Temperature Measurement and Stabilization Strategies for APS

Lester Erwin,
ASD Diagnostics Group

Challenges on the road to submicron beam position measurement.

Where we are heading.
How do we get there?

- CD0 improved temperature stability of ± 0.1 °C for support stands should provide 1 micron peak-to-peak beam stability with 0.5 micro radian peak-to-peak pointing stability over a one-week period

Temperature Coefficients
Decker BIW98 (Glenn Decker's Magic Formula)

- **MECHANICAL STABILITY**

The air and water temperature in the tunnel is generally stabilized to within ± 0.3 °C rms. Given that thermal expansion coefficients tend to be on the order of 1 x10^{-5}, this translates into a vertical chamber motion of order

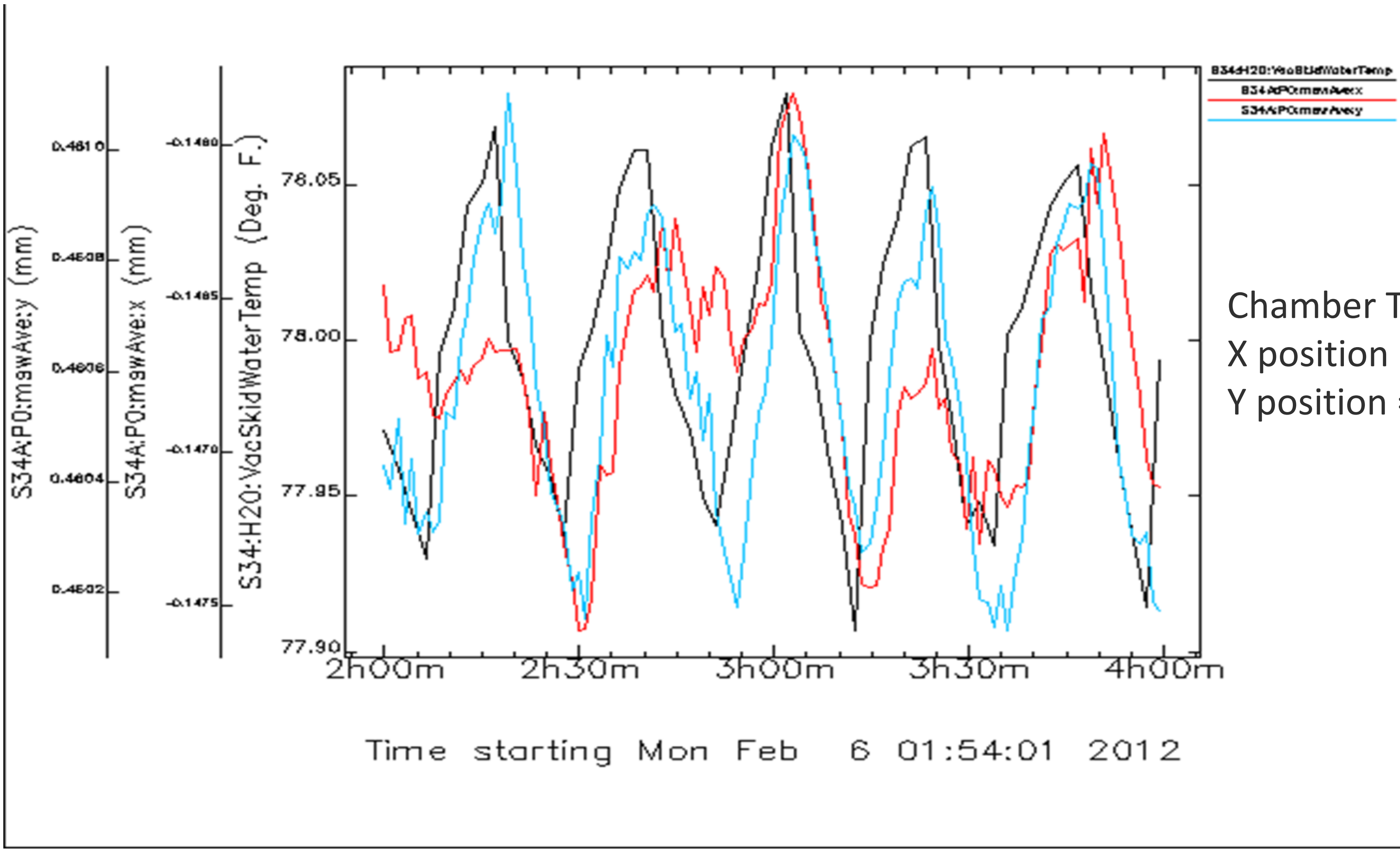
$$1.4\text{m} \times 0.3°\text{C} \times 1 \times 10^{-5} = 4.2 \text{ microns rms}$$

This will almost always be the case; mechanical components typically cannot be stabilized to better than 5 to 10 microns rms owing to one's ability to regulate temperature. Worse yet, as the beam is injected and decays away, the thermal load on the water-cooling systems varies and vacuum chamber shape distortions inevitably result (5).

Thermal Effects on APS Storage Ring

- 1. Chamber water temperature
- 2. Tunnel Air temperature
- 3. Mezzanine Air temperature
- 4. Rack Air temperature regulation
- 5. Sector 32 ID mechanical motion sensor

Vacuum Chamber Temperature versus BPM Position ~1µm-1.5 µm /0.18 º F equals ~10-15 microns/°C



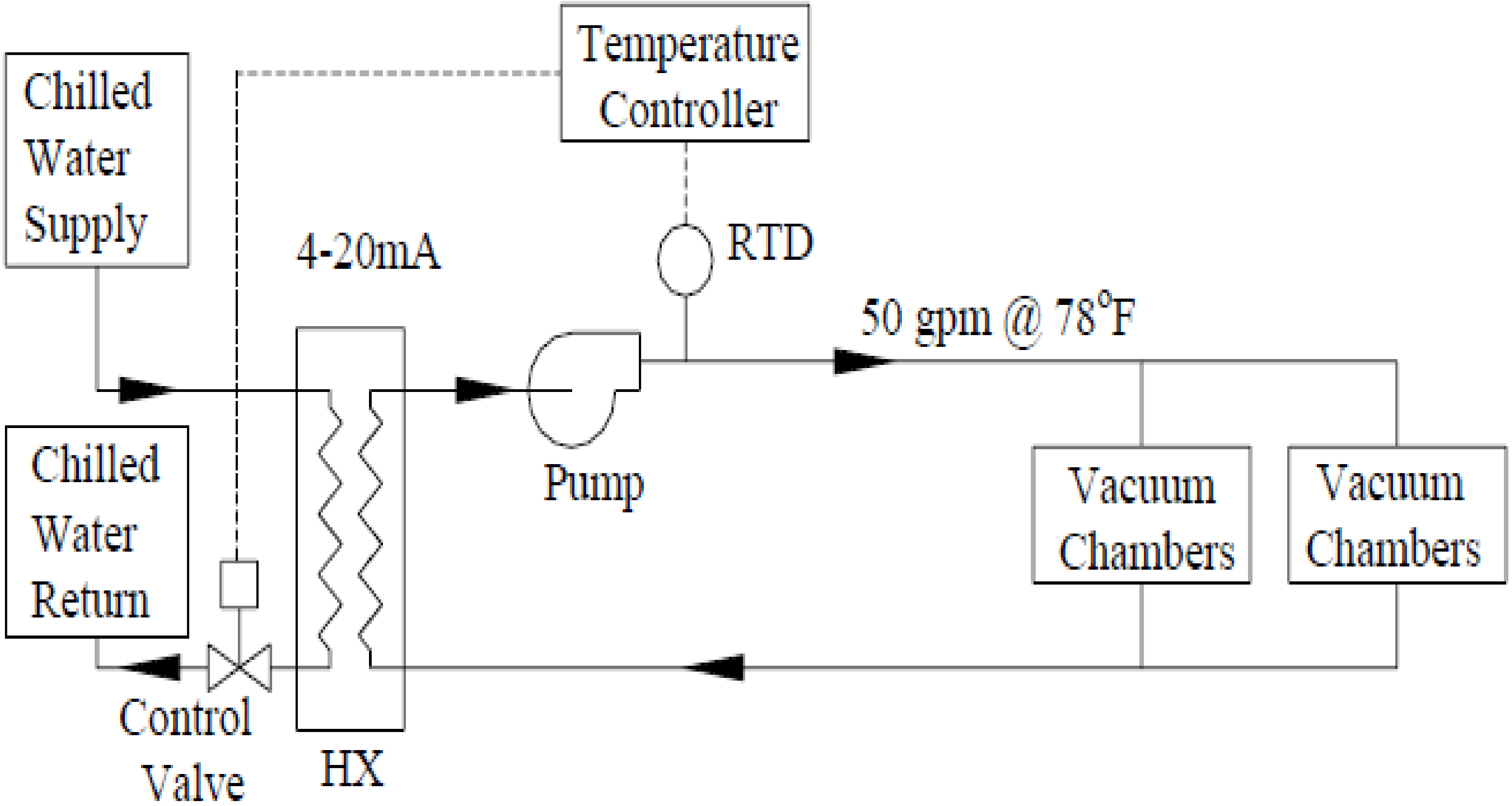
Chamber Temp 0.2°F
X position = 1.5µm
Y position = 1 µm

20 SR Vacuum Chamber Cooling Water Skids

- 20 Pump systems
- 50 GPM/system
- Supply temperature 78 °F ±0.05°F
- 0.5 micron filtration
- Closed system
- Units use chilled water heat exchanger to control temperature
- Controlled by Allen-Bradley PID
- Alarm handler added for temperature and valve position

Gene Swetin

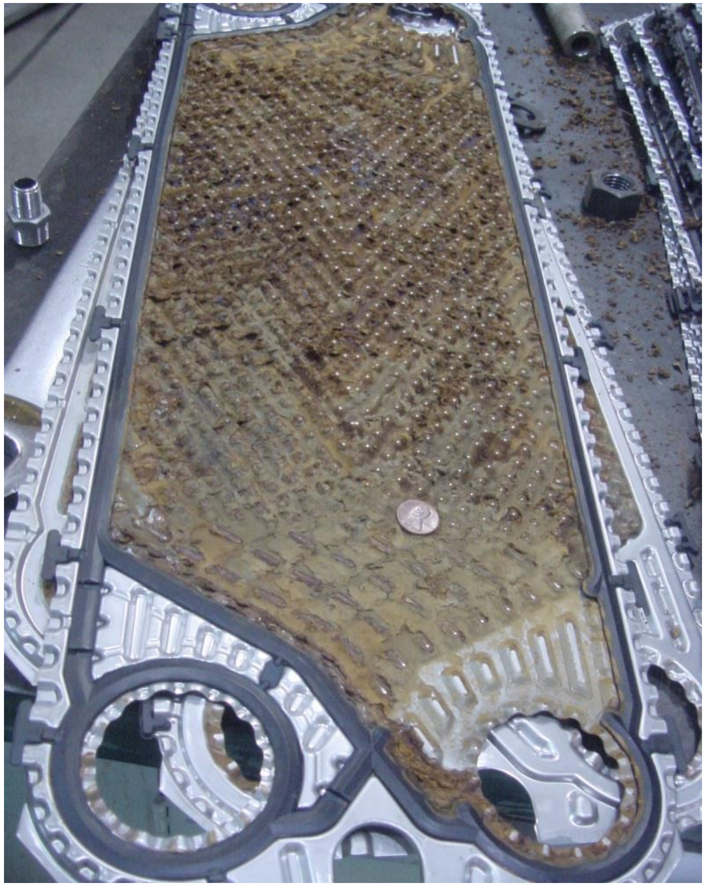
SR Vacuum Chamber Water Skid Basic Diagram

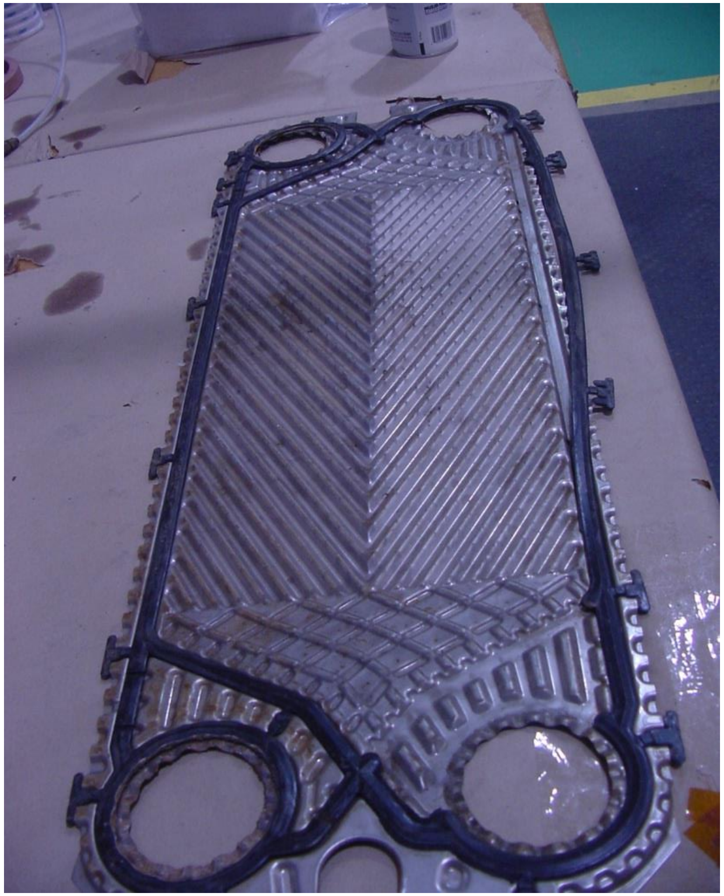


Rick Putnam, Bob Dortwegt

Inside of Plate & Frame heat exchanger showing growth

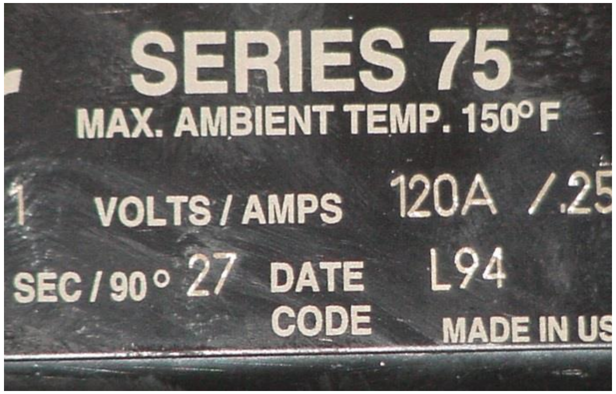
Chilled water side and DI side



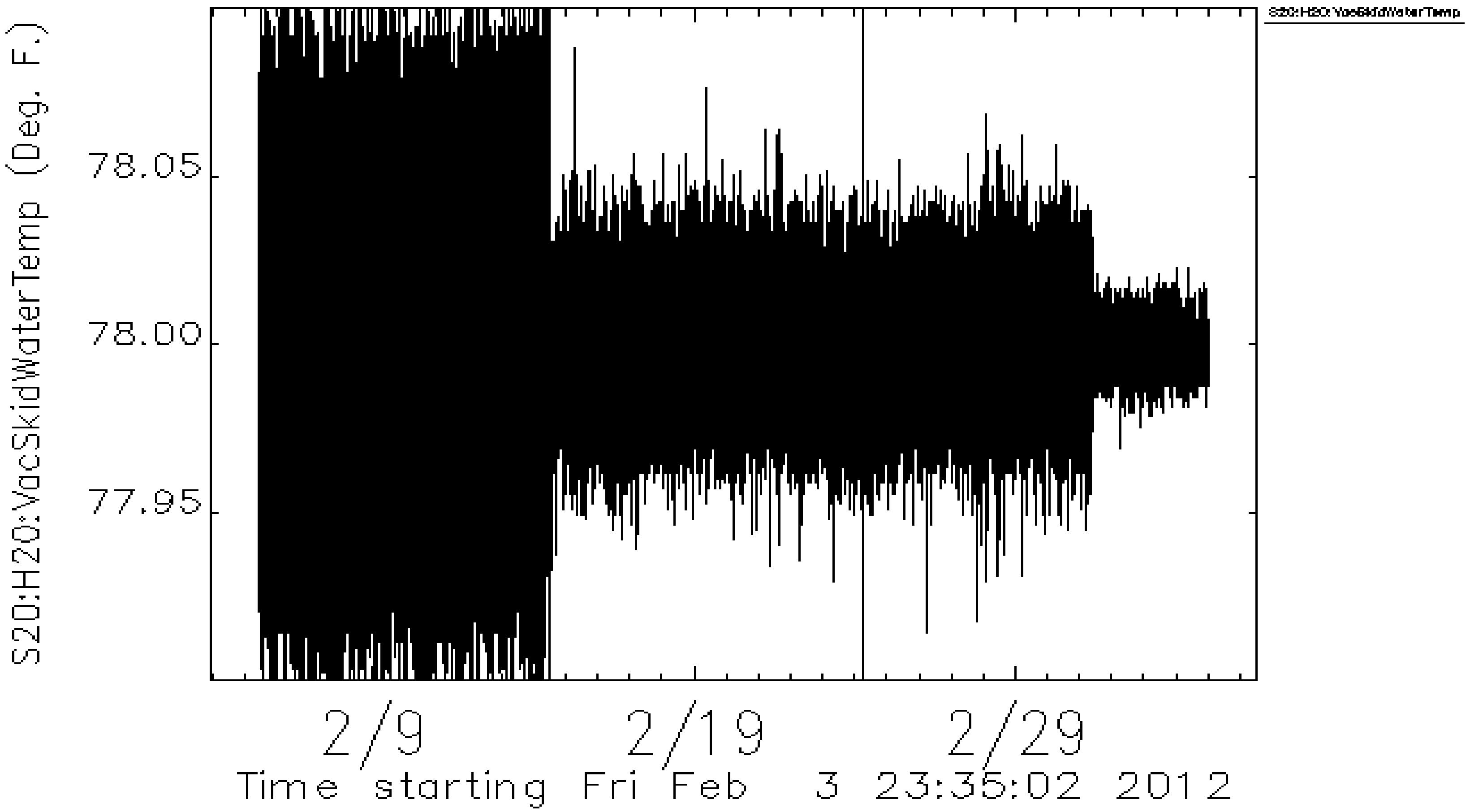


Old Plate and Frame compared to New Tube Type Heat Exchanger

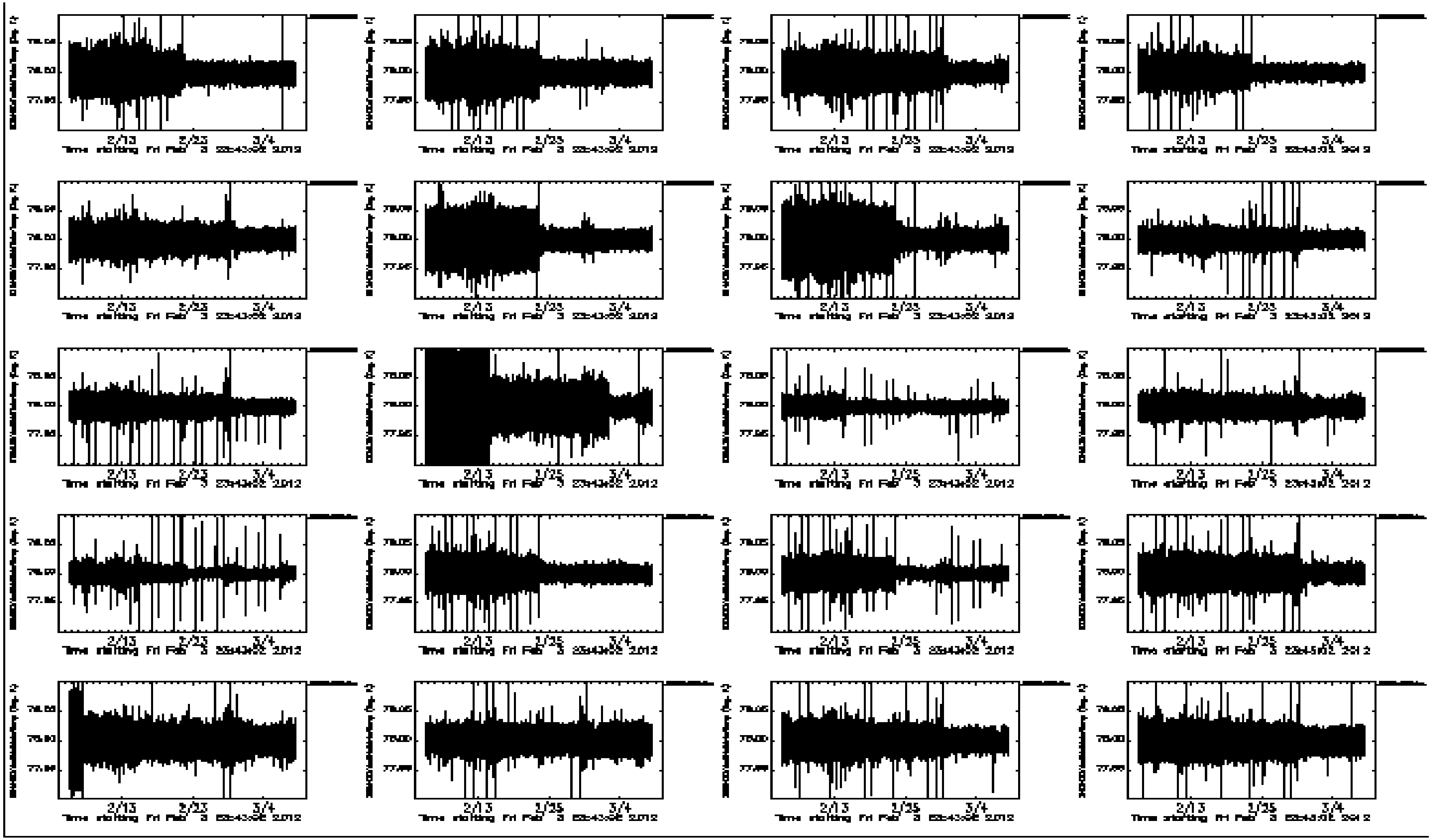
Worcester Actuator and Valve combination. How old are we?



Water Skid 20 After PID Loop Tuning and Tightening of 4 set screws on coupler between Actuator and Valve

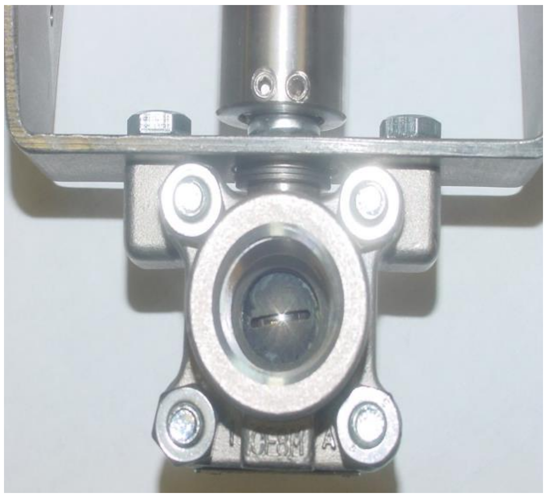


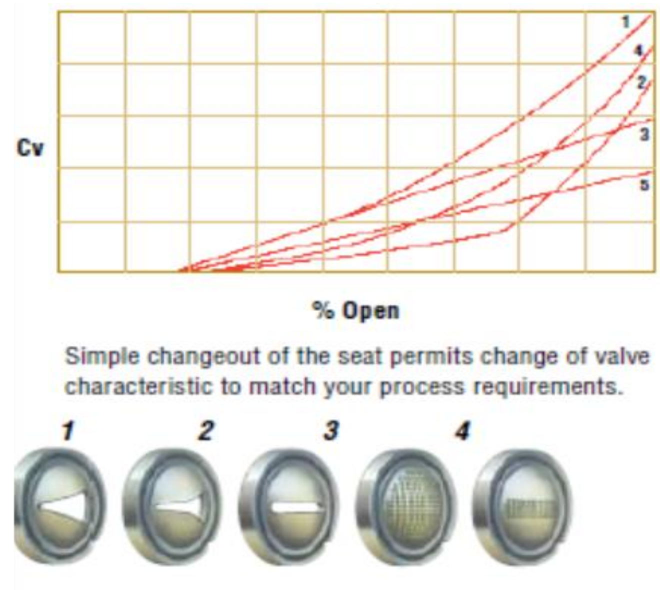
Water Skids after One Month of Tuning and Testing
Plot range ±0.1 ºF



Test Skid upgrades: New Actuator with Digital Positioner, Temperature Transmitter, RTD

Worked with Sales Engineer to determine valve seat size. Used flow, temperature, and pressures. Units had 60 degree V, Recommendation was 1” by 1/32” slot or ½” by 1/16” slot



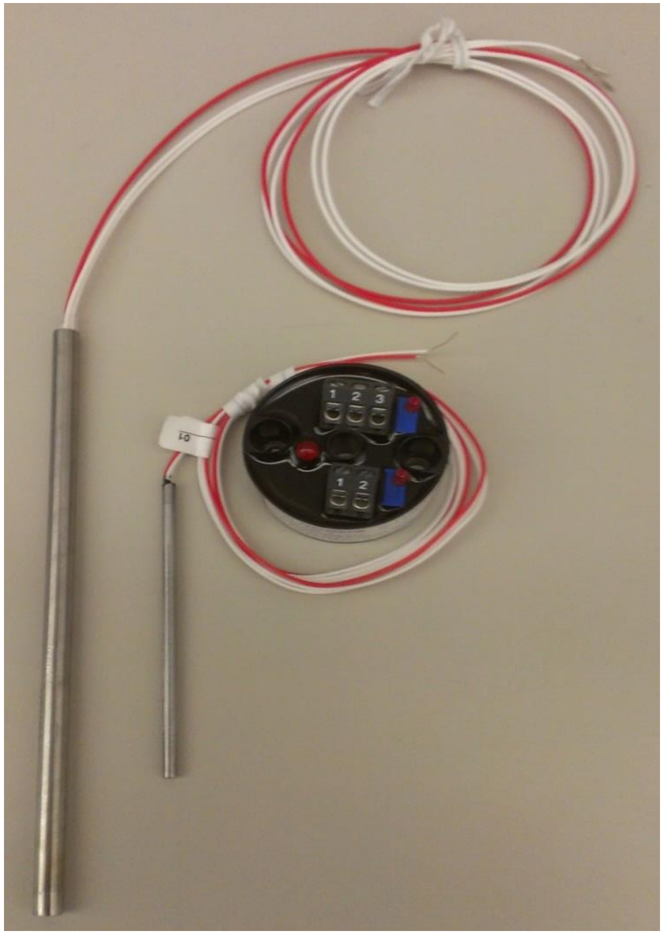


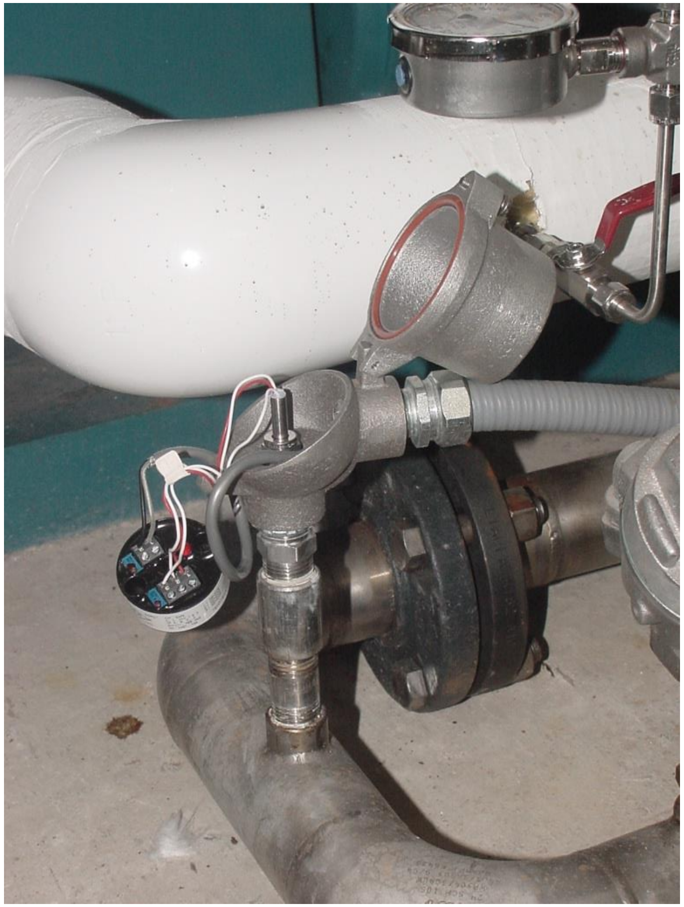
From FlowServe WCENBR1001.pdf

Transmitter converts RTD temperature to 4-20mA

- Minco Transmitter changes to increase resolution
- In order to control within a narrower tolerance, it is necessary to detect temperature changes at least ten times smaller than the desired tolerance band. Most RTD controllers are equipped with analog-to-digital (A-D) converters that divide the useful range of the RTD (sometimes on the order of 1800°F) by the number of bits available. Depending on the number of available bits, this can result in a resolution on the same order as or greater than the tolerance required. For this reason, a transmitter was employed having a 4- to 20-mA output corresponding to a temperature range of only 50°F. The temperature resolution can be determined by dividing the transmitter range by the number of bits available in the A-D converter. For a 16-bit A-D converter (15 bits resolution – 1 part in 32768 – and 1 sign bit), the resolution is approximately 50/2E15 = 0.0015°F. (Rick Putnam and Rob Dortwegt 2002)
- New transmitter temperature range 16°F gives 16/2E15=0.000488°F/Bit

Installed smaller diameter RTD, faster response ¼ inch versus 1/8 inch. Minco Transmitter mounting

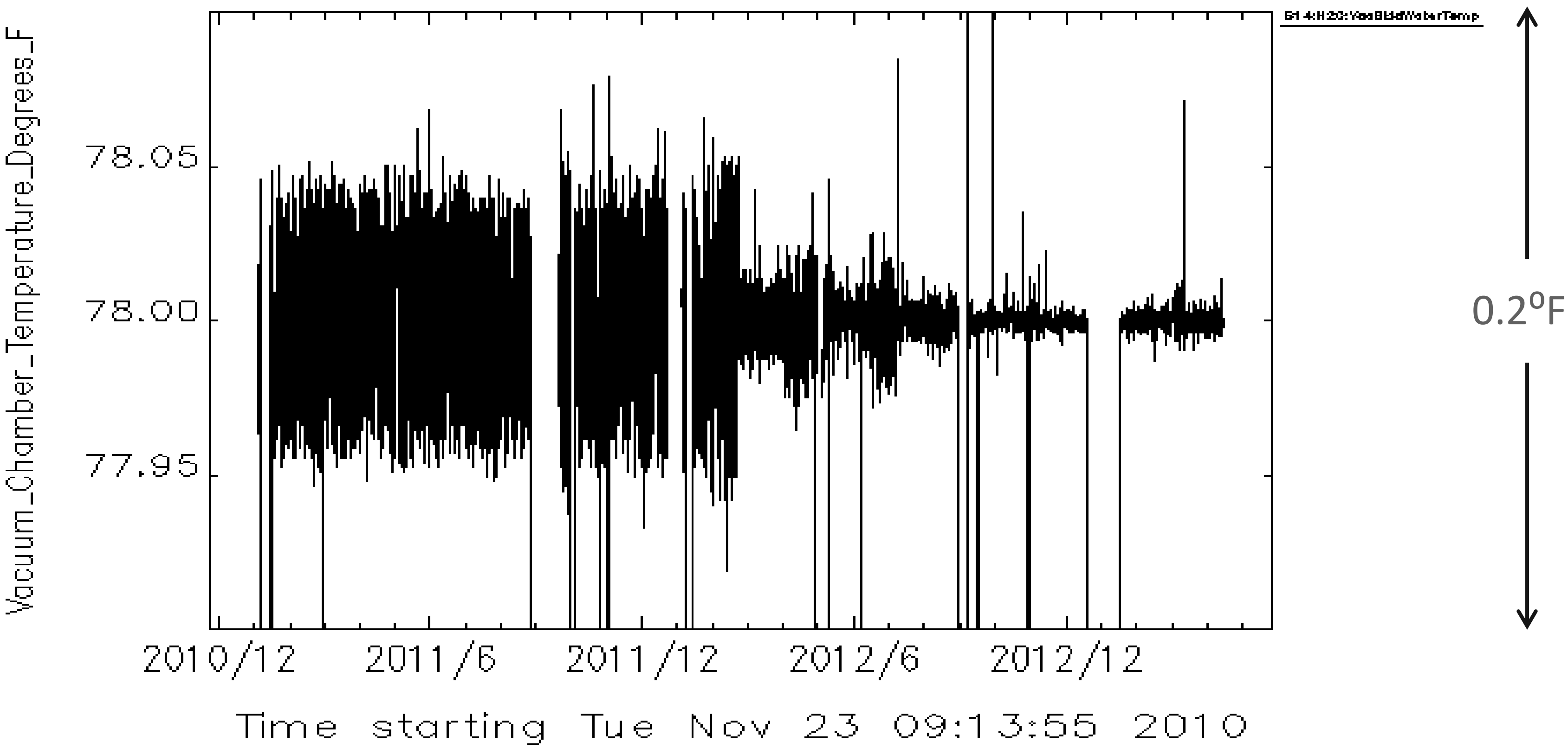




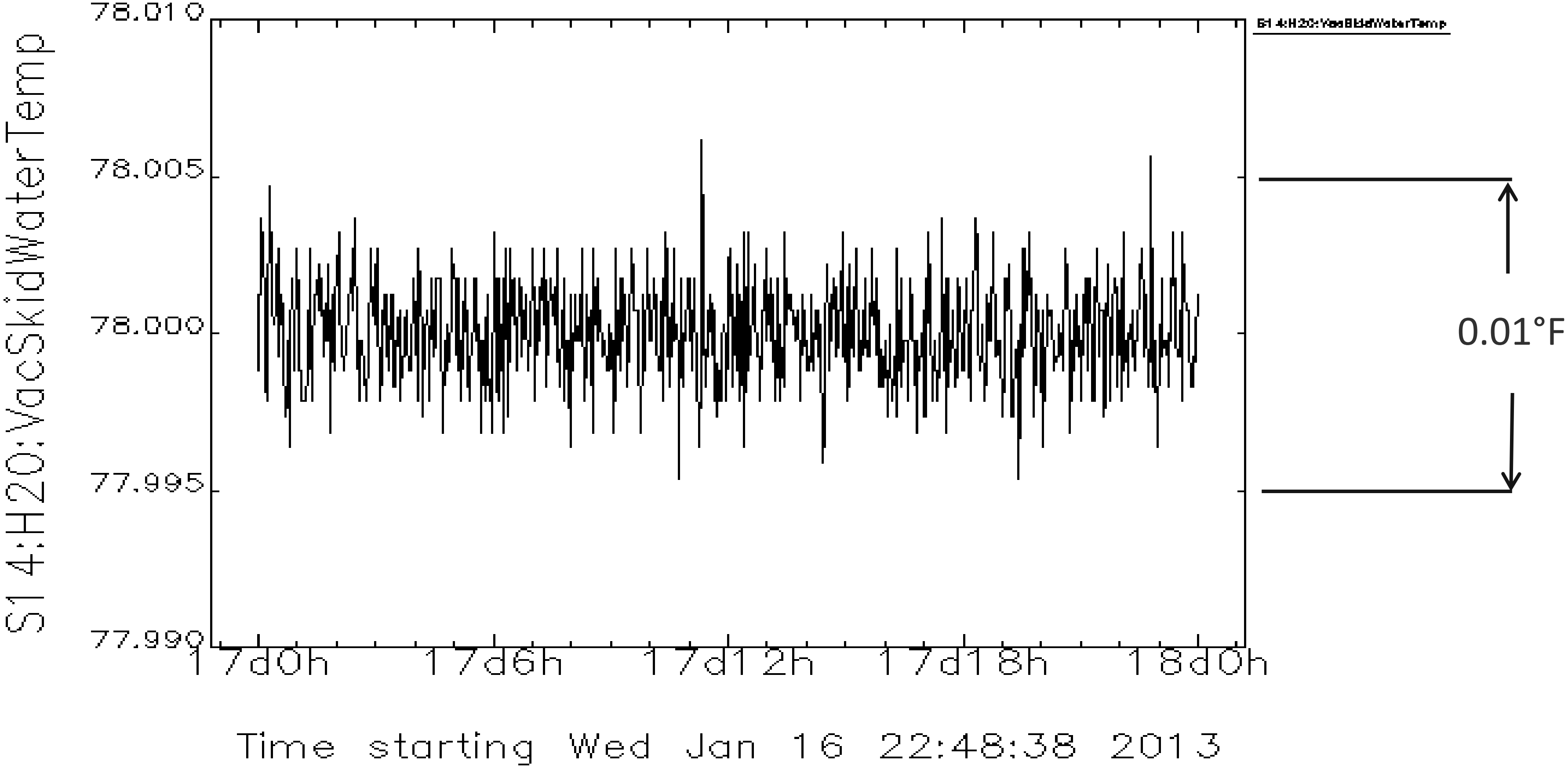
Rob Wright

Vacuum Chamber Cooling Skid 14 Upgrade

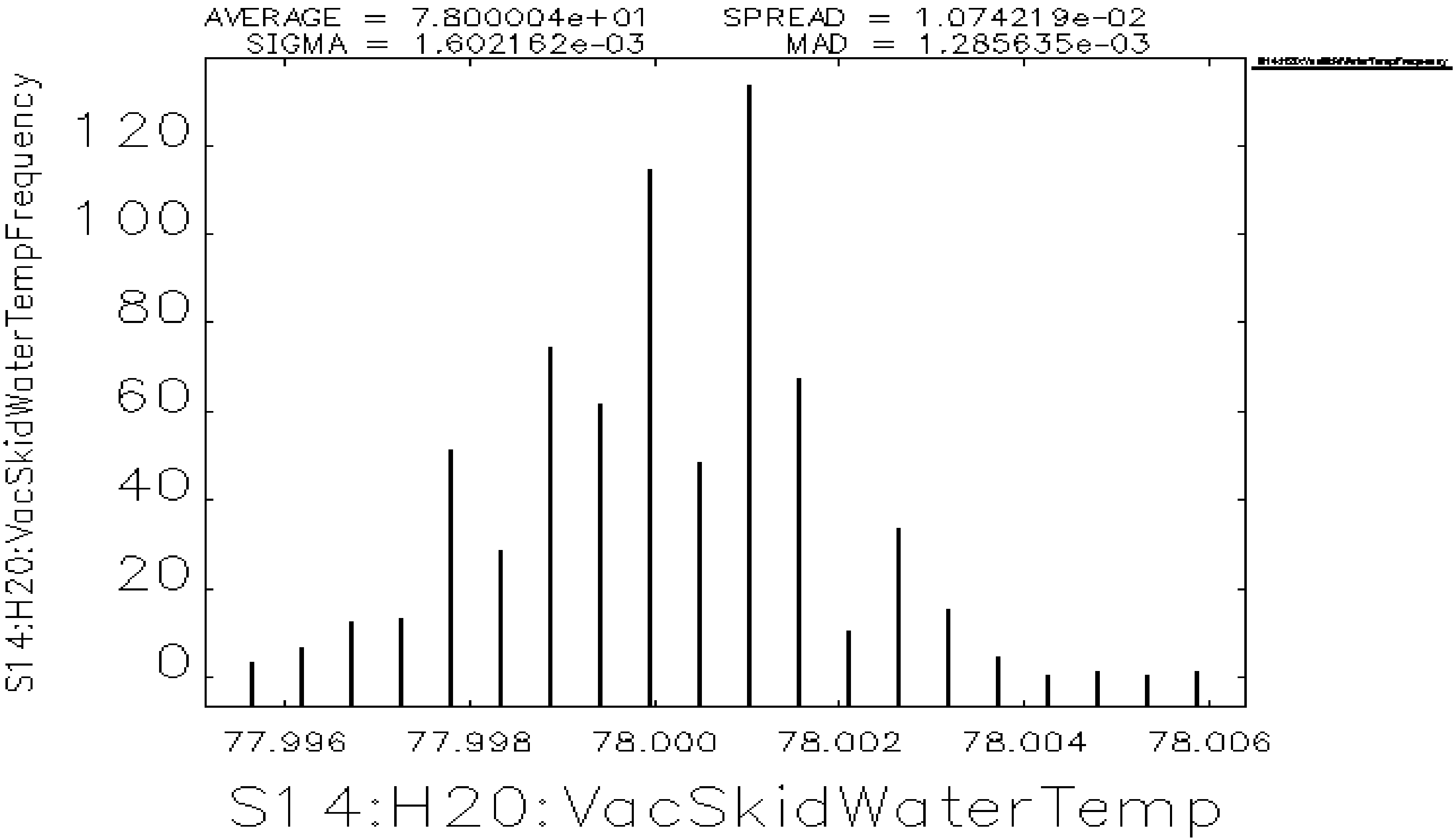
July-Aug 2012



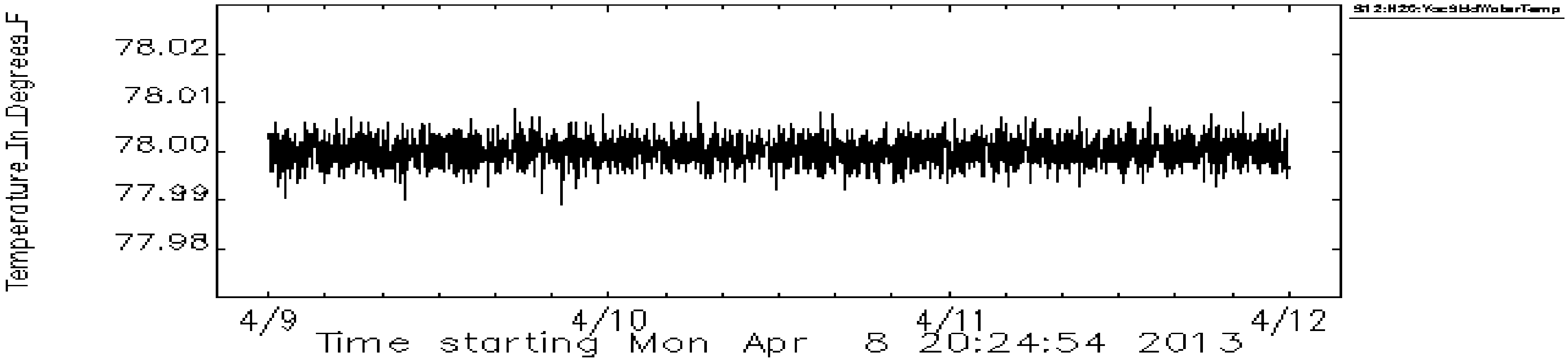
S14 Vacuum Chamber Cooling Skid Plot Close Up

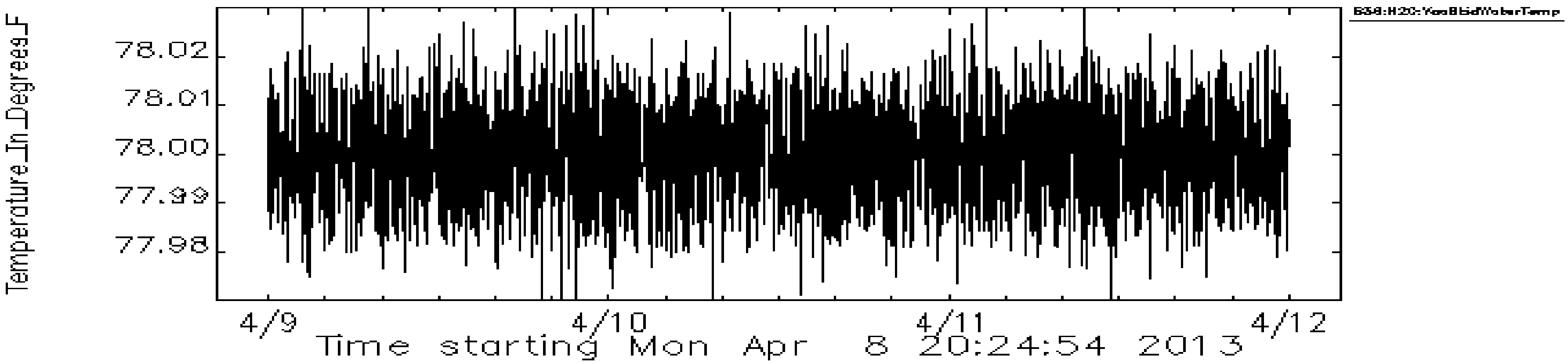


VCCS histogram data for Skid 14 for 24 hour period



Comparing Skids 14 and 36 (Best and Worst)





Water: what needs to be done?

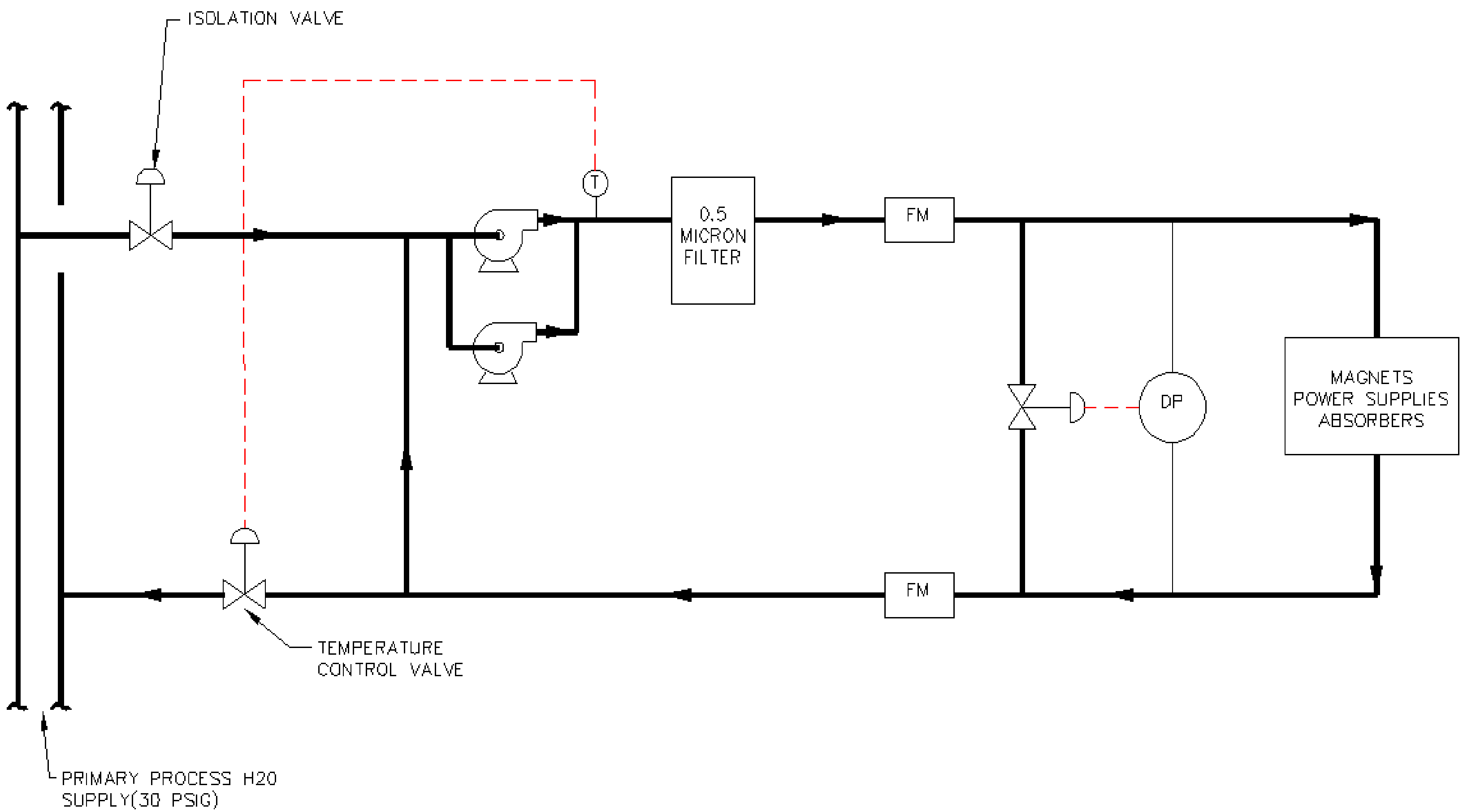
- More testing of skids with upgrades as presently installed.
- We have plans to get 2 more outfitted with new valves, actuator, transmitter, and RTDs, this coming shutdown if time permits and all the parts arrive.
- More data is needed for high current runs.
- More data is needed as far as chilled water, because the new valves may not be able to compensate for temperature and pressure changes. Characterized valve seats may need to have larger openings after 70-80 percent to allow for control during chilled water temperature or pressure changes. We need to see operations of Bldg 450 chilled water during all 4 seasons, before reaching our conclusion. This monthly, and yearly data is not currently available.
- Purchase all new actuator and valves, about $50-60k, this has not been budgeted for yet?
- All new transmitters and RTDs have been purchased. They will be installed as soon as new valves and actuator are purchased and installed.

Copper Water System

- 20 pump stations
- 75 hp
- 350-500GPM
- Supply pressure 135-150 psig
- Supply temperature 78 ^{0} F ±0.2° F
- Filtration 0.5 micron
- Provides water for Magnets, Power Supplies, Absorbers, Front ends and beam lines
- Return Water is used to heat tunnel air
- Units use water mixing for controlling temperature

Gene Swetin

Copper System Basic diagram 78°F ±0.2°F



Gene Swetin

SR tunnel temperature stability is one aspect…

Original tunnel temperature stability spec. was ± 1 deg. C (±1.8 deg.F)

This has generally been met, however enhanced accelerator performance (e.g. reduced emittance) and a higher level of beamline sophistication

make this level of stability insufficient.

Some issues…

– SR air handling units were designed for a much higher heat load than exists, and are unable to provide the fine control now needed.

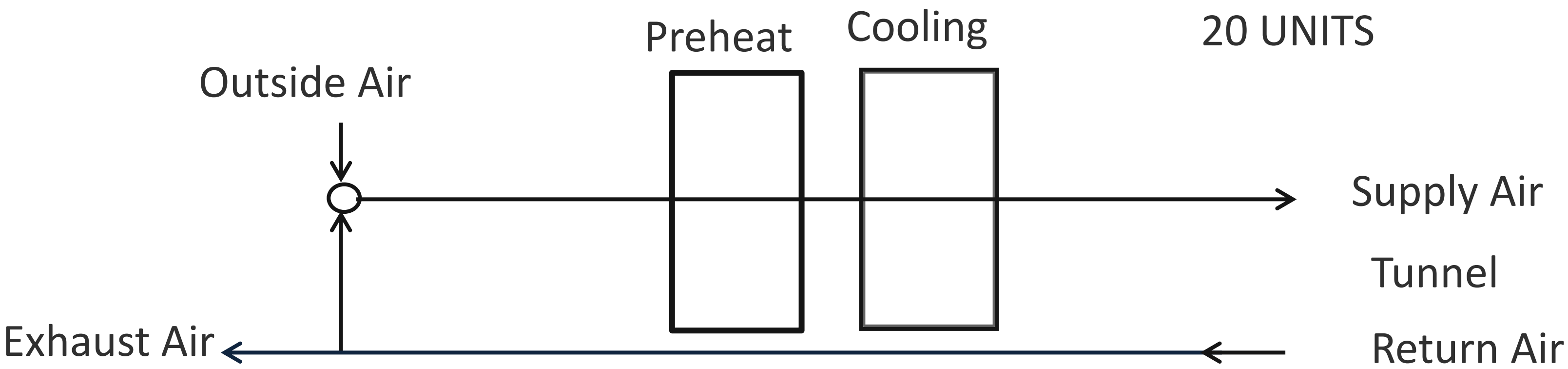
– Air from the experiment hall is designed to infiltrate the SR tunnel, so temperature variations in the experiment hall impact the storage ring.

– SR temperature stability is affected by chilled water temperature and outdoor air temperature.

J Carwardine 08/2006

SR Tunnel Air Handling Units, Original
2 Flavors Now: Outside mixed air, Inside mixed air

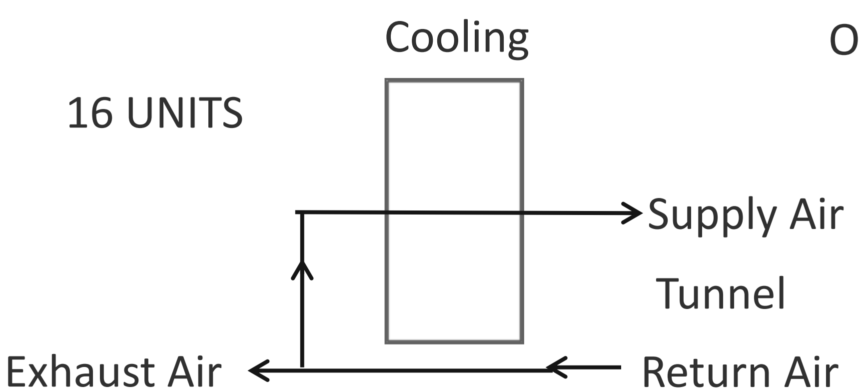
We are moving about 160,000 Cu Ft per minute, just for the tunnel.

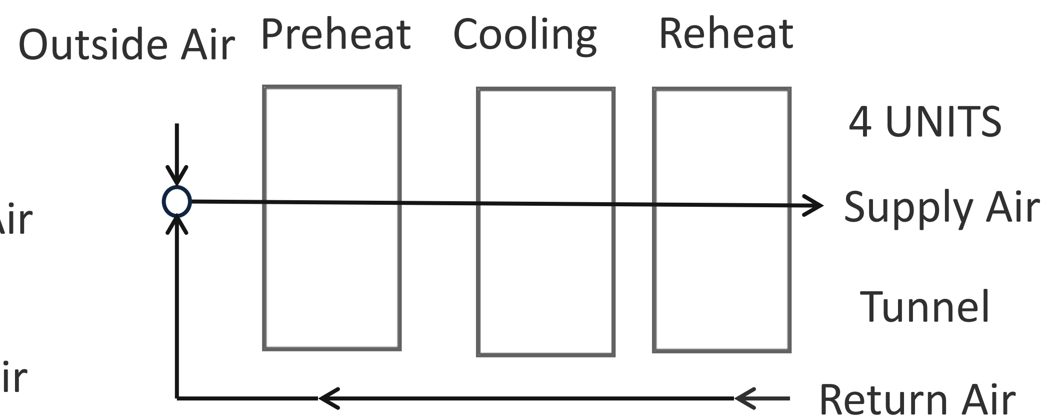


Johnsons Controls System used to control Air Handling Units

Exhaust 1000 Cu Ft per unit

Intake 4000 Cu Ft per unit





Exhaust Air is 5,258 Cu Ft over Intake Air to prevent ozone buildup in tunnel

INTERNATIONAL TEST & BALANCE, INC.

380 Northwest Hwy.
Des Plaines, Illinois 60018.2201
Voice (847) 759-1800
Fax (847) 759-1811

MIXED AIR *UNITS*	Outside Air Design CFM	Outside Air Actual	Supply Design	Supply Actual
AHU 5002	3,500	3,032	8,000	6,419
AHU 5009	3,500	2,576	8,000	5,660
AHU 5013	3,500	3,076	8,000	6,567
AHU 5018	3,500	2,501	8,000	5,106
TOTAL	14,000	11,185	32,000	23,752
PERCENTAGE	44% of supply	47% of supply		74% of design

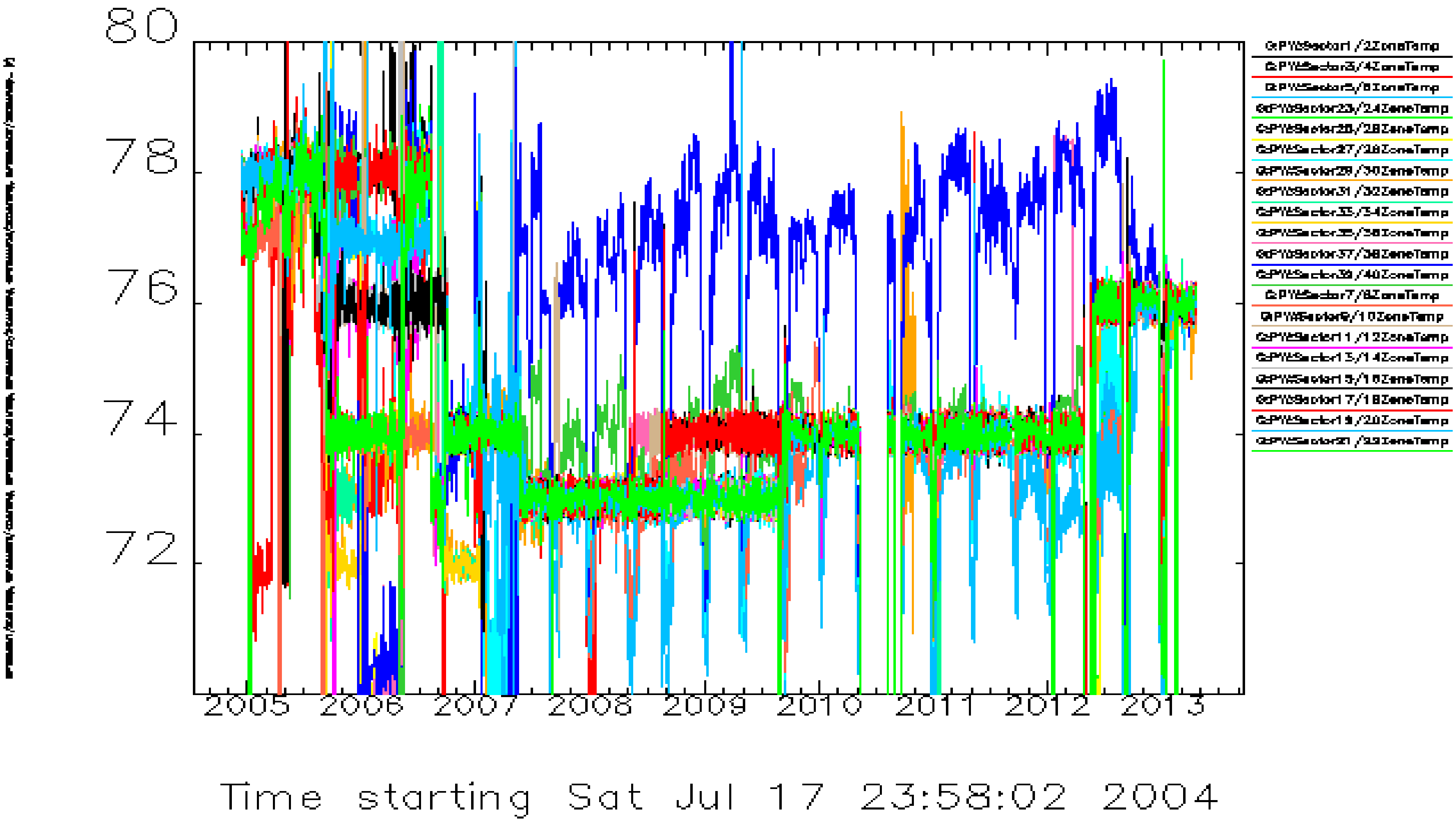
Supply and OA not meeting design.

RECIRCULATION UNITS	Exhaust Design CFM	Exhaust Actual	Return Design	Return Actual
AHU 5001	1,000	981	9,000	7,680
AHU 5003	1,000	766	9,000	8,179
AHU 5004	1,000	891	9,000	7,763
AHU 5005	1,000	975	9,000	8,982
AHU 5006	1,000	1,141	9,000	8,774
AHU 5007	1,000	1,099	9,000	8,310
AHU 5008	1,000	1,133	9,000	8,920
AHU 5010	1,000	533	9,000	* 6,012
AHU 5011	1,000	508	9,000	* 7,461
AHU 5012	1,000	1,216	9,000	8,753
AHU 5014	1,000	1,216	9,000	8,586
AHU 5015	1,000	1,241	9,000	7,825
AHU 5016	1,000	1,424	9,000	9,003
AHU 5017	1,000	966	9,000	9,409
AHU 402	1,000	1,553	9,nnn	9,858
AHU 404	1,000	800	9,000	9,049
TOTAL	16,000	16,443	144,000	134,564

* Max Exhaust without hurting Return CFM.

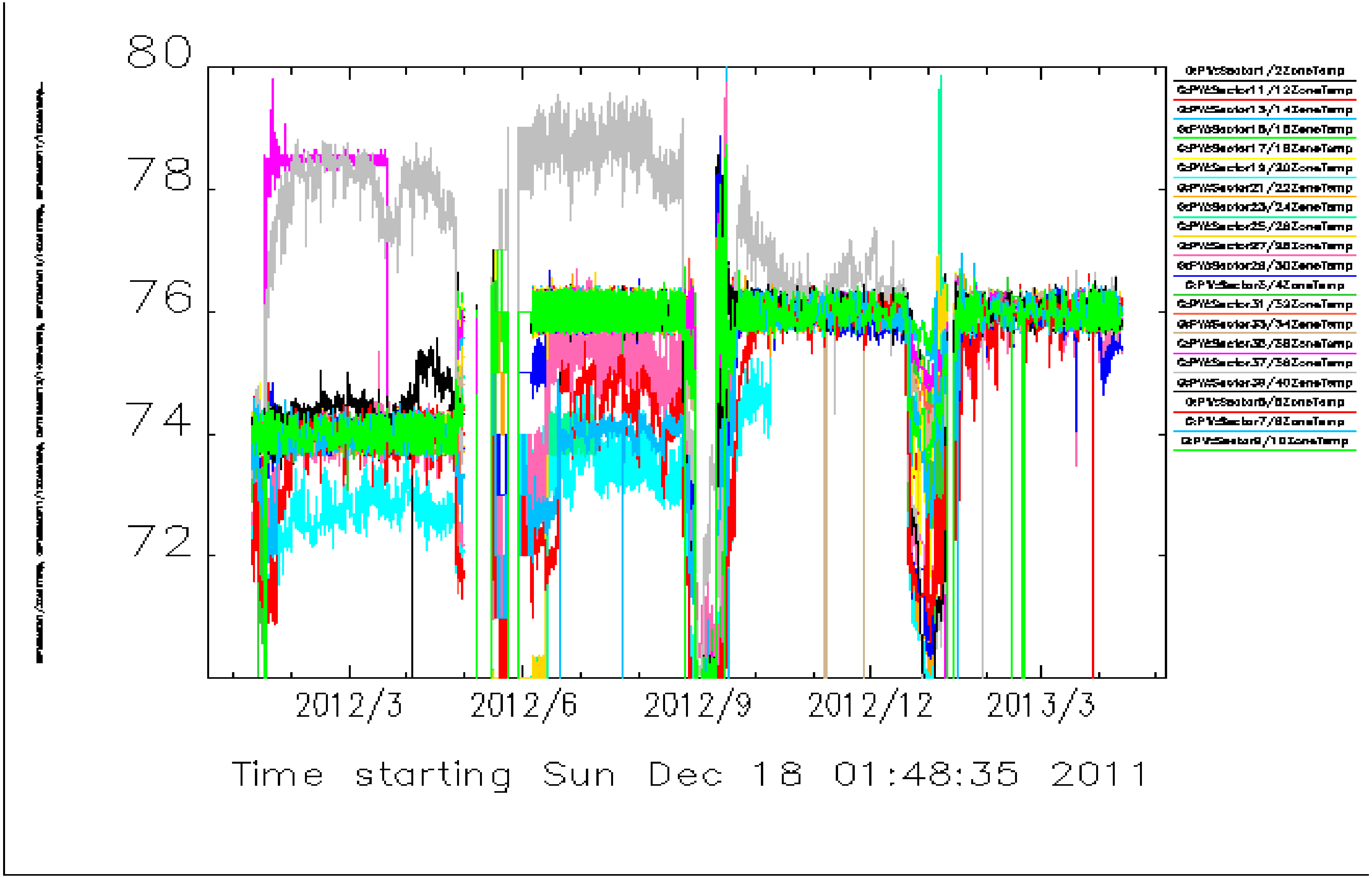
Notes: Required 14% more Exhaust over OA.
Actual Exhaust CFM is 16,443 which is 5,258 over the OA CFM.

SR Air Tunnel Temperatures since 2004



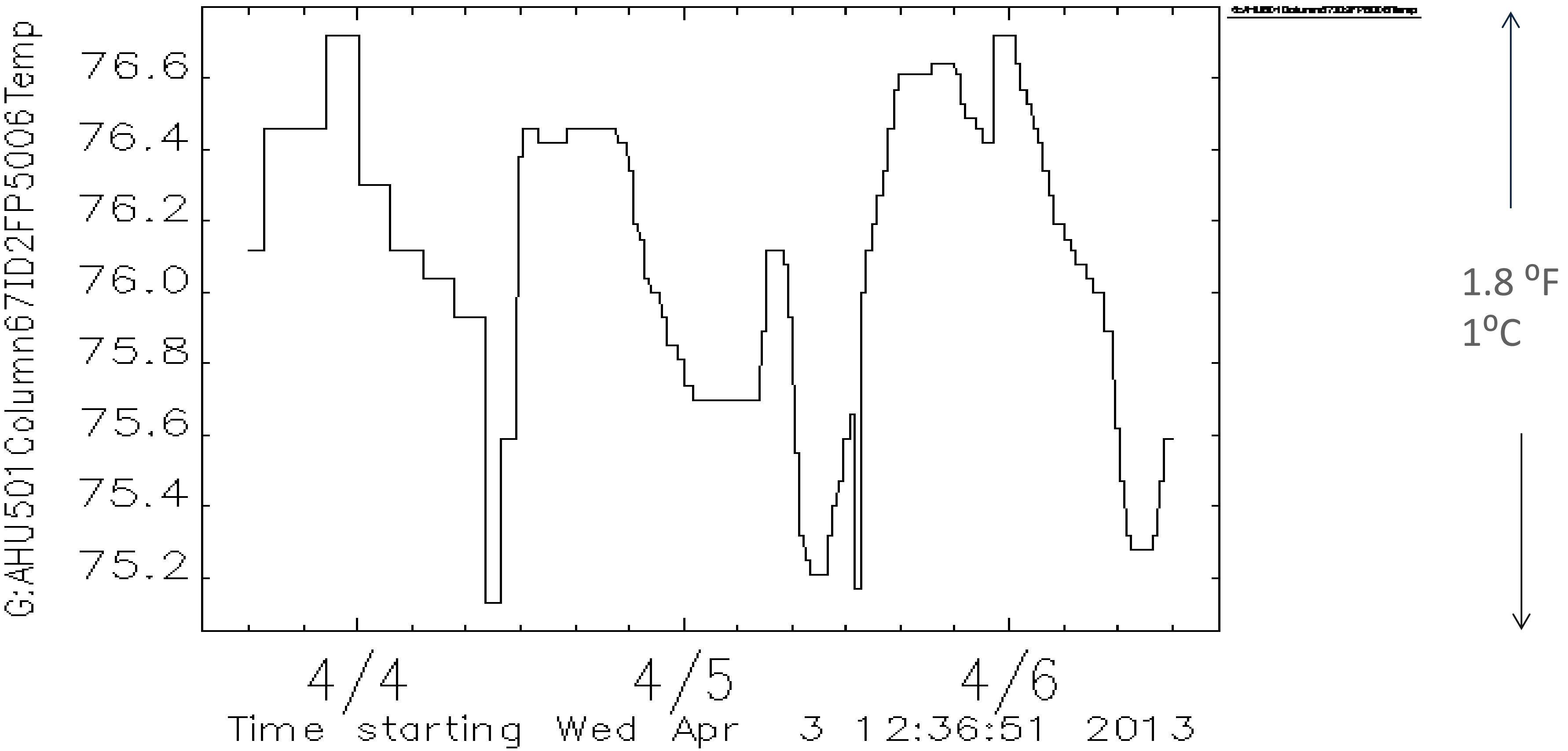
SR Tunnel Air Temperatures since the end of 2011

Improvements: change from 74 to 76, system calibration, and troubleshooting



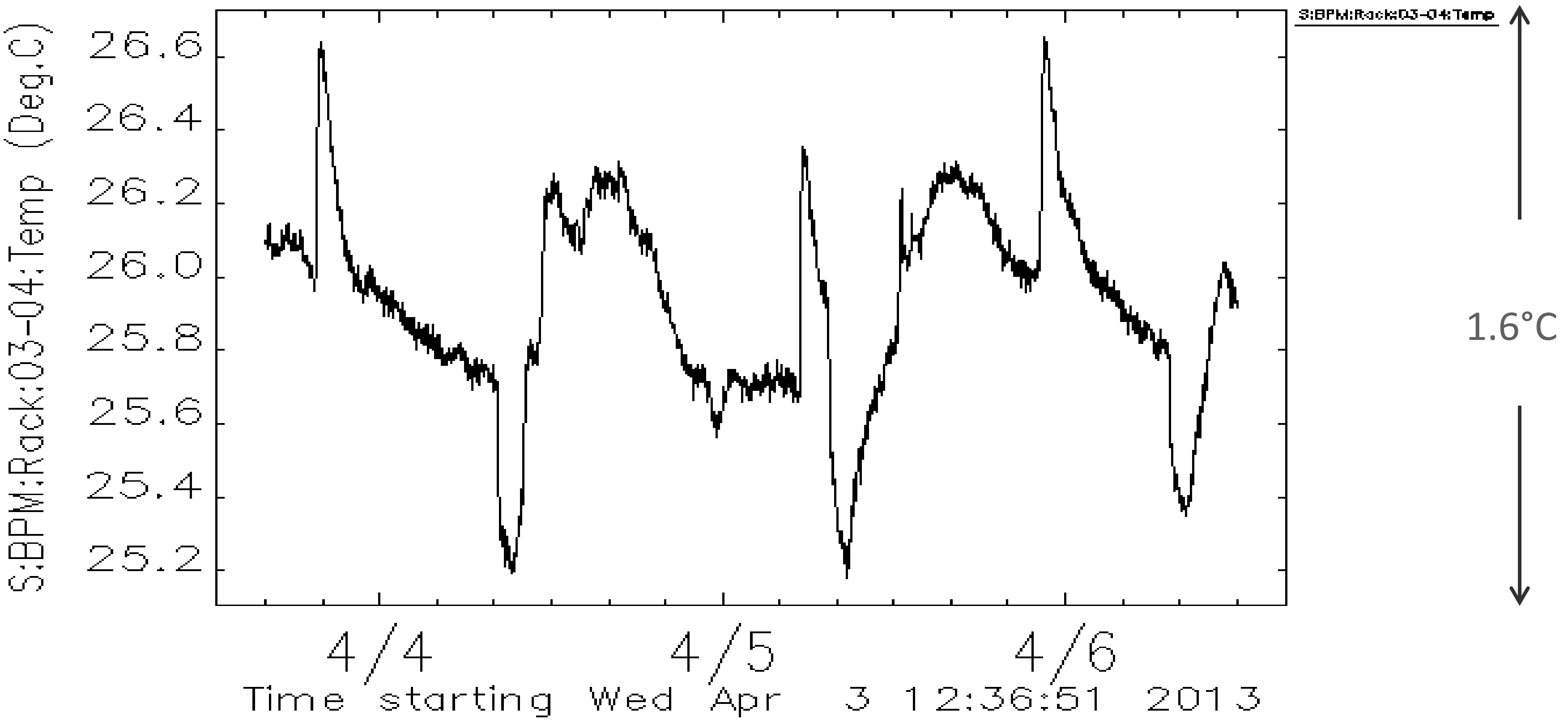
SR Mezzanine Air Temperature

Sensor on Column 67 near SR BPM rack for sector 3
Using read back from Johnson controls system linked to EPICS PVs



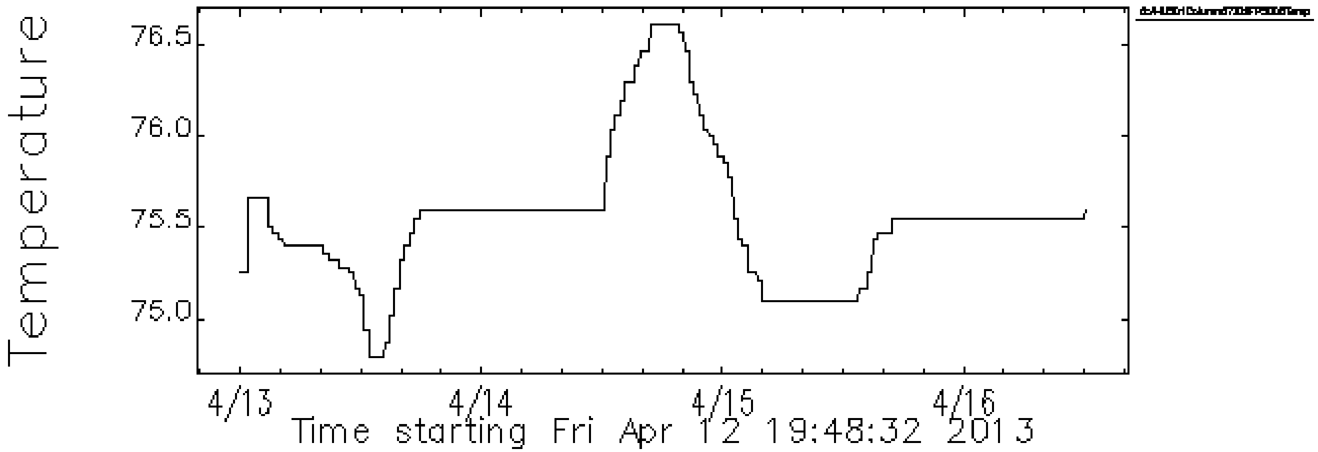
SR BPM Rack RTD temperature

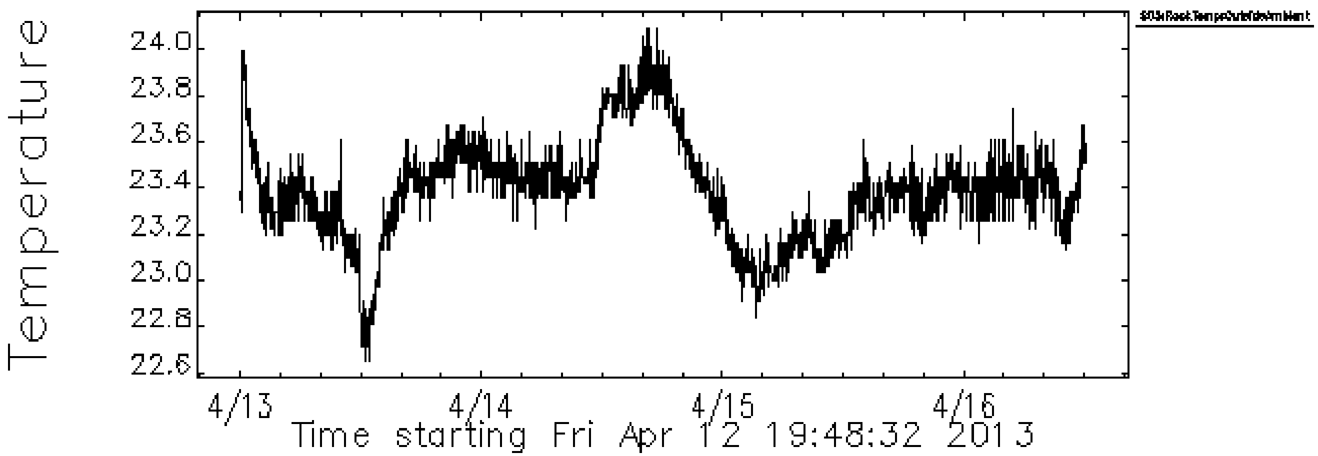
Notice spikes about 0.6 °C



SR Mezzanine Air Temperature Variation

BPM Rack 03 RTD versus Column 67 Johnson controls temperature sensor

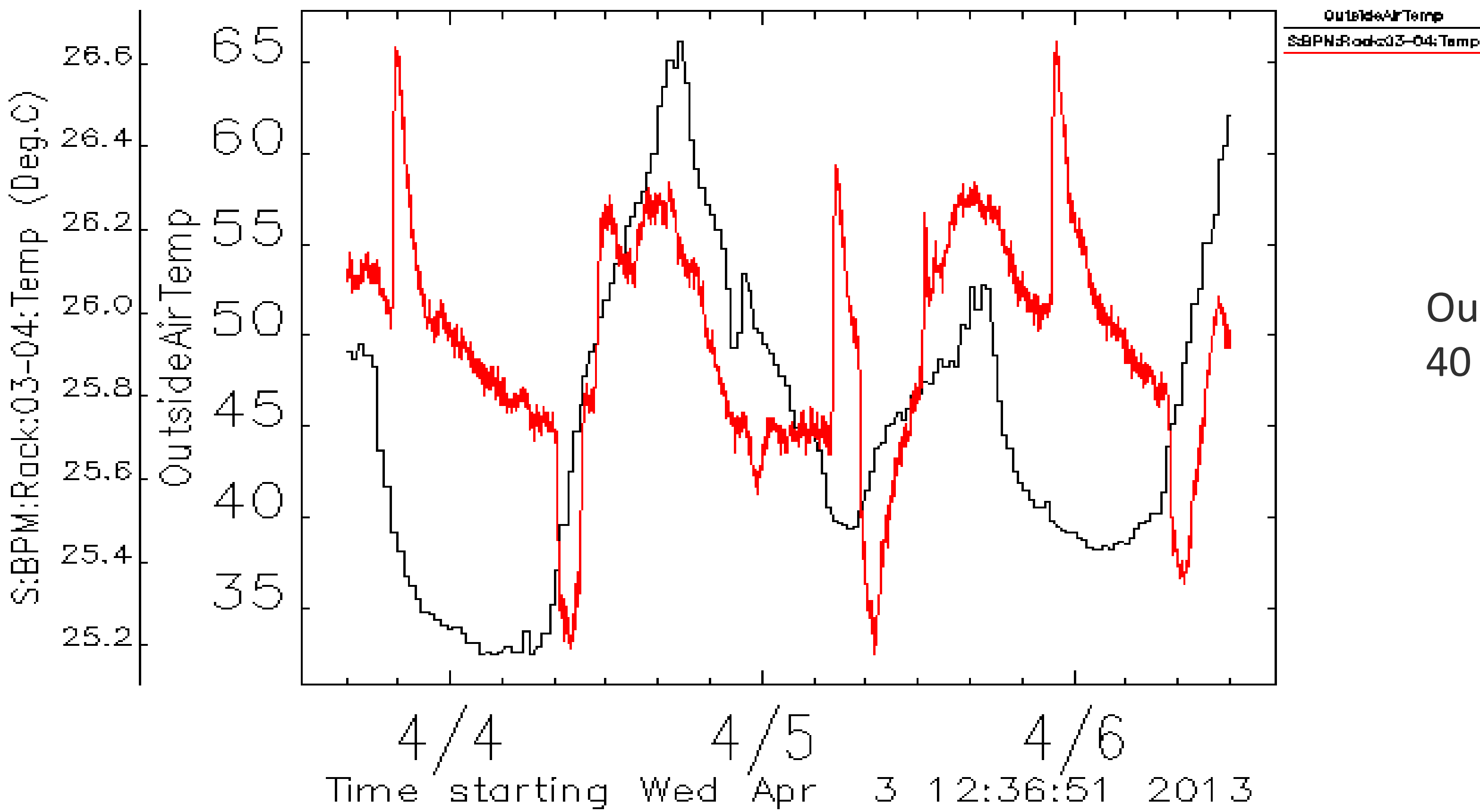




Internal BPM 04 Rack Temp. Outside Air Temp.

Mezzanine air Handling Units use Economizer Mode bringing Outside air for cooling

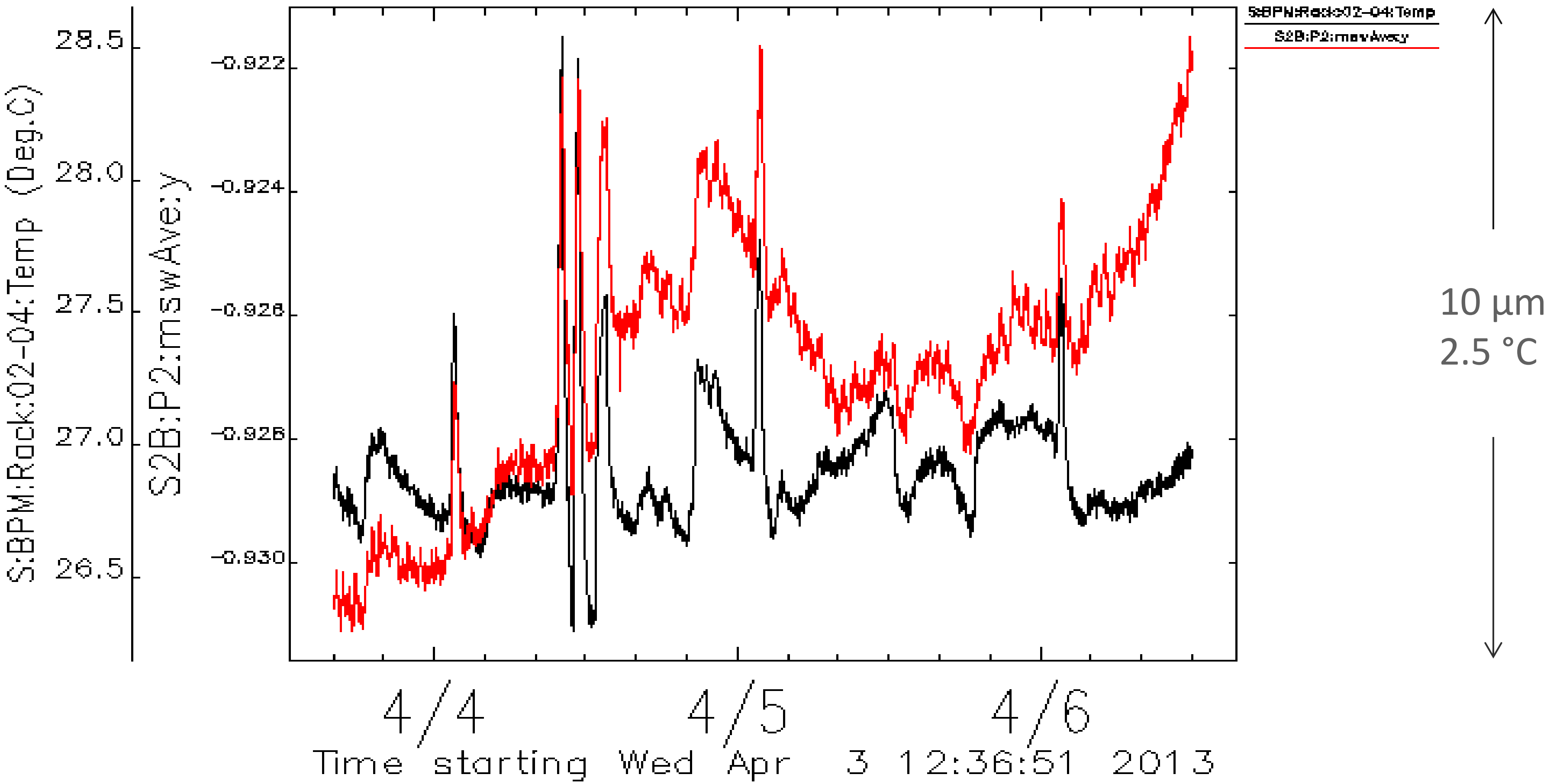
Rack
1.6 °C



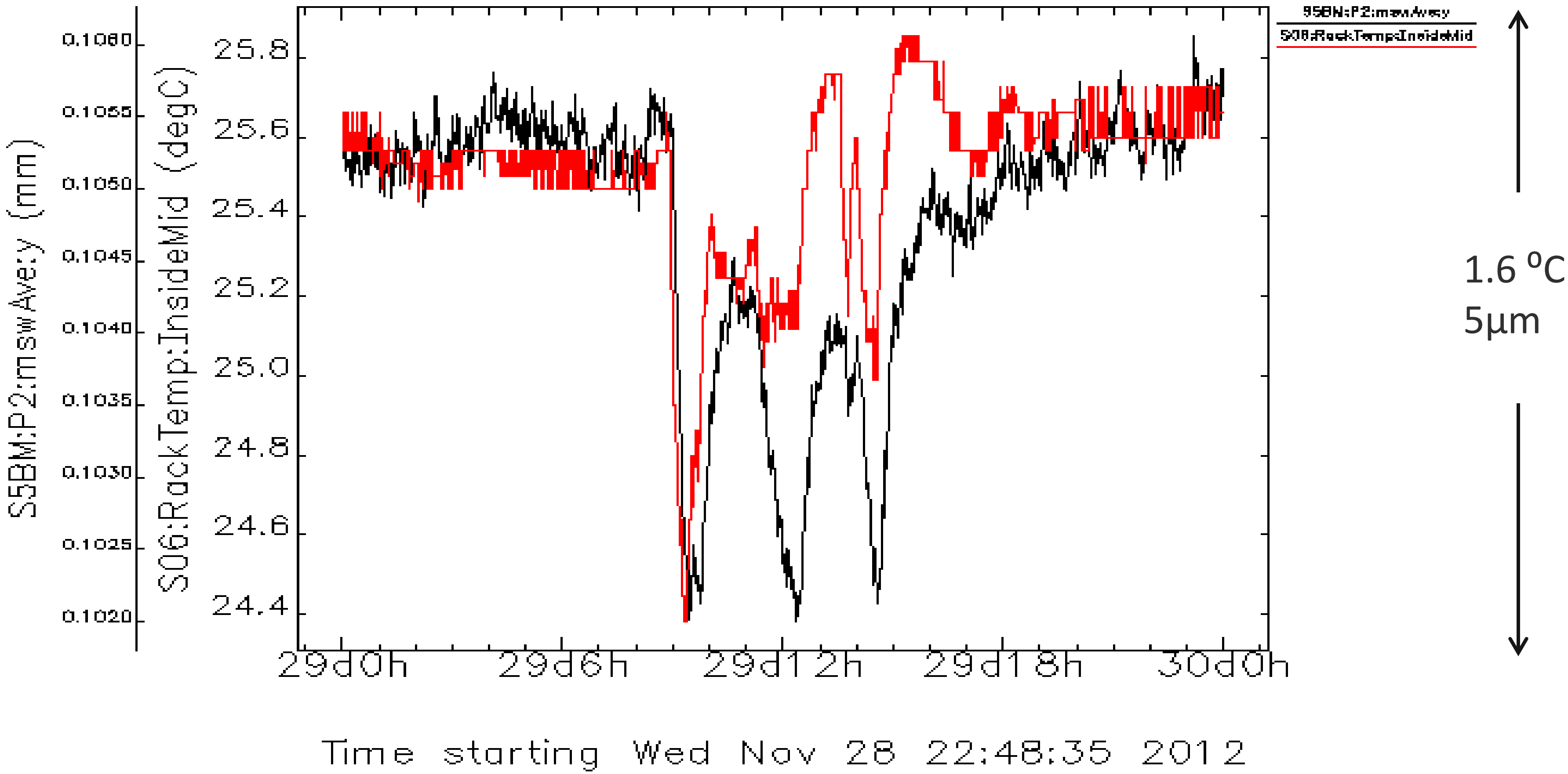
Outside
40 °F

SR BPM rack air temperature versus BPM position

02-4 RTD versus S2B:P2Y about 1 degree C versus 4 microns

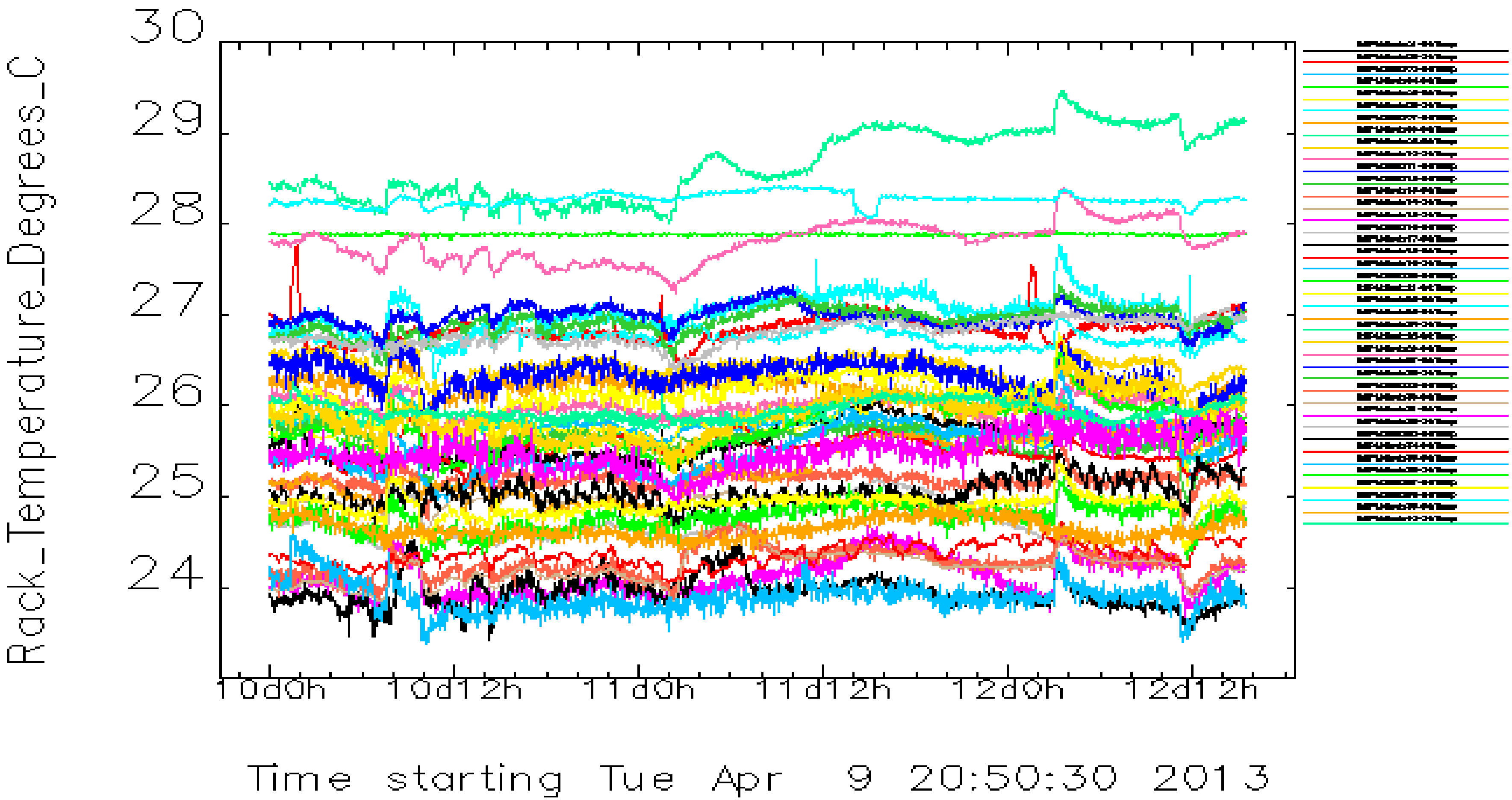


Who Opened the Door to Building 400?



SR Mezzanine Internal Rack Temperatures

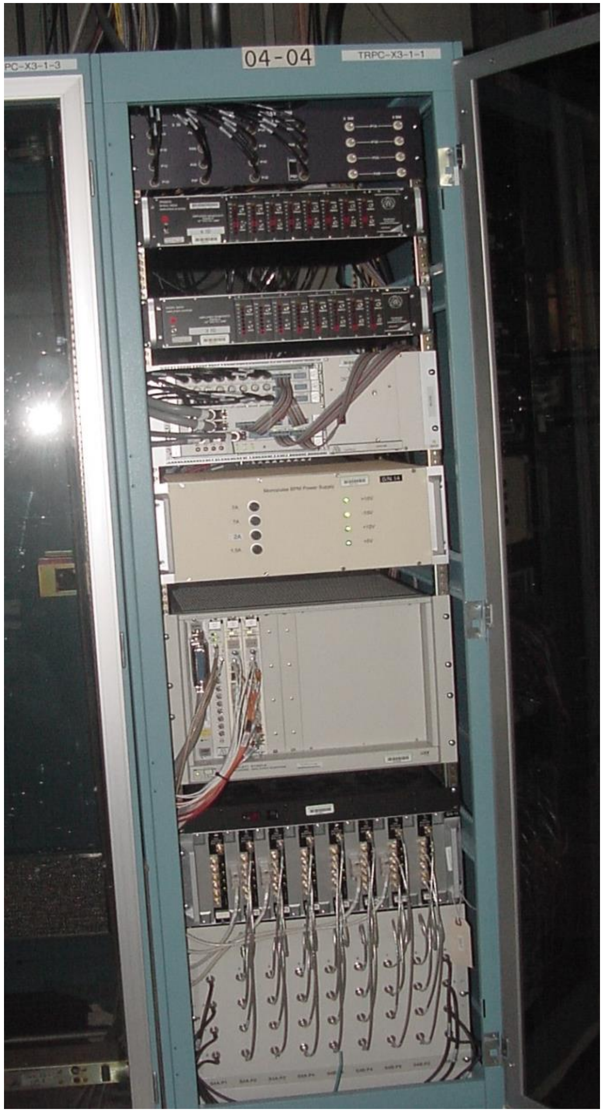
Using RTDs installed during Dec-2012-Jan 2013 shutdown, over 1-1/2 day period



Infrared picture taken seconds after SR BPM 04-04 rack was opened showing temperature difference

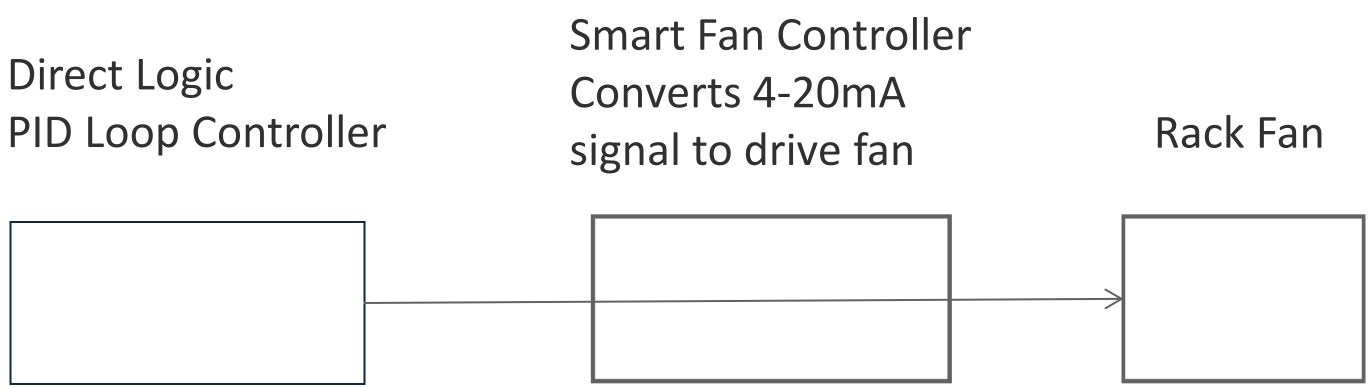
Jeff Collins

Sector 4 BPM Rack regulation modifications

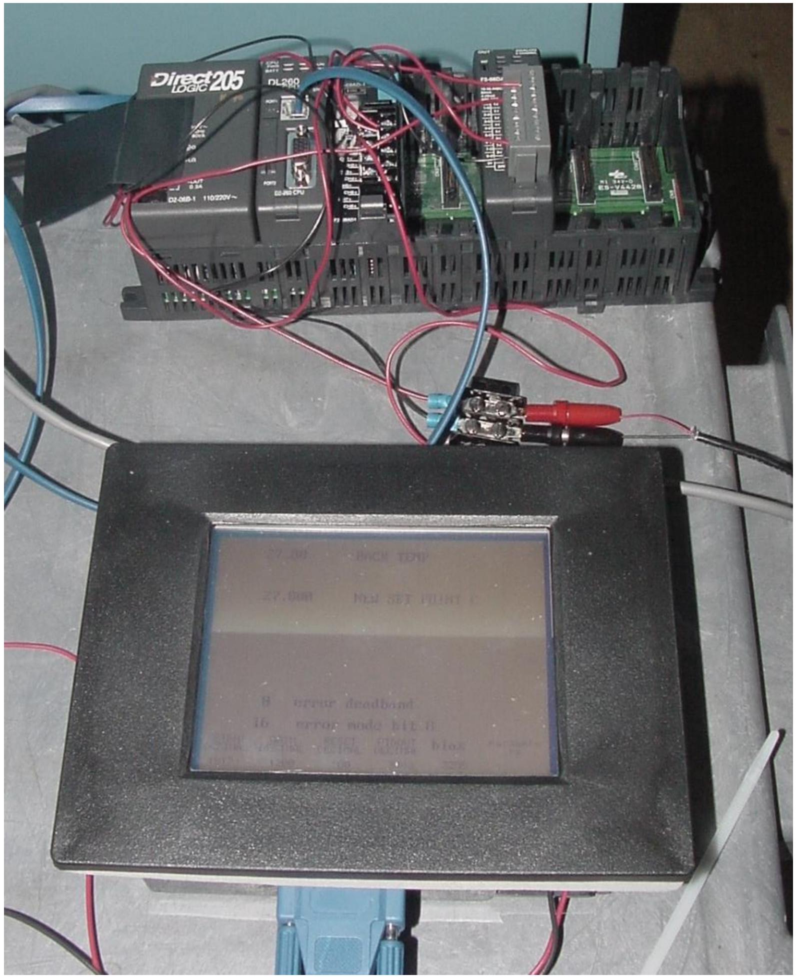


Basic Block Diagram for Fan Control in BPM 04 Rack

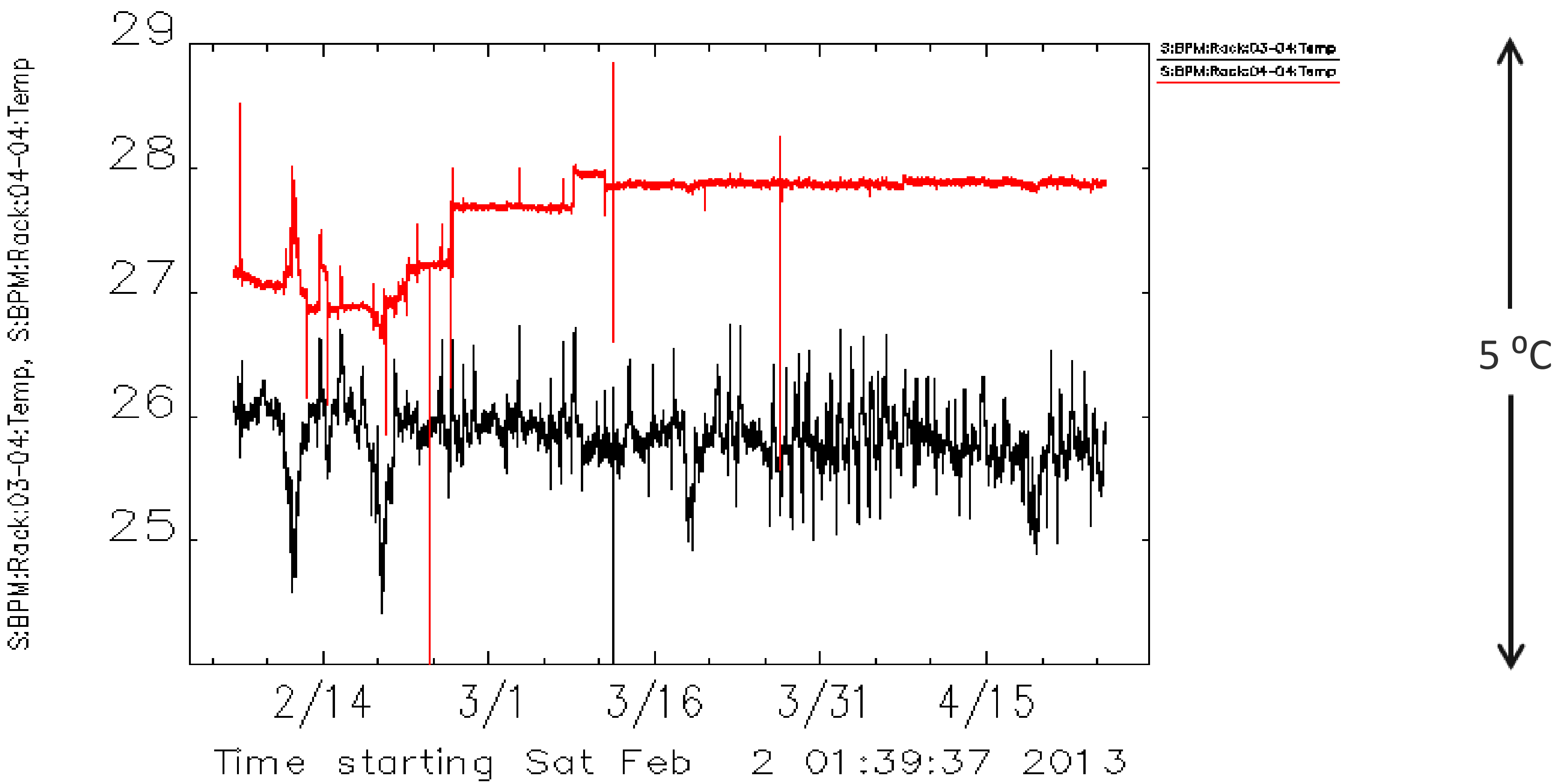
Prototype testing started around July 2012



PID Controller and Fan Controller



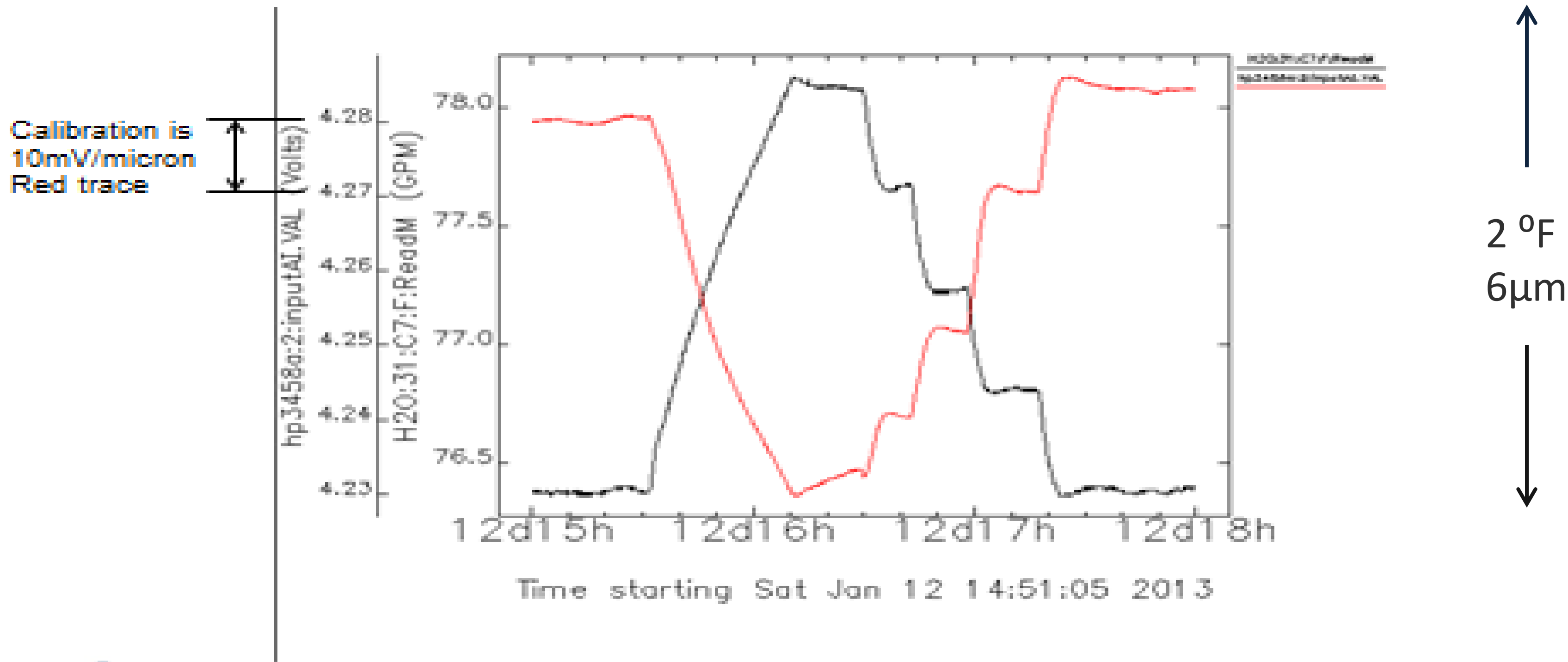
Sector 4 BPM Rack regulating versus Sector 3 BPM Rack with no regulation



Testing Mechanical Motion Sensor At 32ID Results 5.5 microns per 1.8 Degrees F Water

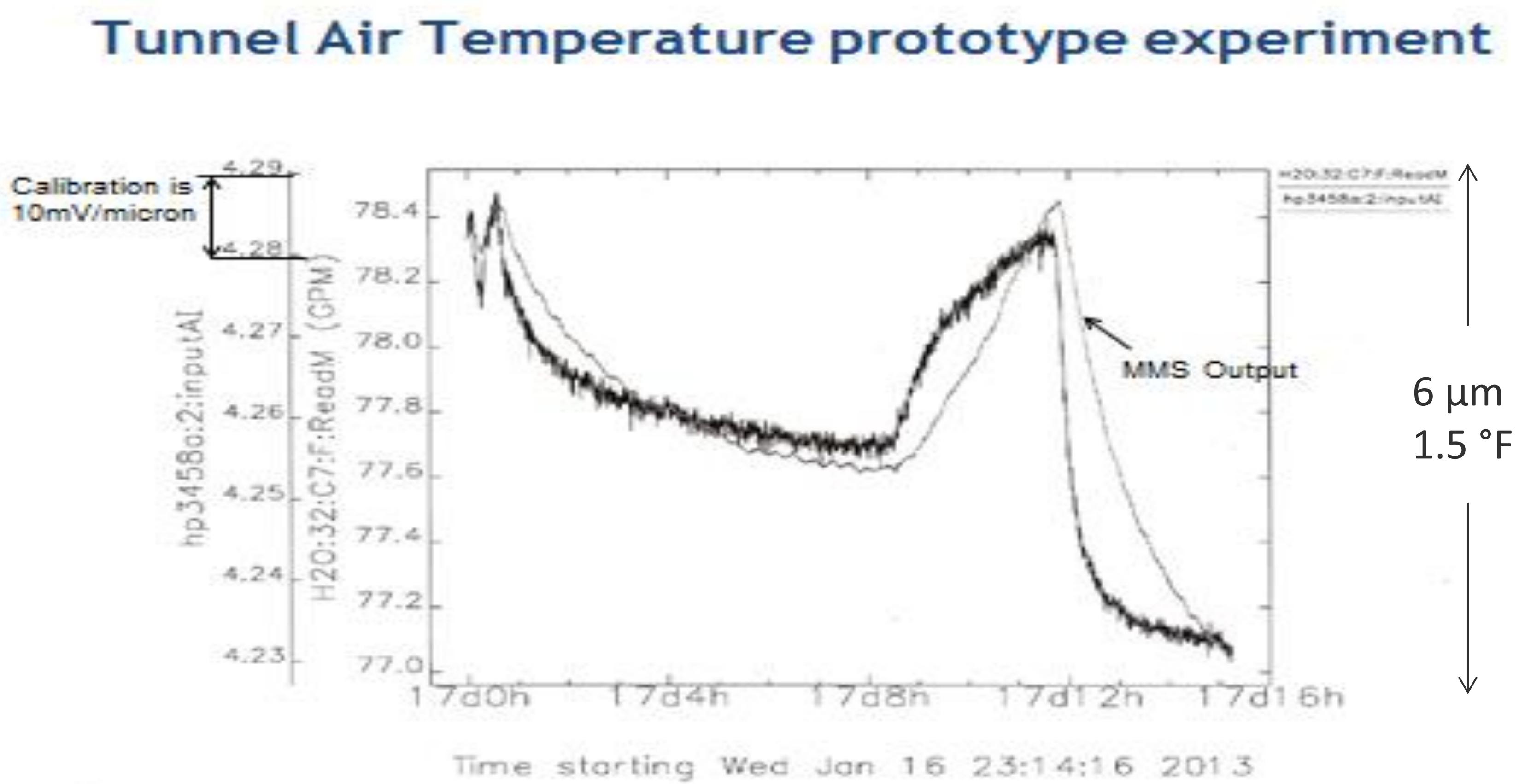
Prototype Testing

Changed Vacuum Chamber Water Temperature 0.5 degree Steps



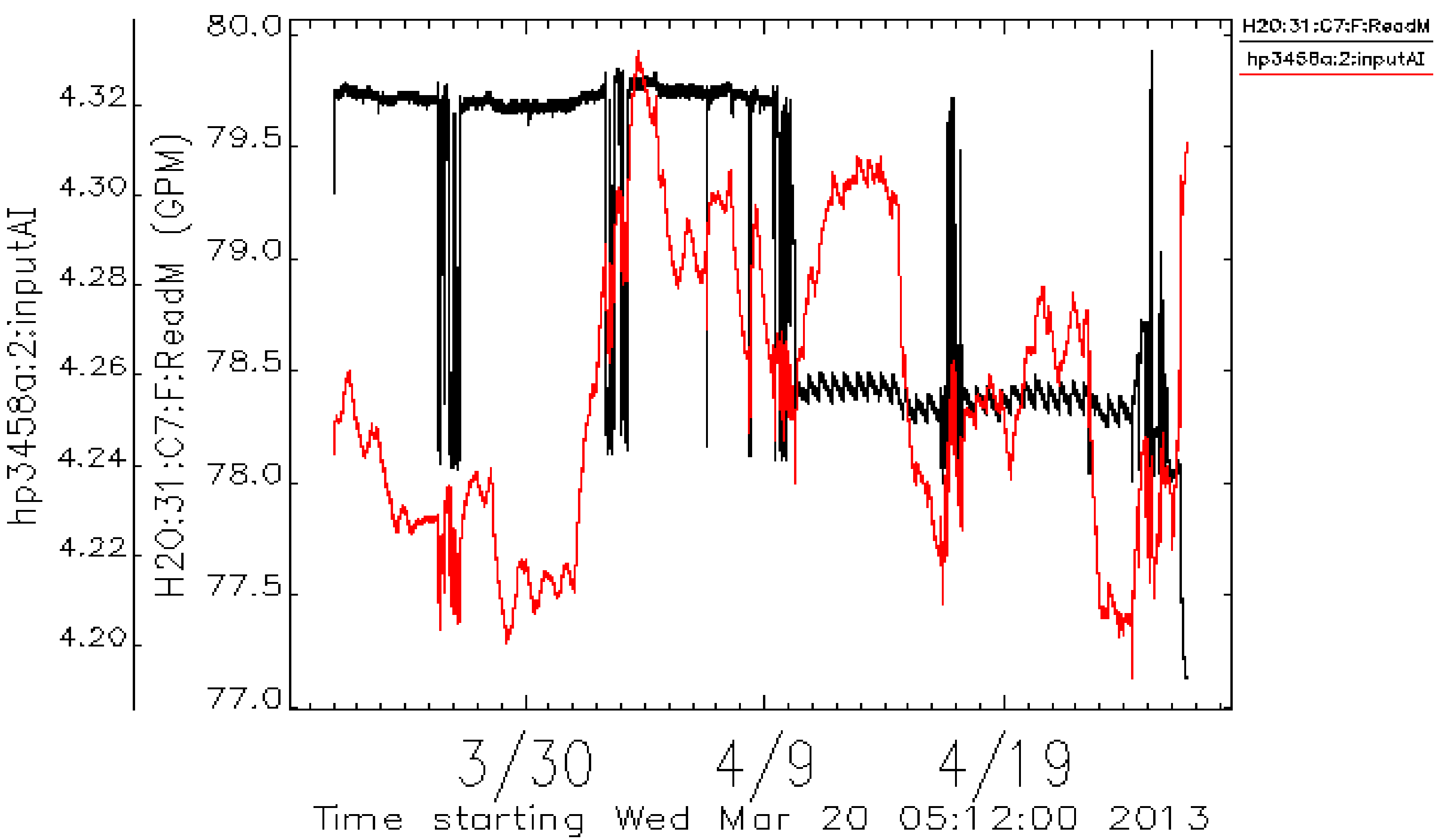
Bob Lill

Testing Mechanical Motion Sensor At 32ID
About 6 µm per 1.5 °F Air



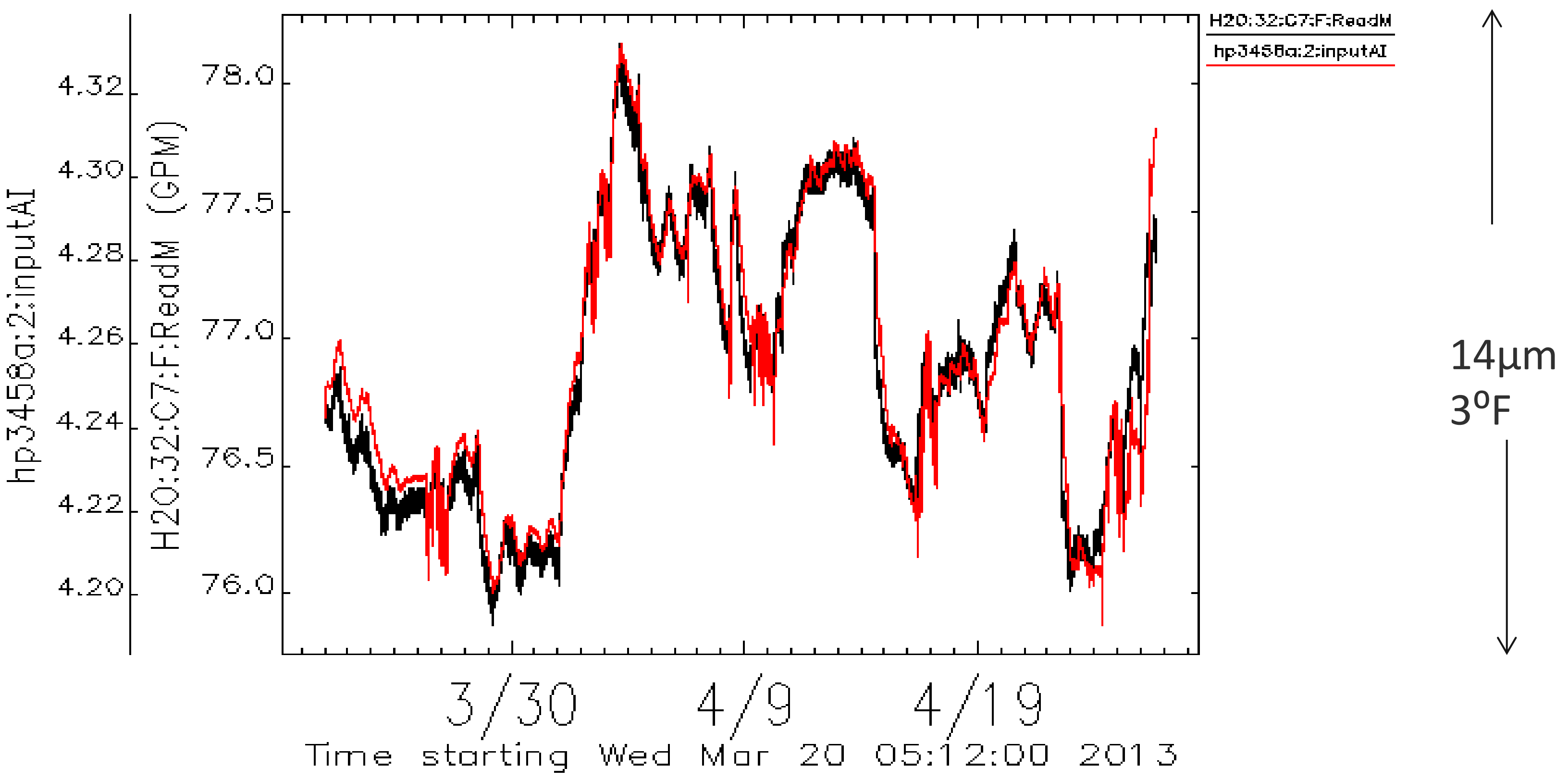
Bob Lill

Mechanical Motion Sensor Water versus Position



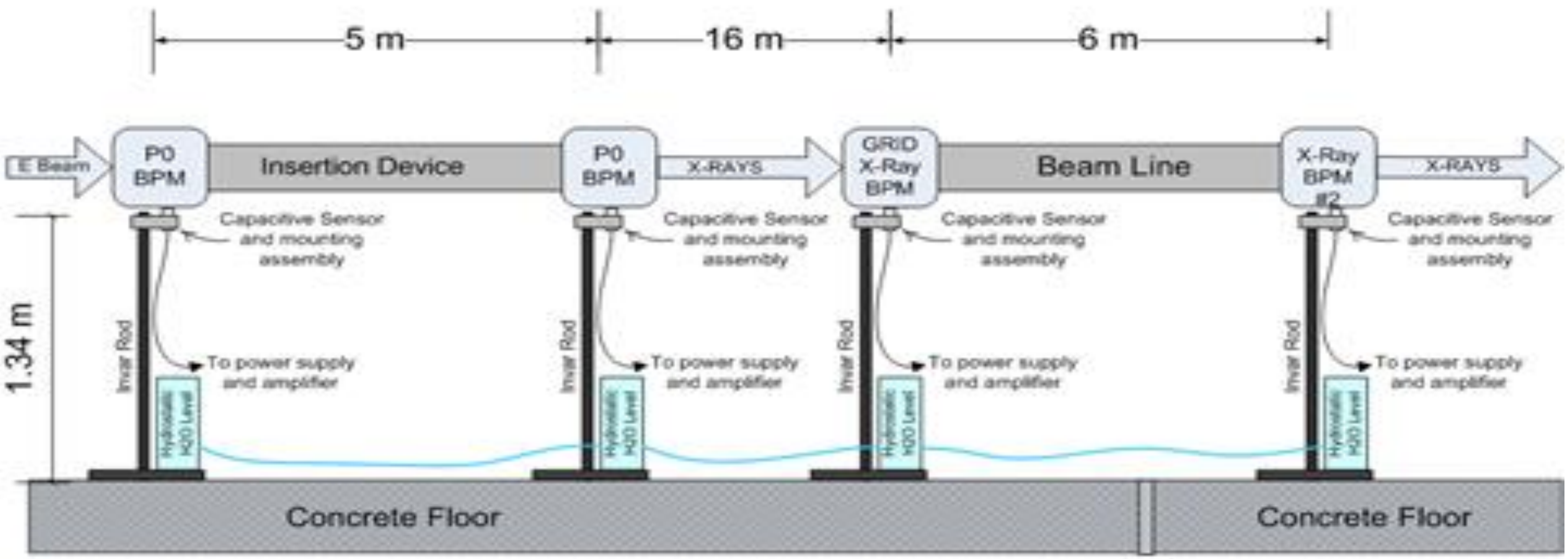
14µm
3°F

Mechanical Motion Sensor Air versus Position



Proposed installation for upgrade

Block Diagram for the Mechanical Motion Sensors



Bob Lill

Conclusion

- Adding alarm handlers to all temperature monitoring system will help us keep better track of regulation.
- There is a lot that can be done with temperature regulation that will bring us closer to sub-micron beam position measurement.
- We need to determine the best paths for improvement .
- We need to maintain our systems better.
- Look closer at our systems to determine where small changes may lead to big improvements. Sometimes all it takes is simple software and mechanical changes. But getting to this point is not always easy.

Thanks to:

- Marvin Kirshenbaum
- Gene Swetin — Randy Zabel
- Rick Putnam — Ron Blake
- Rob Wright — Bob Lill
- Gary Siatka FMS — Marty Smith
- Bob Brachle FMS — Jeff Collins
- Stan Pasky — Rob Soliday
- Glenn Kialus
- Greg Fystro
- Nick Sereno
- Glenn Decker
- Jim Lima Sale Engineer For Corrosion Fluid Products Corp.

References

- March 4 2010 Glenn Decker

"Limits to Achievable Beam Stability" (0.5 um /0.1 deg F)

- Sept 7 2006 Om Singh "Implementation and Performance Overview APS Orbit Feedback Systems"

Improve SR air temp regulation (page 29)

- goal is for 0.5 degrees F p-p regulation

-a priority action item

- Lesson Learned – for APS II or new machines
- Provided best available tunnel air and cooling water temperature regulation (page 30)

End of talk here

- Extra slides after this point

Temperature Coefficients
Decker BIW98

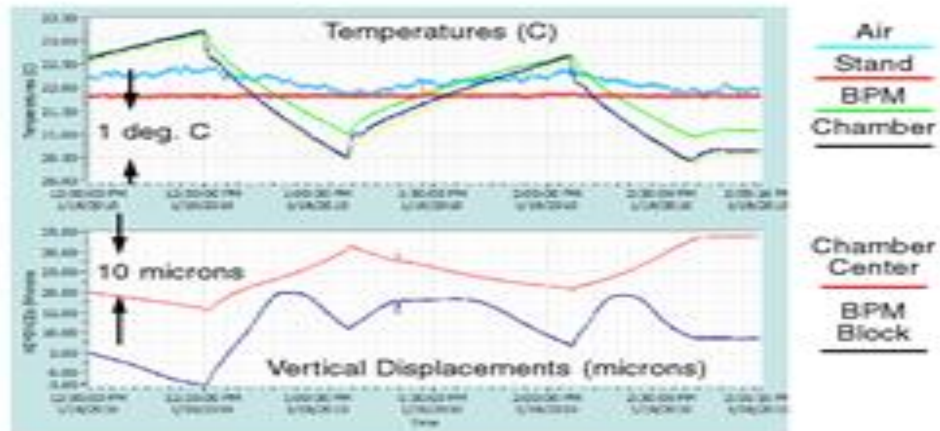
- **MECHANICAL STABILITY**

In spite of the potential for beam position monitor electronics to detect submicron beam motions, the lack of an absolute mechanical datum and mechanical component stability dominate our ability to stabilize the orbit at very low frequencies. For example, our small aperture insertion device vacuum chambers are rigidly supported 1.4 meters above the floor. The air and water temperature in the tunnel is generally stabilized to within ± 0.3 °C rms. Given that thermal expansion coefficients tend to be on the order of 1 $x10^{-5}$, this translates into a vertical chamber motion of order 1.4m x 0.3°C x 1 x 10^{-5} = 4.2 microns rms. This will almost always be the case; mechanical components typically cannot be stabilized to better than 5 to 10 microns rms owing to one's ability to regulate temperature. Worse yet, as the beam is injected and decays away, the thermal load on the water-cooling systems varies and vacuum chamber shape distortions inevitably result (5). Chamber motions at the APS are typically smaller than ± 2 microns, a consequence of careful masking of all vacuum chamber surfaces by discrete water-cooled radiation absorbers

Sector 32 ID chamber mechanical measurements 10 microns per1 Degree C

R&D Tests at Sector 32B:P0 January 2010

Laser Proximity Sensor

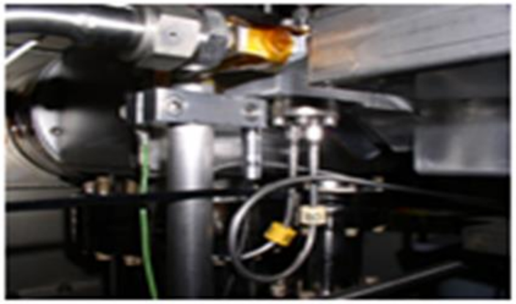


Keyence Proximity Sensor 50 nm Resolution

32 ID mechanical measurement installation

Prototype Design Installed at Sector 32P:B0

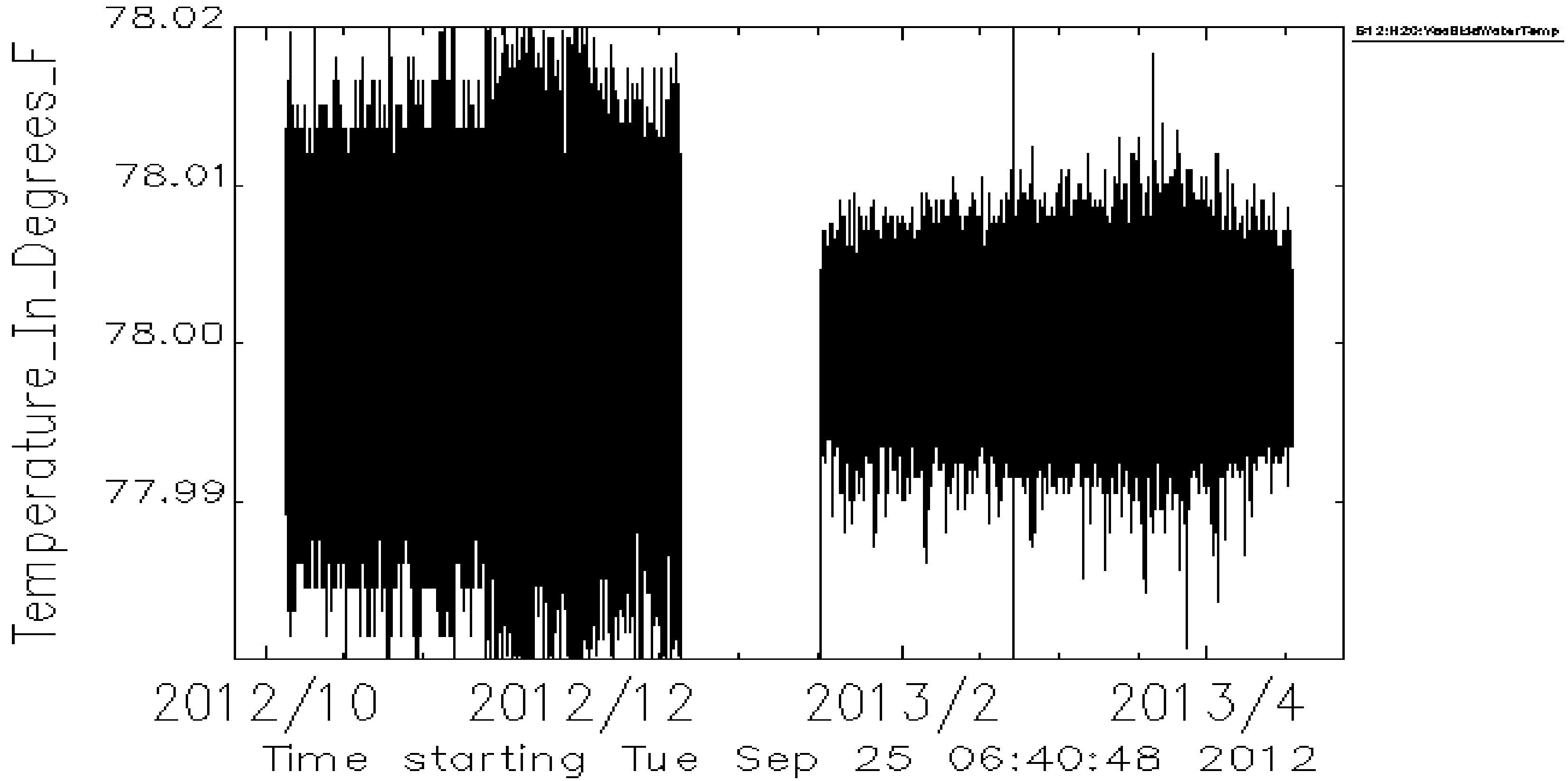
- The capacitive detection installed at S32B:P0 will monitor movement of the BPM relative to the floor directly below
- Typical resolution for this sensor is 50 nanometer with a 0.5 mm range
- Early test reconfirms BPM movement correlated to chamber water temperatures



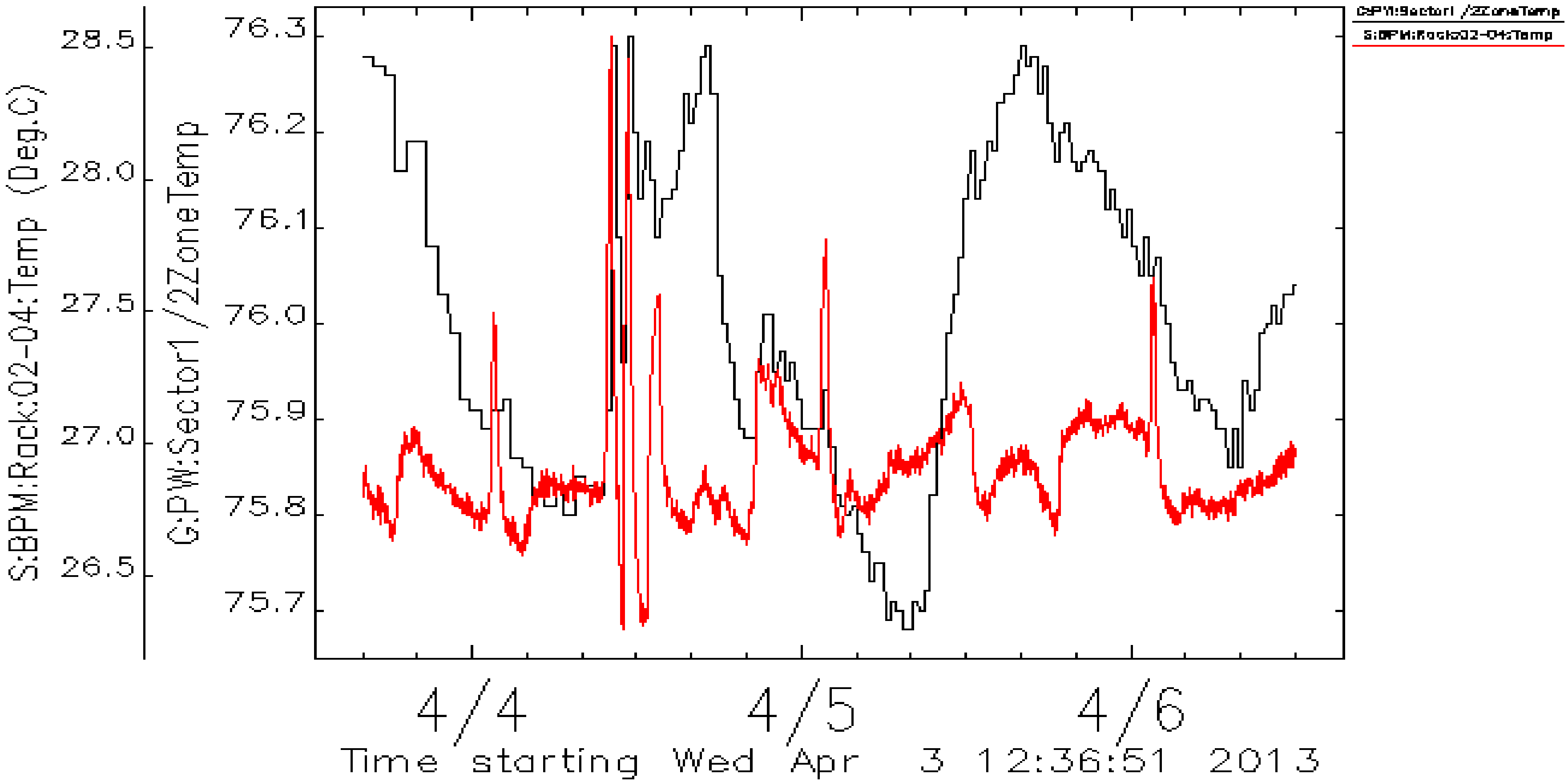
Bob Lill

Vacuum Chamber Cooling Skid 12 Upgrade

Dec 2012-Jan 2013 Shutdown Actuator, ½ inch by 1/16 inch slit, 16˚ F range Minco Transmitter, (RTD not upgraded)



Rack and Tunnel Temperature



SR Tunnel Air Temperature for Sectors 37 and 38

Stopped Regulating after 2006-2007 upgrade