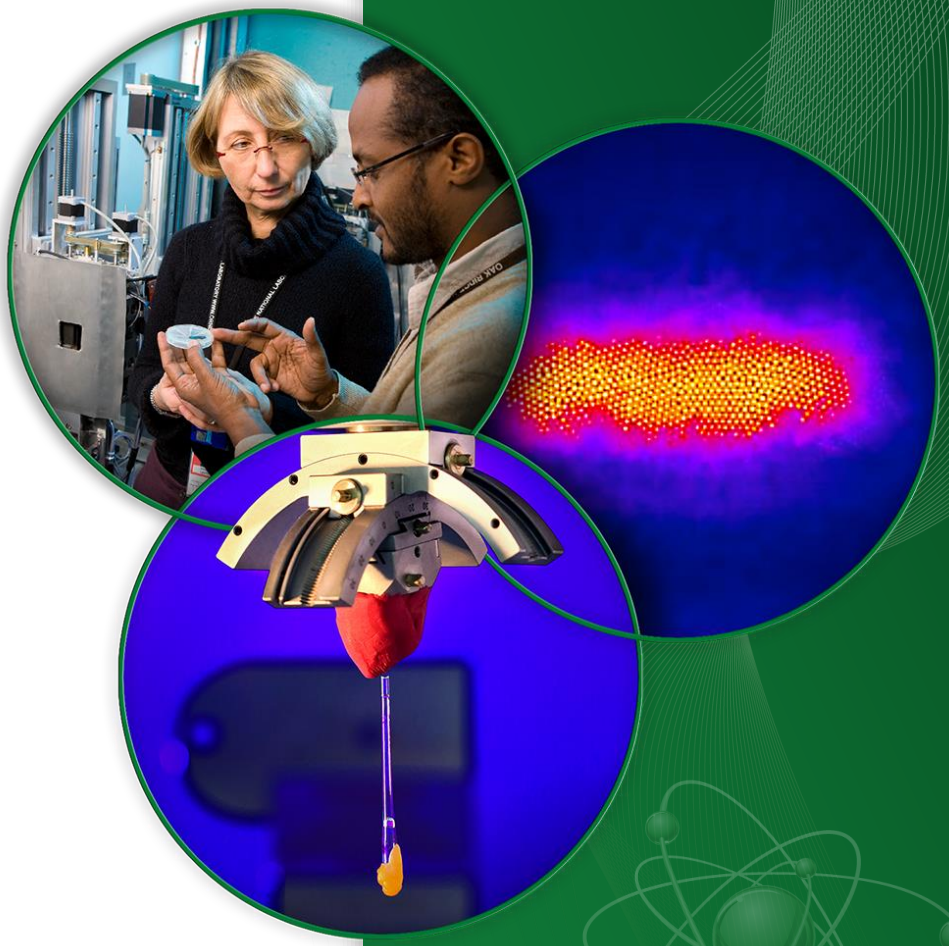
2-K Pump Down Studies at SNS



Presented at the
CEC/ICMC 2015 – C3OrA

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July 01, 2015

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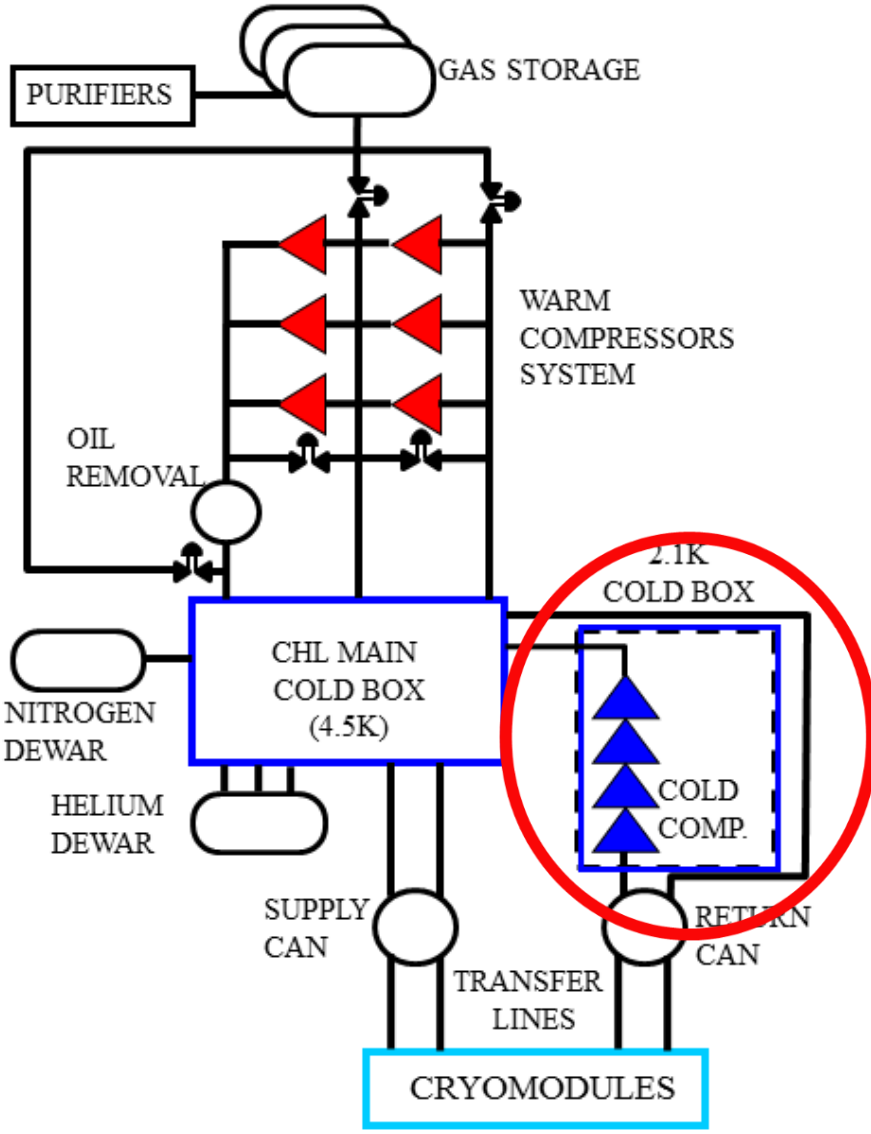
Outline

- SNS CHL system
- Pump down development history
- Pump down issues
- Power factor
- Planned studies
- Future considerations
- Summary

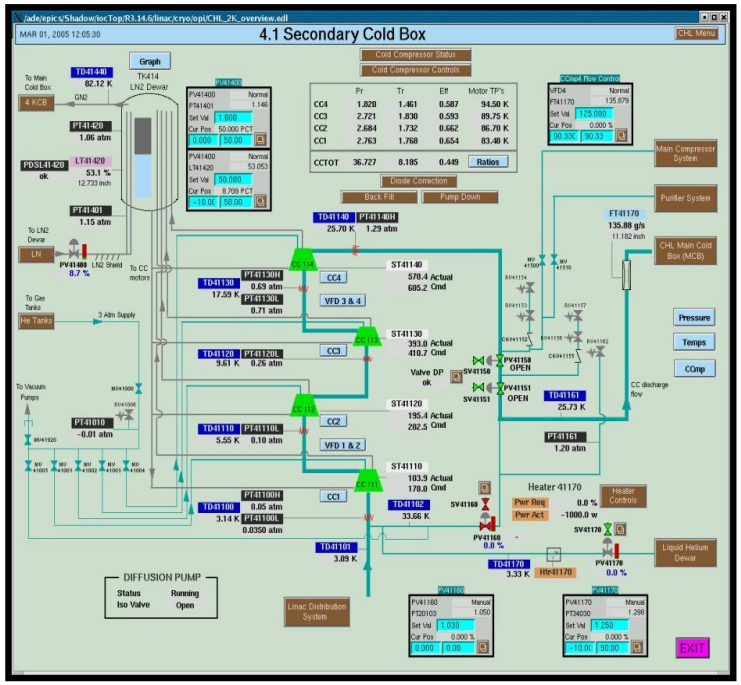
SNS CHL

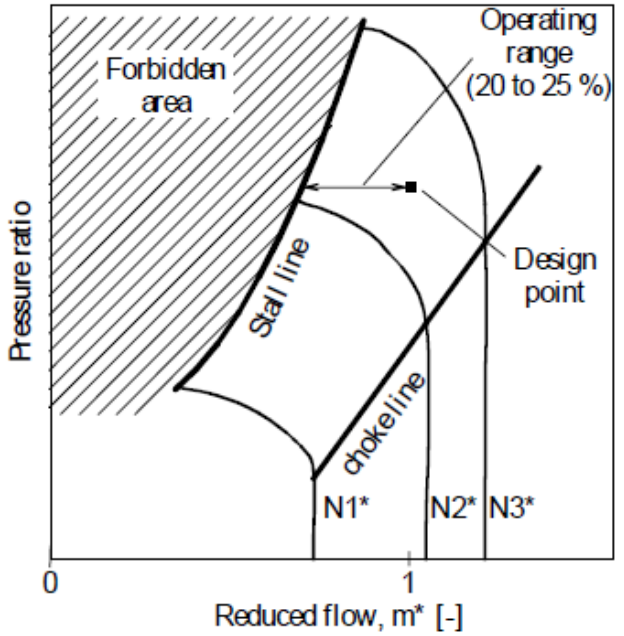
- Design
  - 2400 watts at 2.1 K
  - 8300 watts shield cooling
  - 15 g/s liquefaction load for coupler cooling
  - Adequate margin for upgrades
- Provides cooling to the SCL
  - 11 medium beta cryomodules each housing three SCRF cavities
  - 12 high beta cryomodules each housing four SCRF cavities
  - 9 additional slots in linac for future upgrades



SNS 2K cold box

- Design parameters
  - 125 g/s
  - Suction pressure 0.040 bar
  - Discharge pressure ~ 1.25 bar
- Four cold compressors
  - Commercial centrifugal compressors
  - VFD controlled
  - Magnetic bearings
  - LN2 cooled motors

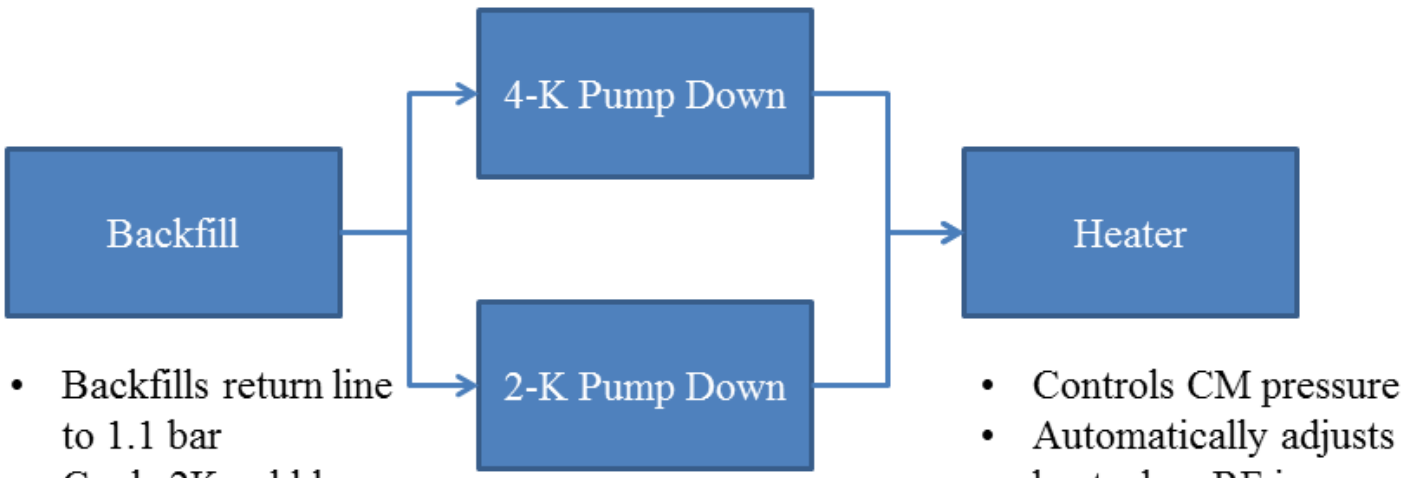




Pump down development history

- Pump down
  - Transitioning from 1.1 bar to 0.040 bar in the cryomodules
- System commissioned
  - 2 weeks in 2004
  - Additional 2 weeks in 2005
- Iteratively developed pump down
- Sequences developed to automate process

2K Control Sequences



- Controls cryomodule settings
- Controls 4-K plant

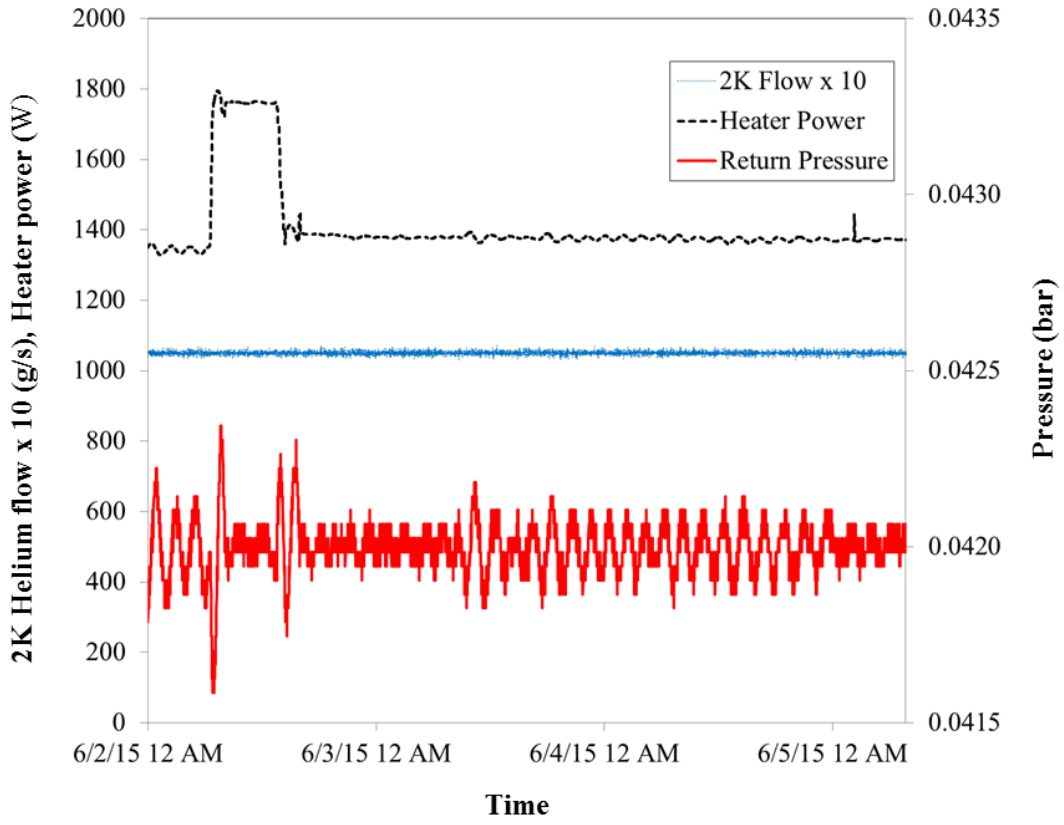
- Backfills return line to 1.1 bar
- Cools 2K cold box
- Starts cold comp. at min. speed

- Establishes loop control of 2-K flow using CC4
- Sets gear ratios of CC1 – CC3

- Controls CM pressure
- Automatically adjusts heat when RF is applied to cavities

Results of pump down development

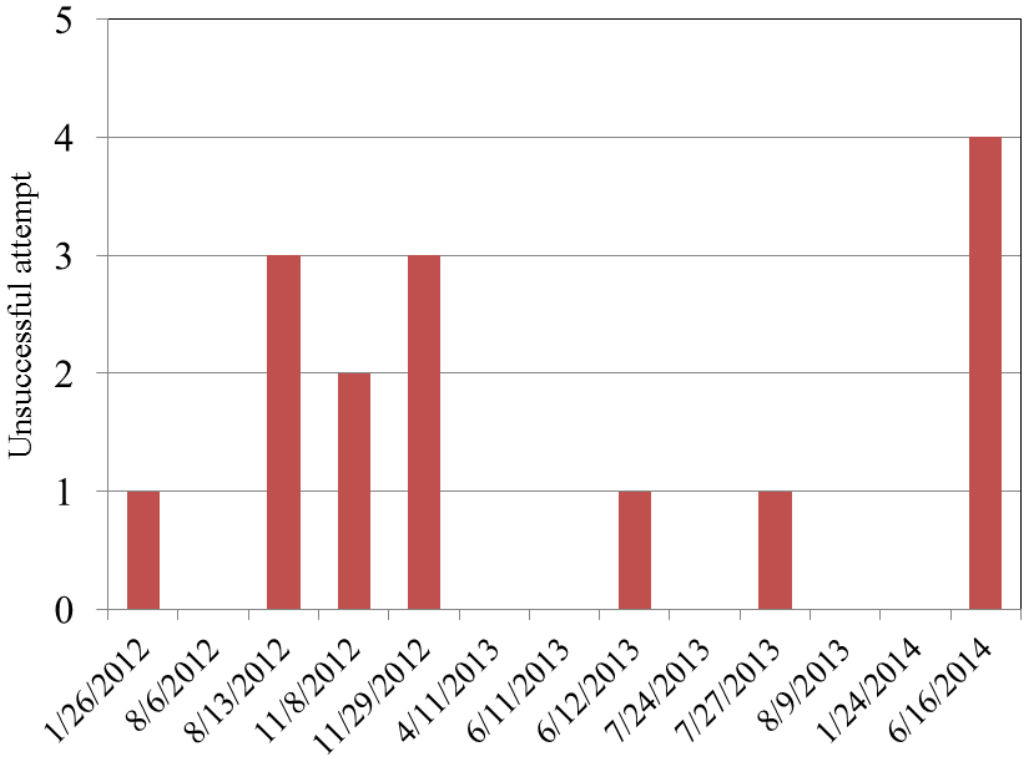
- Pump down was robust and repeatable
  - 26 of 27 attempts were successful from 2007 – 2011
- Pressure stability of LINAC is +/- 0.1 mbar



- System was >99.5% reliable from 2007 - 2011
- Pump down became a routine operation performed by the qualified CHL specialists

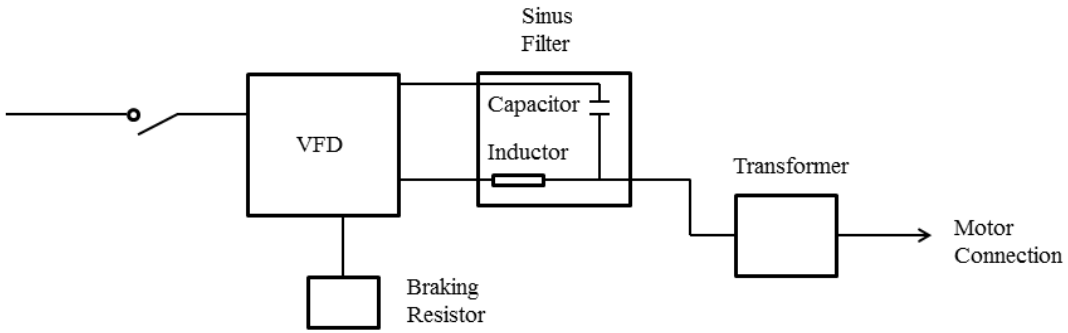
2-K pump down issues

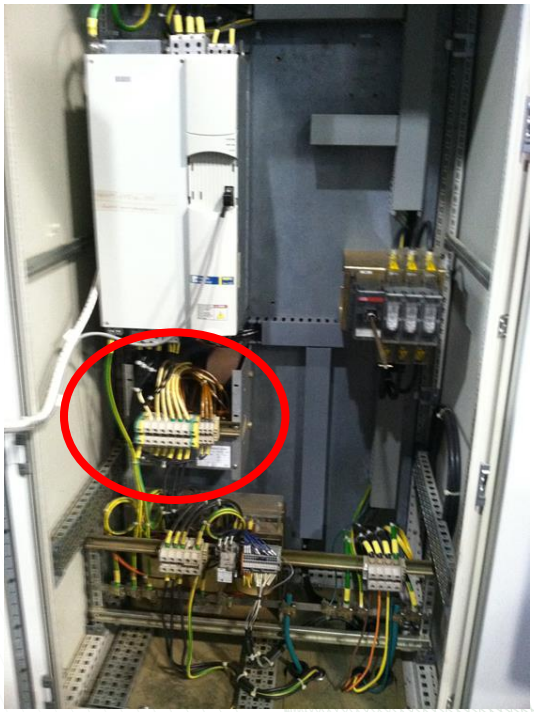
- Pump down issues arose from 2012 – 2014
  - Only 14 of 29 pump down attempts were successful
- Three causes of unsuccessful pump downs were identified
  - VFD issues
  - Sinus filter failure
  - Unknown
- At this point, SNS requested Jlab assistance and a meeting was held in March of 2015
- During maintenance periods, pump down is scheduled 1 week prior to beam production



2-K pump down issues

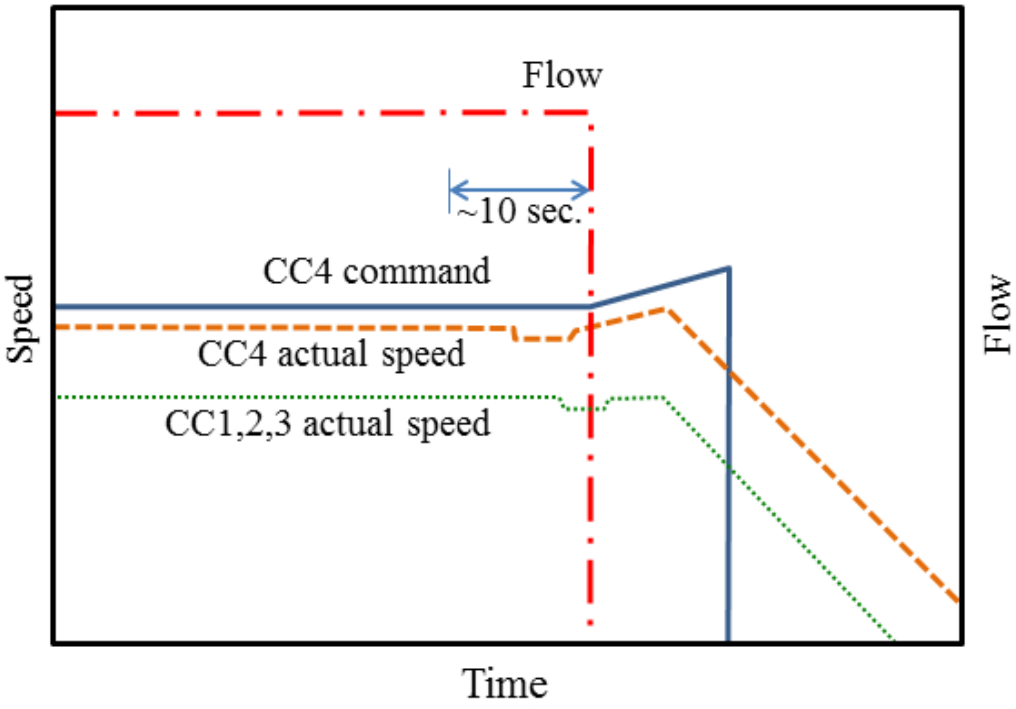
- VFD issues were confirmed to cause four unsuccessful pump downs
  - Failed fan motors and failed components on the control cards
  - Air conditioning was added to VFD cabinets in 2008
- The sinus filter on VFD3 failed in June of 2014 causing four unsuccessful attempts
  - Supplied from vendor incorrectly wired





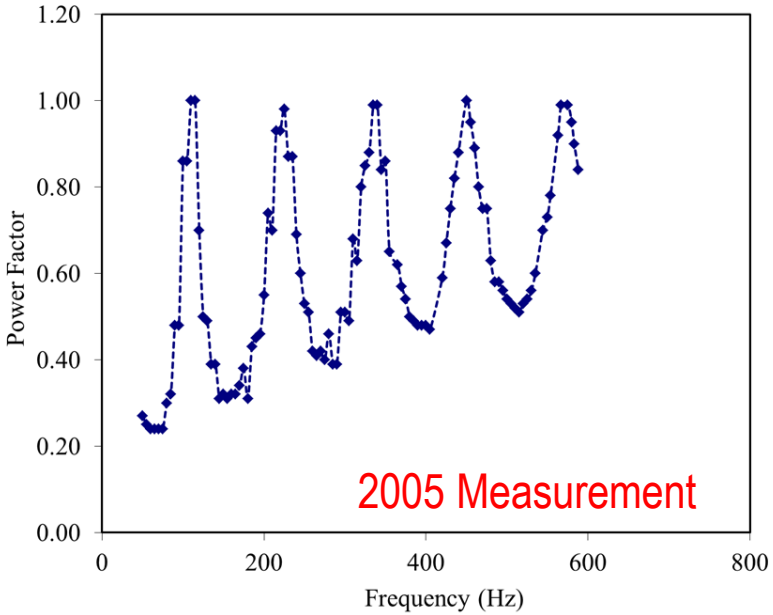
2-K pump down issues

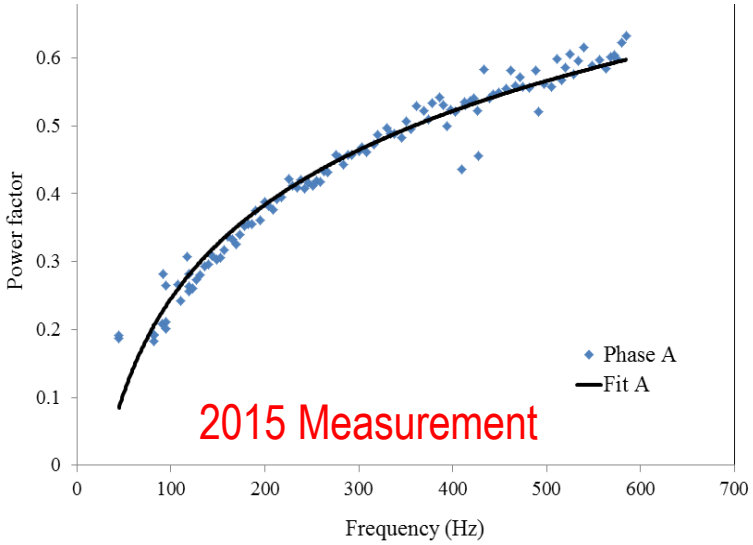
- Seven unsuccessful pump downs were attributed to unknown
- Pump data was collected in 1 second intervals
  - "VFD slip" was identified as a cause of unsuccessful pump downs
  - "VFD slip" – when output frequency and actual motor speed dip while the command is held constant
- Efforts are under way to study VFD performance



Power factor measurements

- Power factor is defined as the ratio of real power flowing to the load to the apparent power in the circuit.
  - Measures how well the voltage and current are in phase
- Problems during the original pump down development led to studying CC power factor
- Original measurements displayed a 60 Hz dependency
  - Suspected dependency was the result of measuring equipment
- New data does not show 60 Hz dependency
  - Values are still quite low





Planned studies

- Path for study
  - Rewrite pump down sequence to control CC1-3 based on CC4 command
    - Localizes effects of slip to one cold compressor rather than all four
  - Evaluate VFD controls (firmware, controllers, and signal wiring)
    - Ensures all versions of VFDs, controllers, and firmware are compatible
  - Study V/f curve within VFDs
    - Adjust values to maximize torque of CCs
  - Retake power factor data
    - Confirm recent measurements
    - Collect data for at least two of the cold compressors
  - Improve detection of and possibly prevent surge

Future considerations

- Capabilities within VFDs
  - Explore new generation VFDs and their control options
  - Ability to test VFDs under load
- Surge interlock
  - SNS uses a drop in differential pressure across the 2-K flow meter over time
  - Improve basis for detecting and possibly preventing a trip on surge
- Improve power factor in systems with VFDs
  - Best to do thorough analysis to adopt designs even for similar applications prior to procurement of equipment

Summary

- The original pump down development produced a robust reliable process
- Issues have emerged from power factor, VFD components, sinus filter and “VFD slip”
- Plans are being developed to identify the cause of “VFD slip”
- Jlab and SNS are working collaboratively to conduct this work