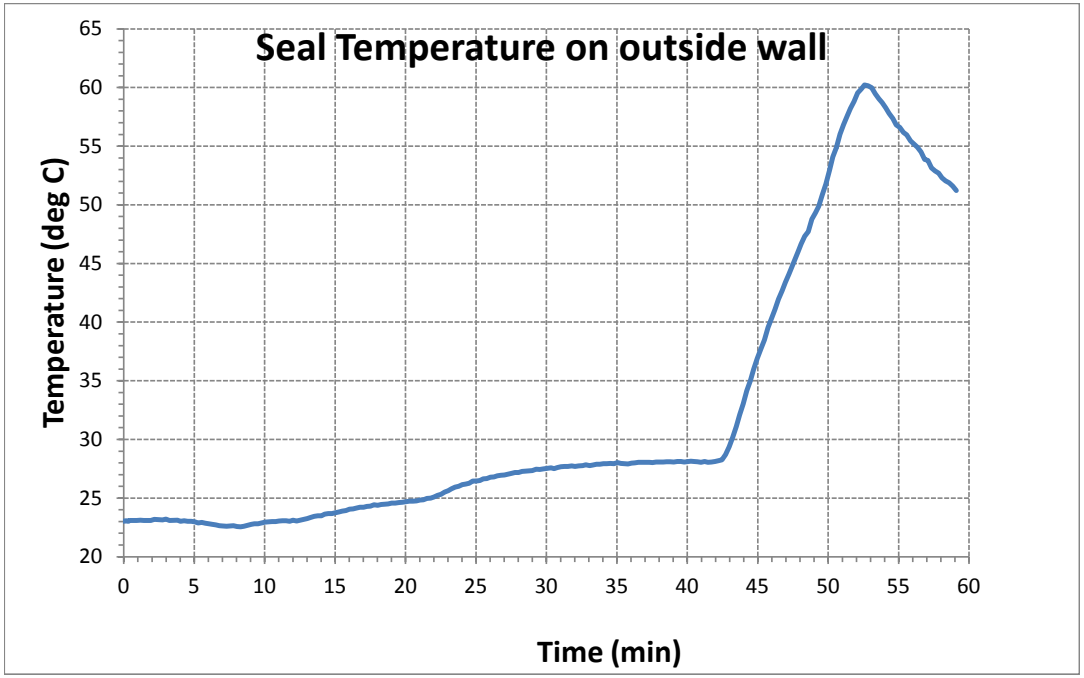
Scan #	Time	Time	Speed	
	H:M:S	min	rpm	Comments
1	10:32	0	0	started data recording
17	10:35	3	0	took full RGA Scan
20	10:36	4	0	took full RGA Scan
40	10:41	9.2	0	took full RGA Scan
43	10:42	10.2	0	took full RGA Scan
47	10:43	11.2	200	
123	11:03	30.5	200	took full RGA Scan
162	11:13	40.5	200	took full RGA Scan
168	11:14	42	2000	
191	11:20	48	2000	took full RGA Scan
197	11:22	49.6	2000	Torque ramped up & vacuum leak occurred
208	11:24	52.3	0	Stopped motor
235	11:31	59.1	0	Ended data recording



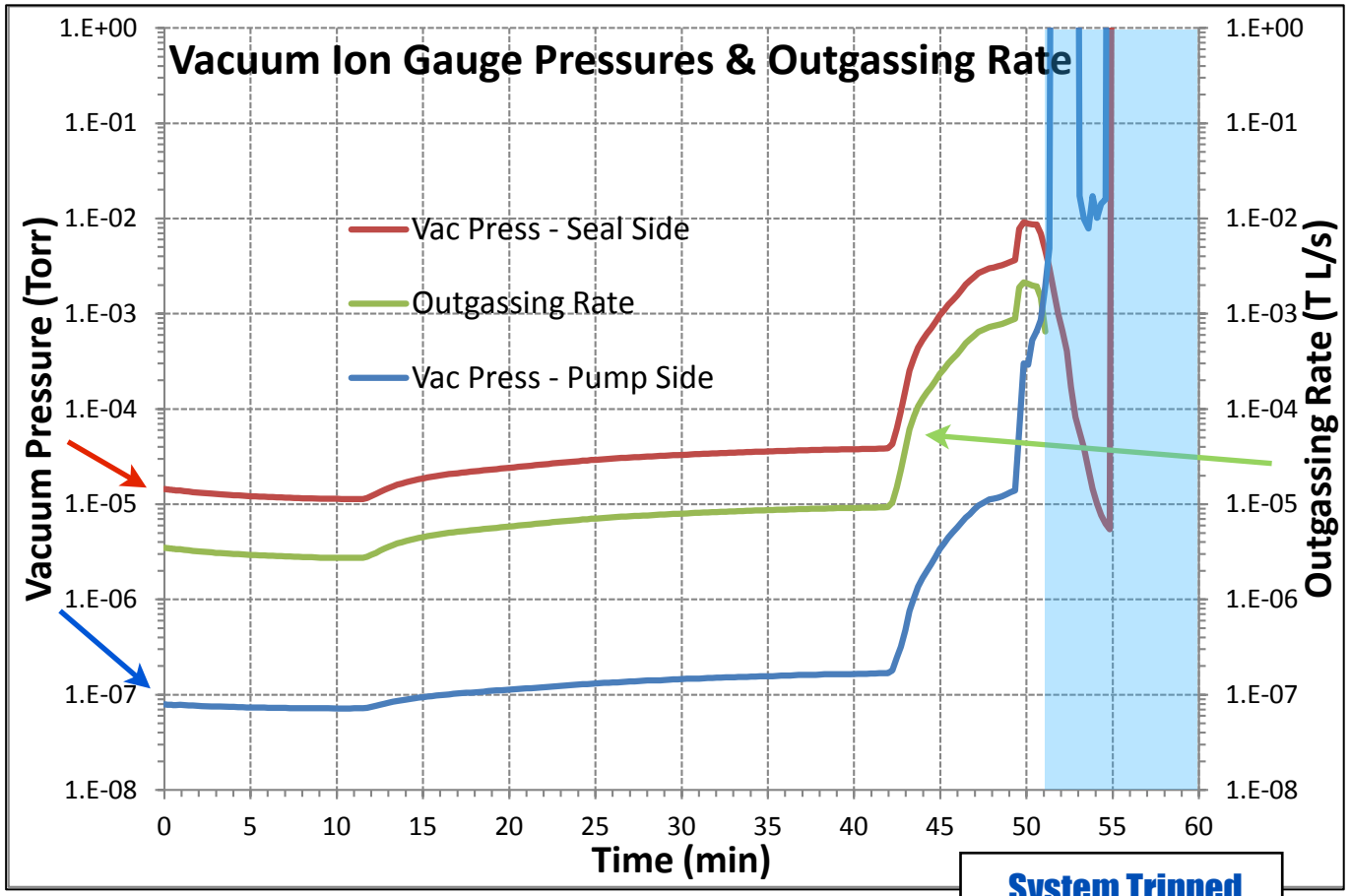
... and we killed it.

Temperature data was disturbing

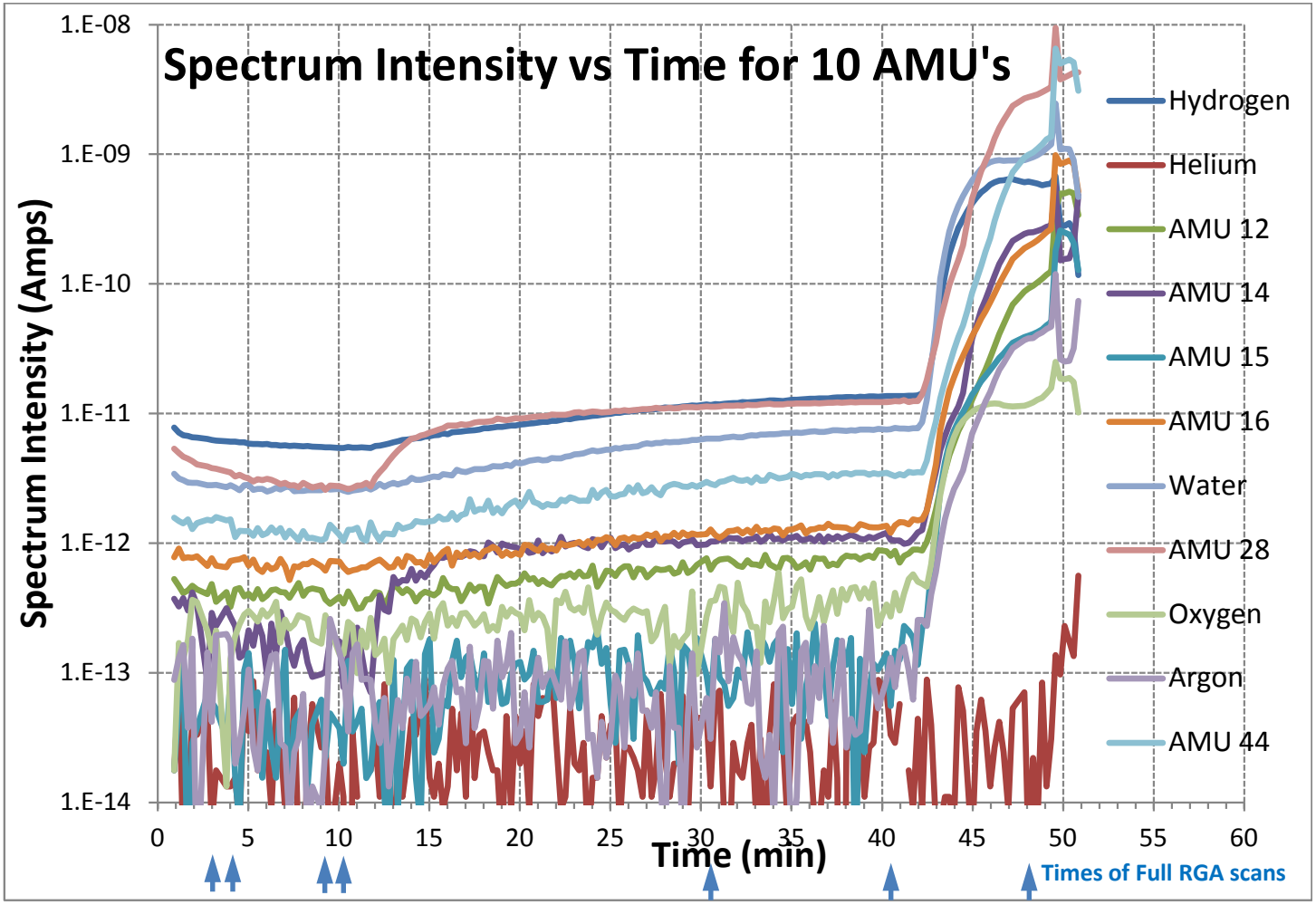
- Rigaku reported running at 55 ℃ without problems
- Temperature was still rising when we turned it off



Outgassing looked like it was stabilizing when the seal failed

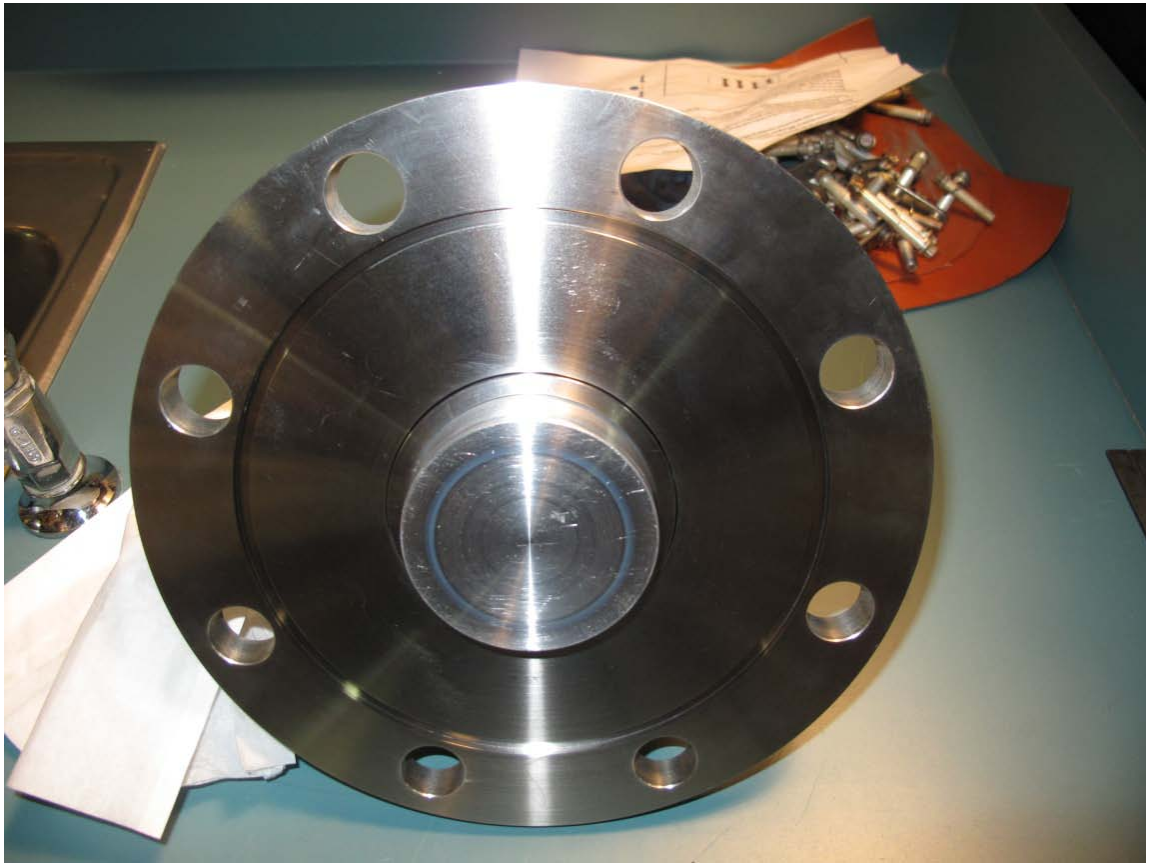


Residual Gas Analyzer output showed a spike



Seal inspected after failure

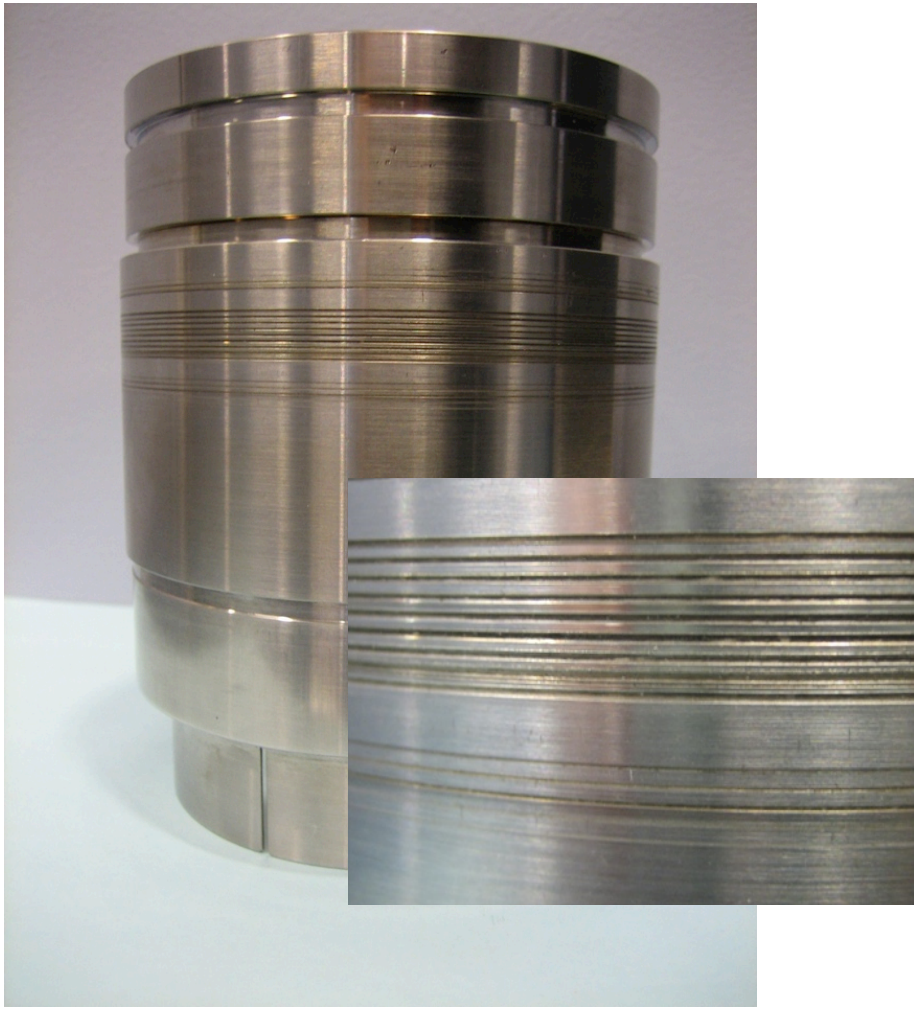
- No visual signs of failure or residue
- No signs of residue inside the chamber



Checked whether there was a problem on the shaft seal

- O-rings were good.
- No sign of slipping
- No indication of any problem here

Rigaku post-mortem shows a design flaw

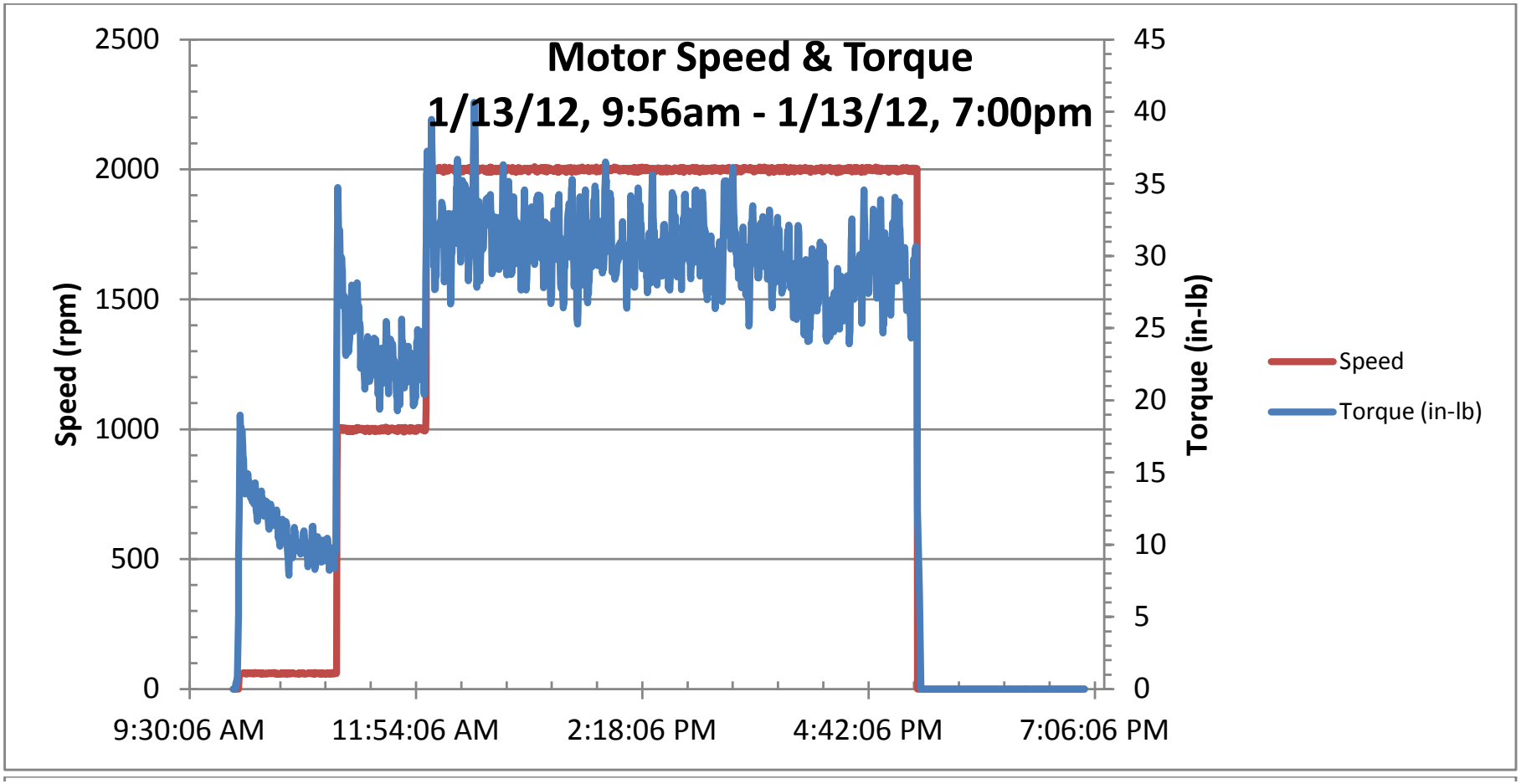


- Differential expansion between dissimilar metals caused contact between pieces at high temperature
- Grinding occurred leading to failure
- Rigaku agreed to rework the piece under warranty

While waiting for feedback from Rigaku we acquired a second plug compatible seal from FerroTec

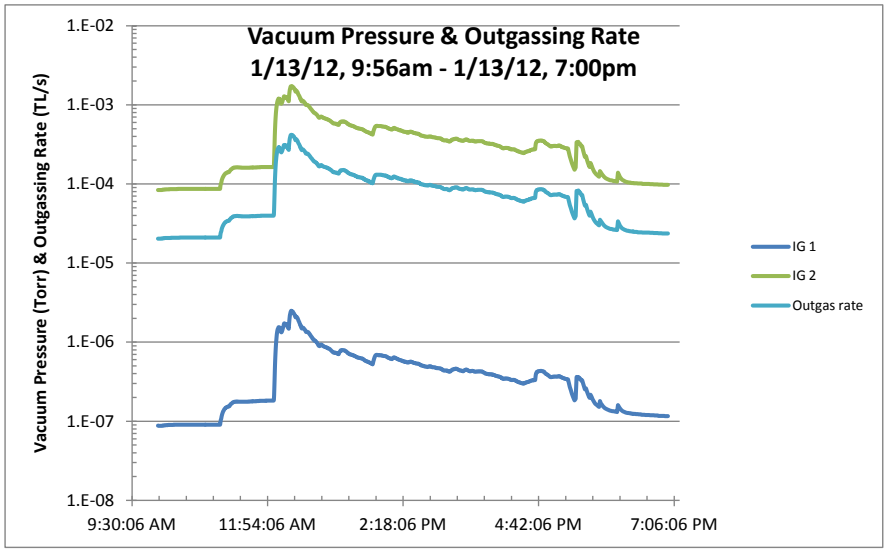
- Since it seemed that we had a heating problem with the Rigaku seal we chose a lower viscosity / higher outgassing ferrofluid.

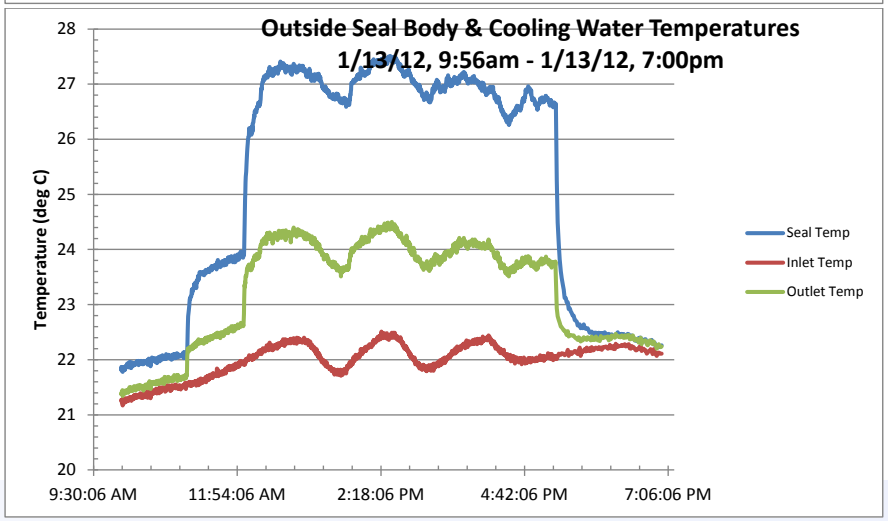
The ferrotec seal ran without significant problems at 2000 RPM



We logged about 38 hours total running time at 2000 RPM

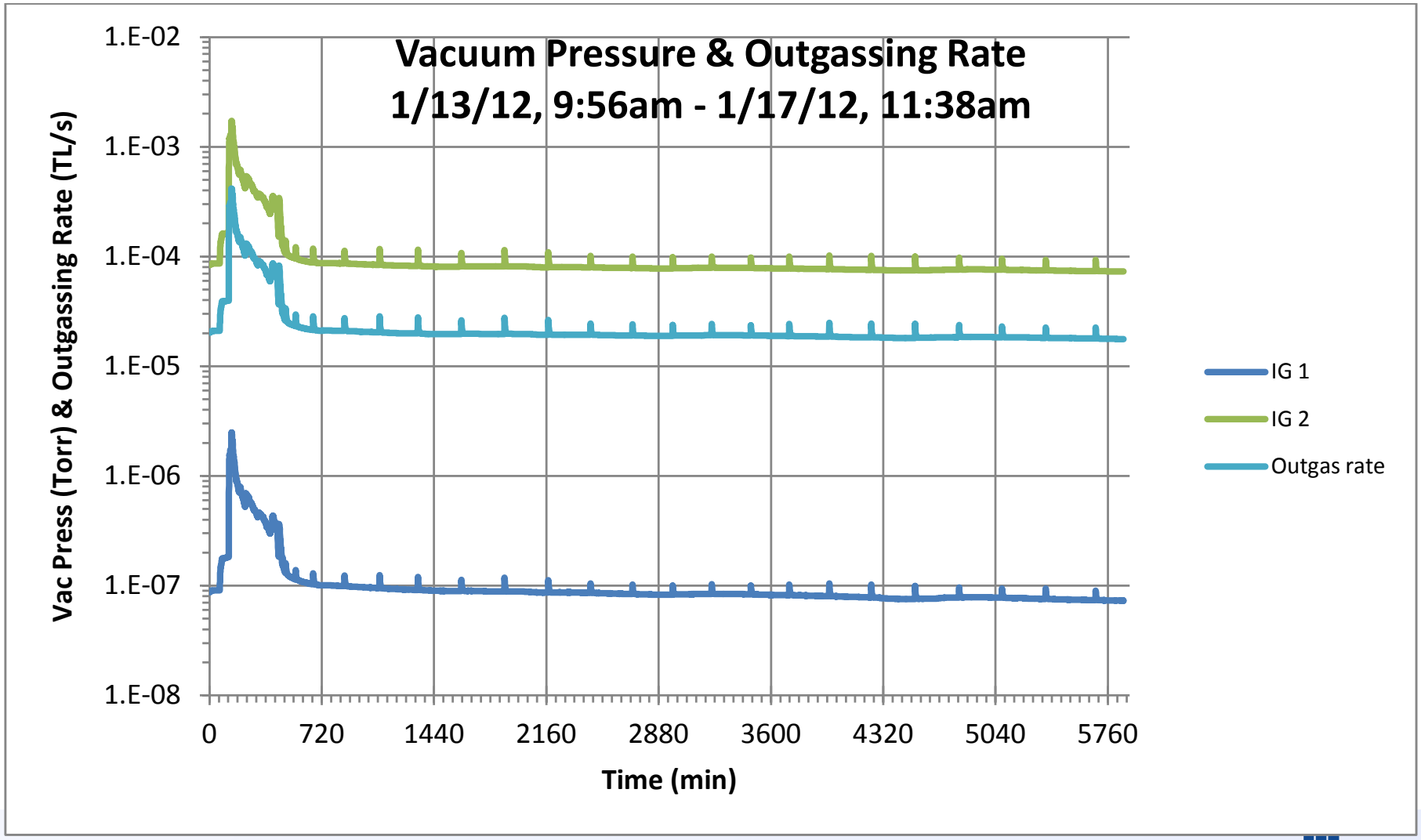
Temperature was stable, outgassing rate was falling over the 5 hours at 2000 RPM



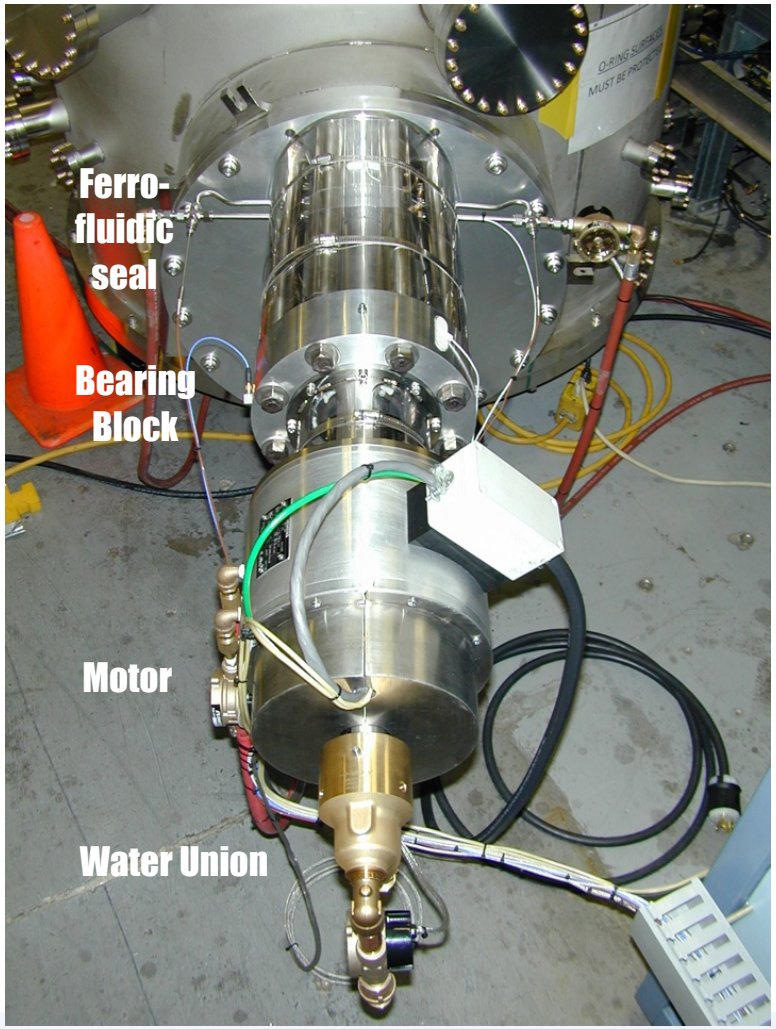


- Seal seemed to be performing normally

After operation took data at 0 RPM: outgassing was stable but the seal outgassing spikes regularly



Operation of FerroTec seal #1 on the full test stand began in May 2012



- The DAQ records the system state every 30 seconds.
- Slow control is designed to shut down the wheel if any limits are exceeded
  - Unmanned operation is standard

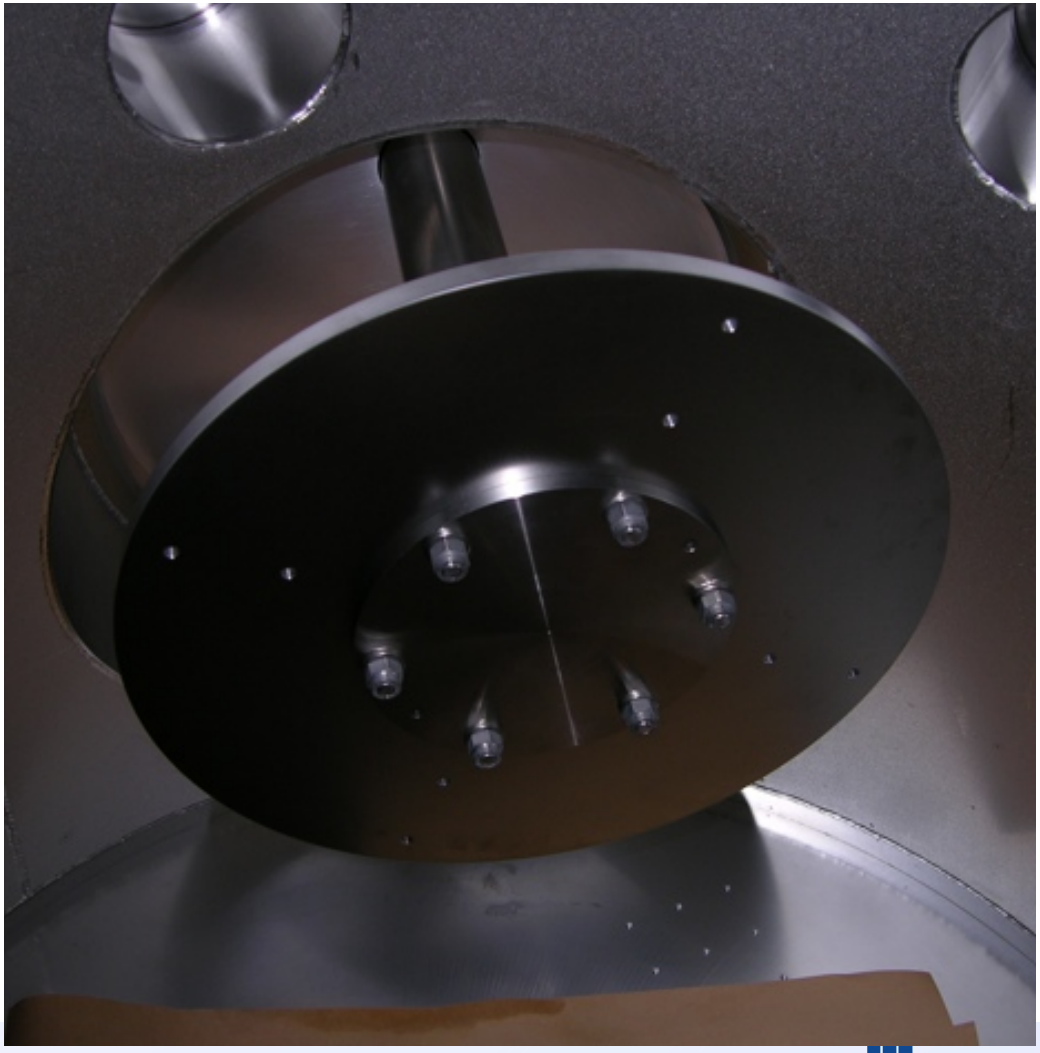
We monitor:

- Motor
  - RPM
  - Power
  - Torque
- Vibration
  - Three axis sensors on motor, bearing block, seal
- Vacuum Pressure
- Temperature
  - Ambient, Seal, Bearing Block, Motor, Cooling water inlet and outlet
- Residual Gas Analyzer currents
- Cooling water flow rate
  - Seal, Bearing Block, Motor, Shaft

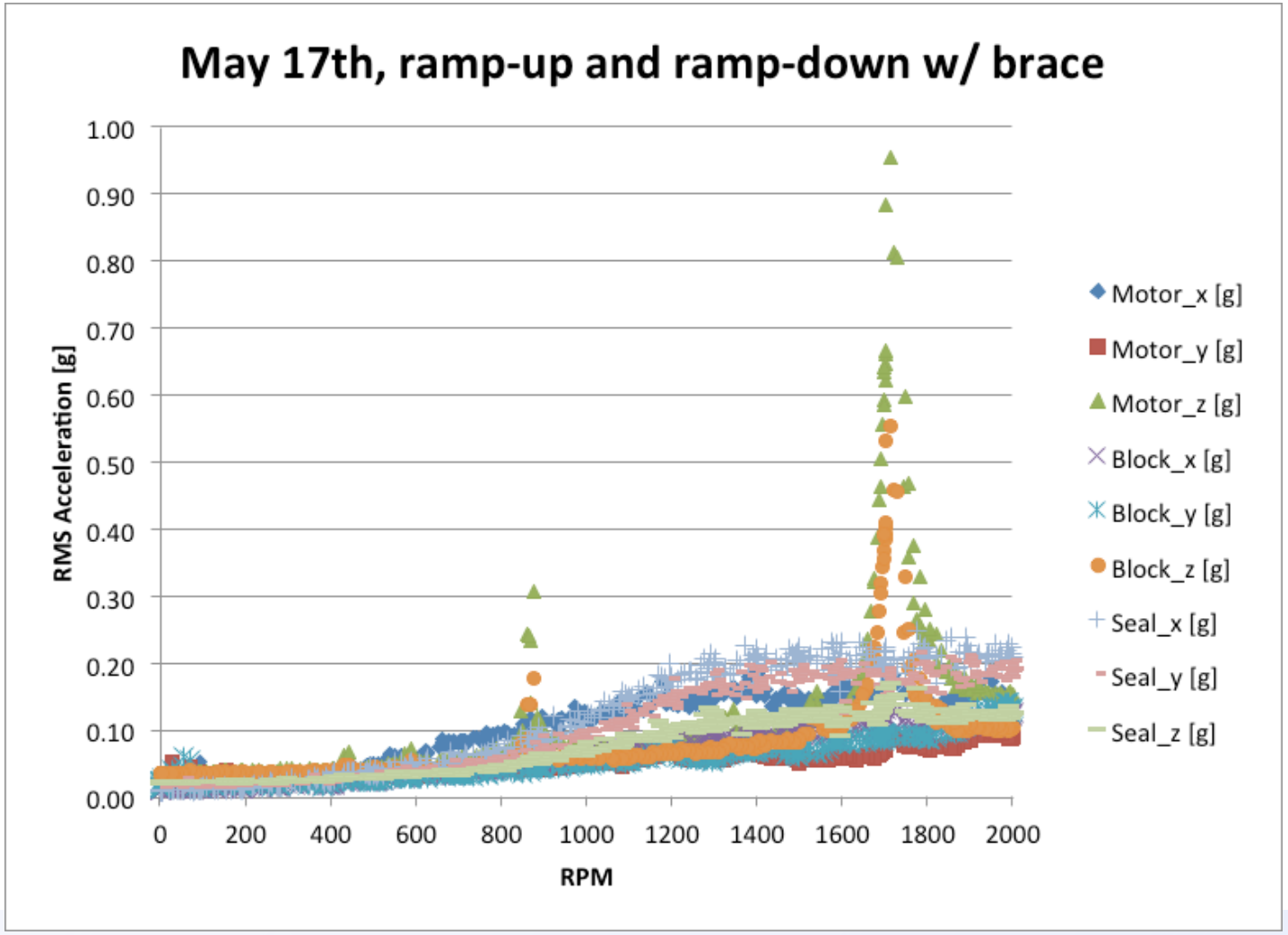
Medium disk was installed and balanced

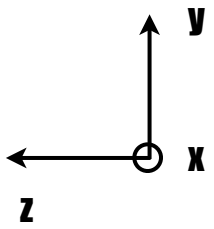
- Same weight as titanium wheel
- No shielding required for safety

- Cooling water in the shaft has an effect on the balancing
- Not quite as stable a balance point as a solid shaft would have



Balancing data from the FerroTec seal



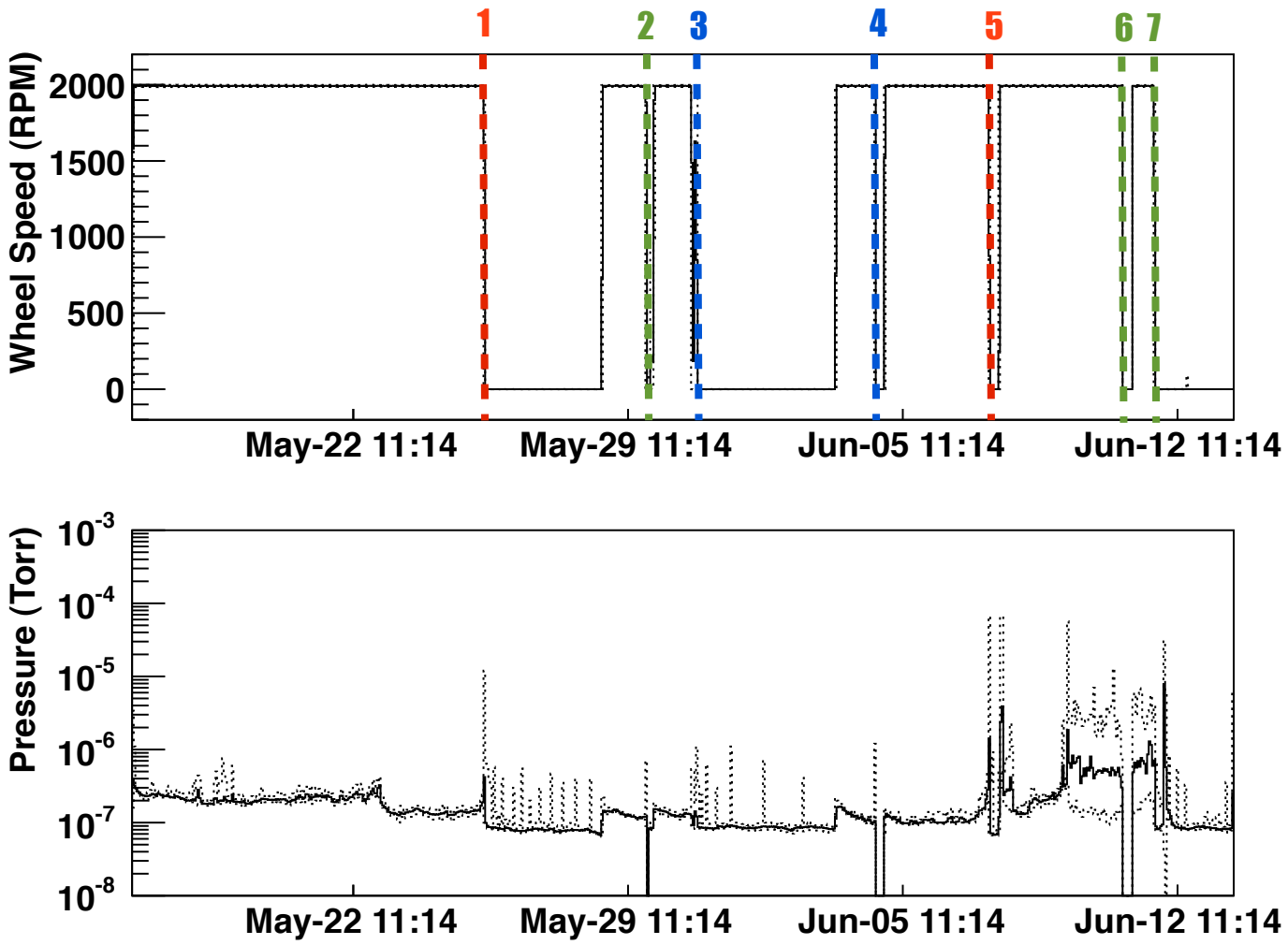


x = along shaft

y = vertical

z = horizontal

FerroTec Seal #1 ran for 1 month (450 hours up)



Pressure Trip

System Trip

Planned Down

1 - Pressure Spike

2 - DAQ software change

3 - Cooling water flow

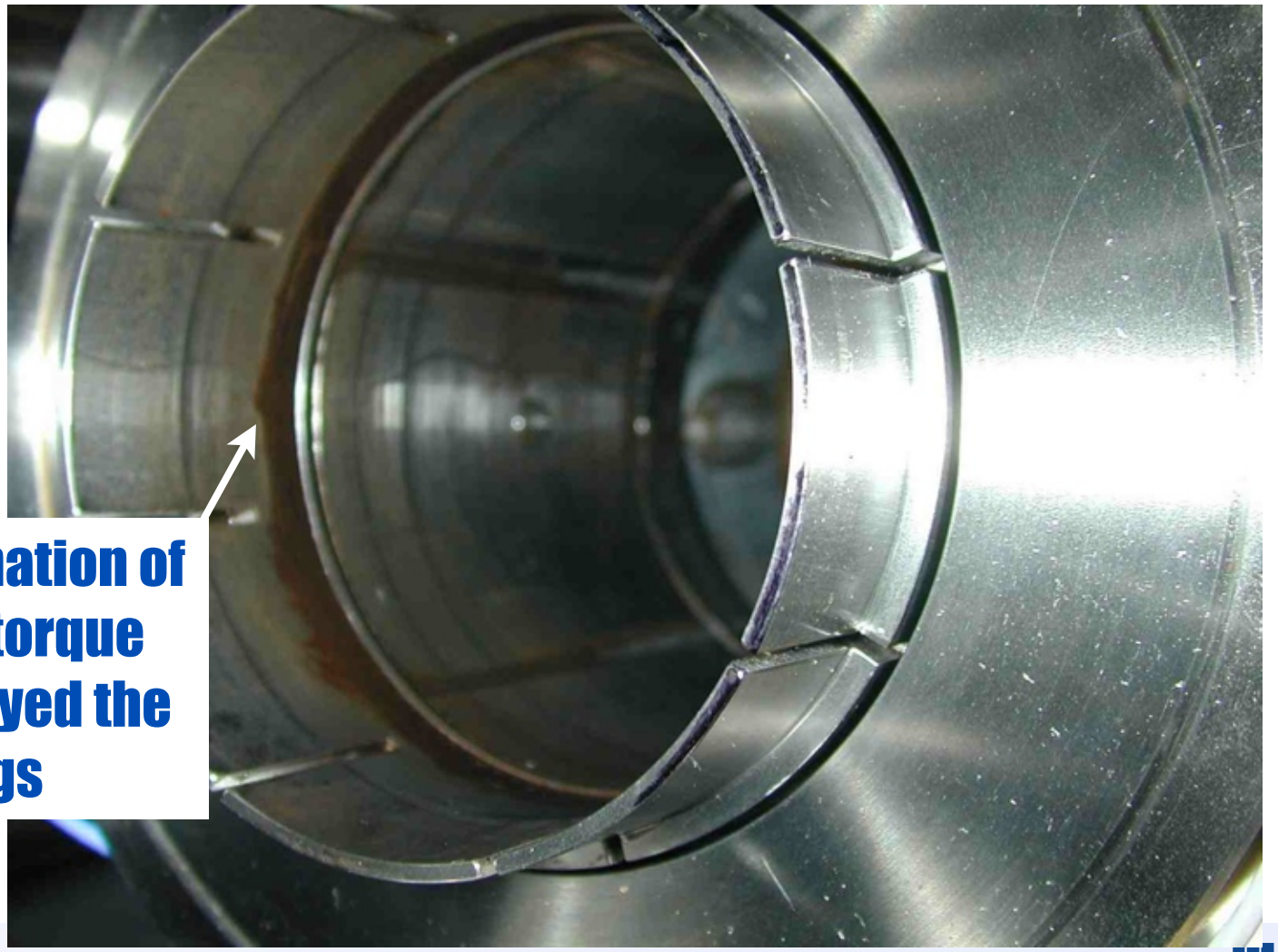
4 - Vibration Limit

5 - Pressure Spike

6 - Wheel stopped for pressure test

7 - System down for rework

We dismounted the shaft to look for failure of the O-rings that sit inside seal



The combination of heat and torque had destroyed the O-rings

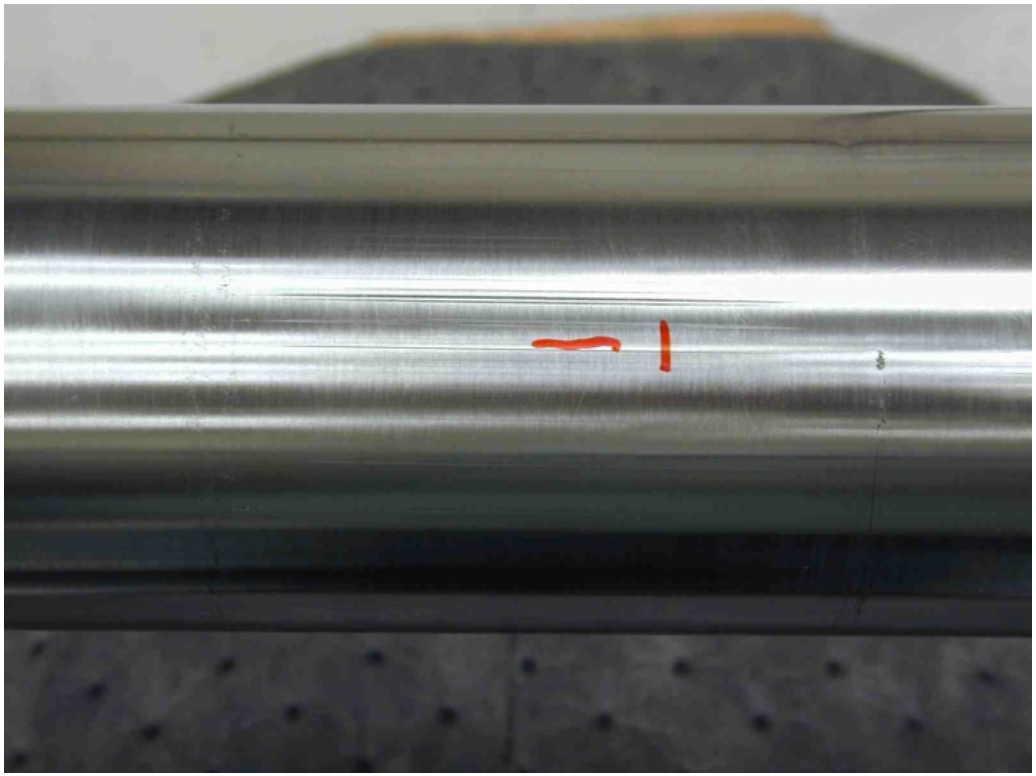
The ferrofluid seal didn't fail

- The collar which is supposed to clamp the seal to the shaft had been left off
- The O-rings became the components that transferred torque from the shaft to the seal
- Eventually the O-rings were destroyed

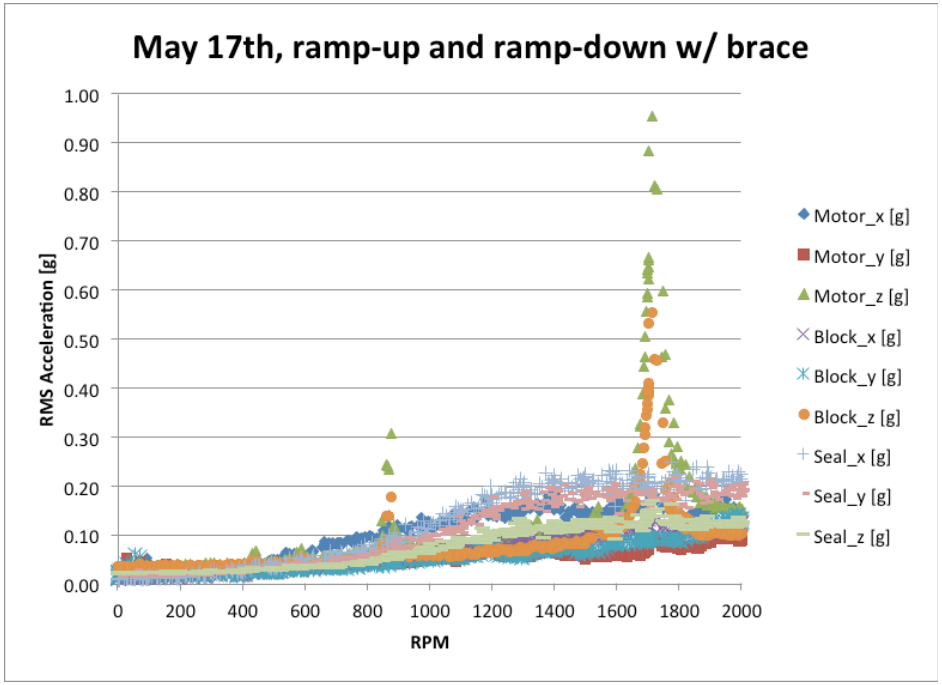
The remains of the O-rings melted to the shaft

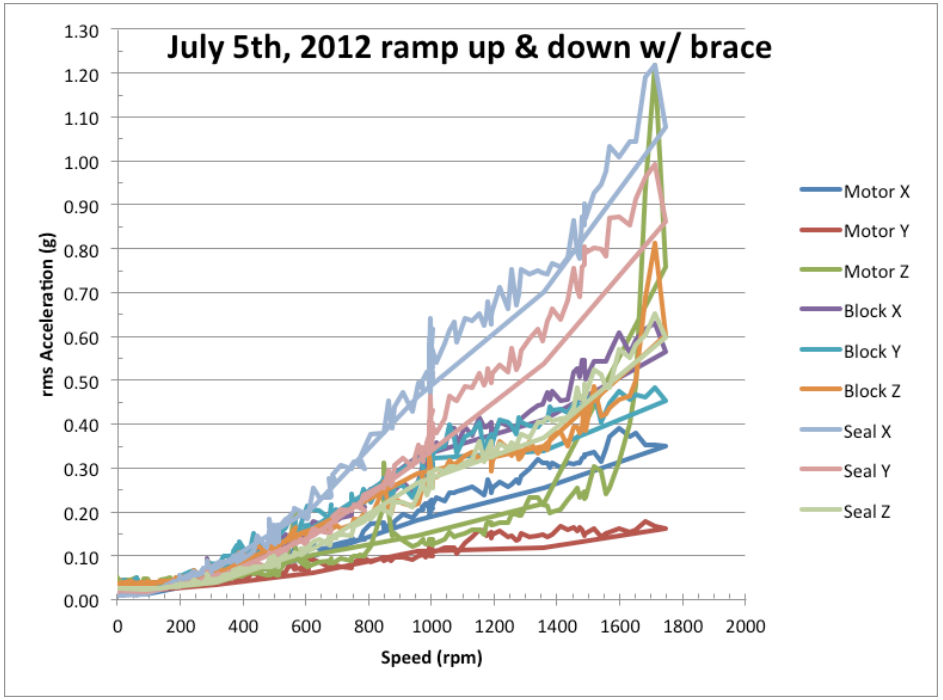
The system was refurbished

- A great deal of force had to be used to extract the shaft from the seal.
- The seal and the shaft had the O-ring residue cleaned off and were reinstalled with new O-rings



The vibrational characteristics of the seal changed dramatically after the rework

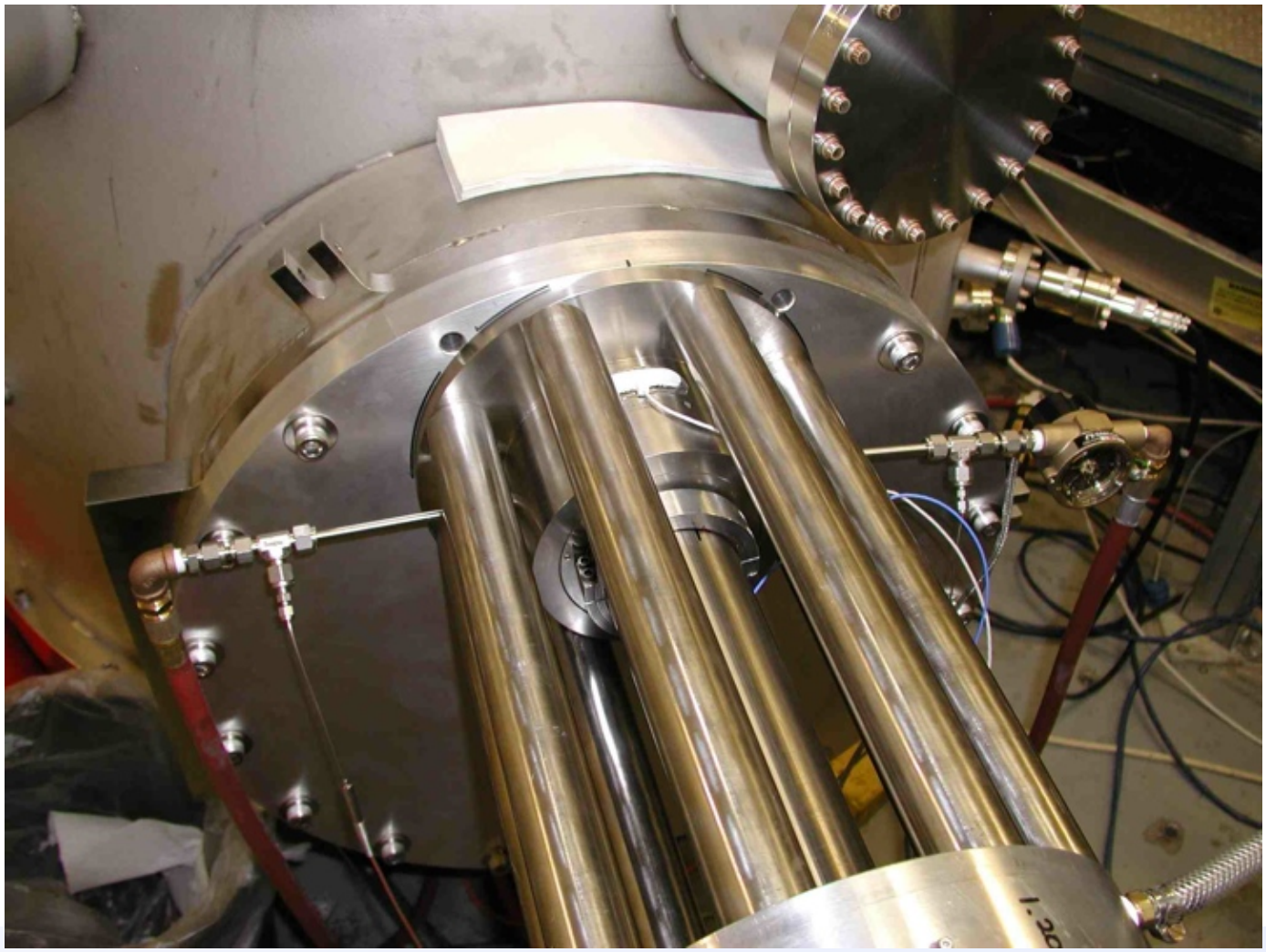




Vacuum was still good but system vibration became unacceptable

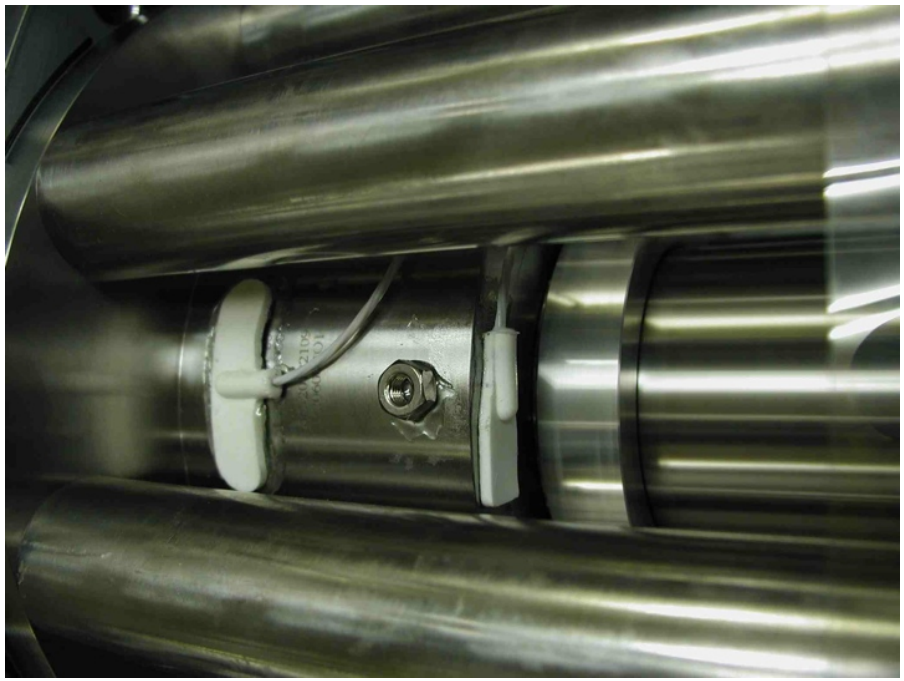
After investigating other possible sources of vibration we concluded that the force of extracting the shaft had damaged the seal bearings

The FerroTec seal #1 was dismounted and the refurbished Rigaku seal was installed



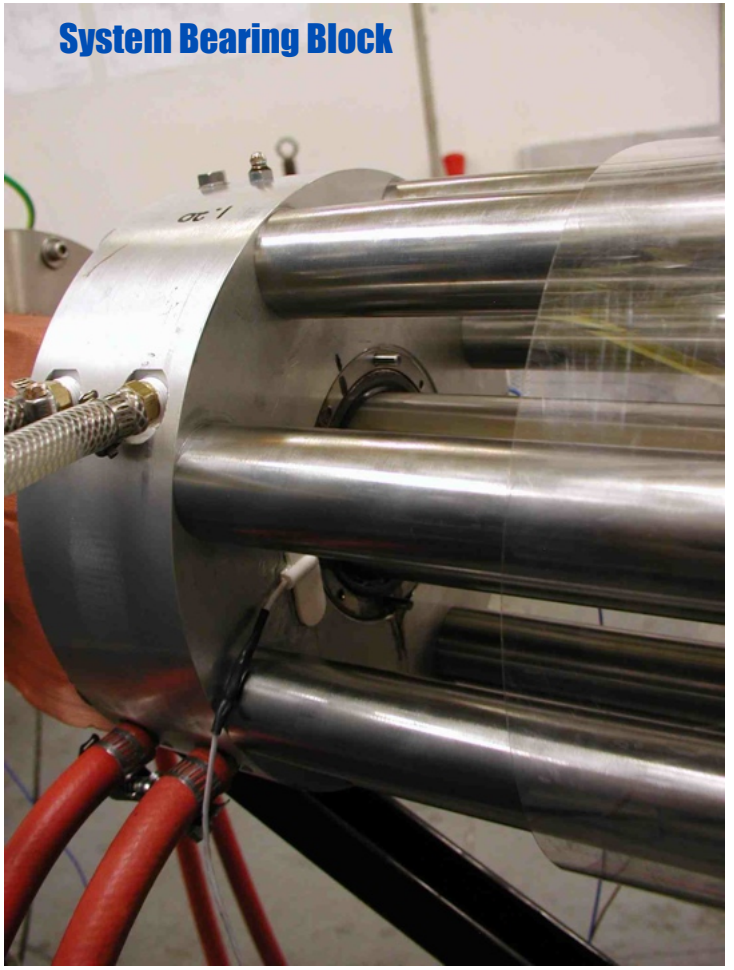
The Rigaku seal was not able to be run successfully at 2000 RPM

- Seemed OK when run unloaded on the vertical test stand
- Under load there was a large acoustic noise from the bearings
- Repeated pressure spikes
- High Temperatures on the case at 1000 RPM
  - 31 C on case
  - 46 C on the end



Rigaku seal was dismounted, FerroTec seal #3 was installed

- Installation completed August 30th
- Ran at 500 RPM over the weekend with no seal problems but developed a water leak in the central shaft at the bearing block
- Once the leak is fixed we will balance and run at 2000 RPM
- We will allow the system to run until it develops a problem



Lessons Learned

- Ferrofluidic seals are not boring, each one has its own individual personality
  - We would prefer them to be anonymously interchangeable and predictable
- They all have outgassing spikes
  - A differential pumping region just after the seal would be a useful modification
- We are pushing them to speeds at which there is significant heat dissipation
  - Off-the-shelf models do not seem to be well designed for this.
  - Improved cooling design is a must for any future system

History and Status of our Available Seals

- Rigaku #1
  - Catastrophic failure after 15 minutes at 2000RPM on the outgassing test stand
  - Rigaku analysis indicates differential expansion of components lead to failure
- Rigaku #1 reworked
  - Switched fluid for low viscosity type
  - Unacceptable behaviors seen on the test stand
- Ferrotec #1
  - Low viscosity fluid
  - Normal operation for 38 hours at 2000 RPM on the outgassing test stand
  - Higher outgassing than Ferrotec expected
  - Ran normally on the test stand until O-ring failure, damaged during rework
- Ferrotec #2
  - Ran rough on the outgassing test stand, better outgassing than Ferrotec #1.
  - Returned to Ferrotec for analysis
- Ferrotec #3
  - Currently mounted on the test stand

Future Work

- This work will come to a conclusion after Sept 28th
  - As long as the current seal is working properly it will be allowed to run and collect data after that

- Any future development of the Ferrofluidic seal concept will need to be in partnership with manufacturers to create a device optimized for our needs.
  - Improve cooling channel routing in the stationary section to dissipate heat from the ferrofluid and the bearings
  - Replace the inner rotating section with one designed to be the outer sleeve of the shaft.
    - This will eliminate the O-rings
    - This will improve contact with the shaft cooling water for additional cooling