Central Helium Liquefier 1
Sub-Atmospheric Cold Box 1

Cold Compressor #5

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Outline

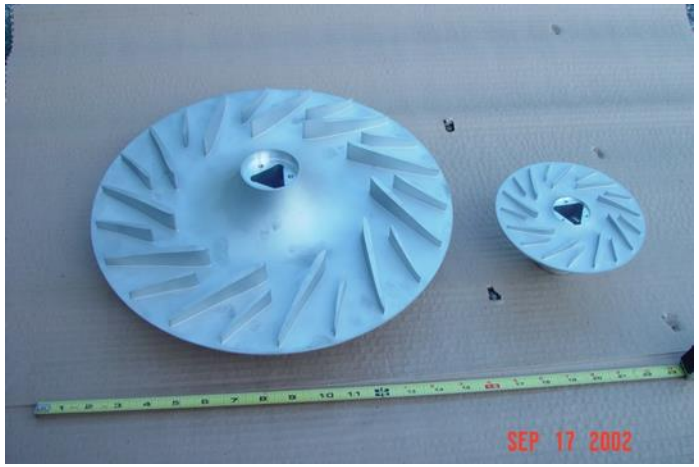
The purpose of this talk is to provide historical context for the subatmospheric, cold box and discuss the two recent failures.

- Background
- CC4 Event
- CC5 Event
- Path Forward
- Tentative Schedule

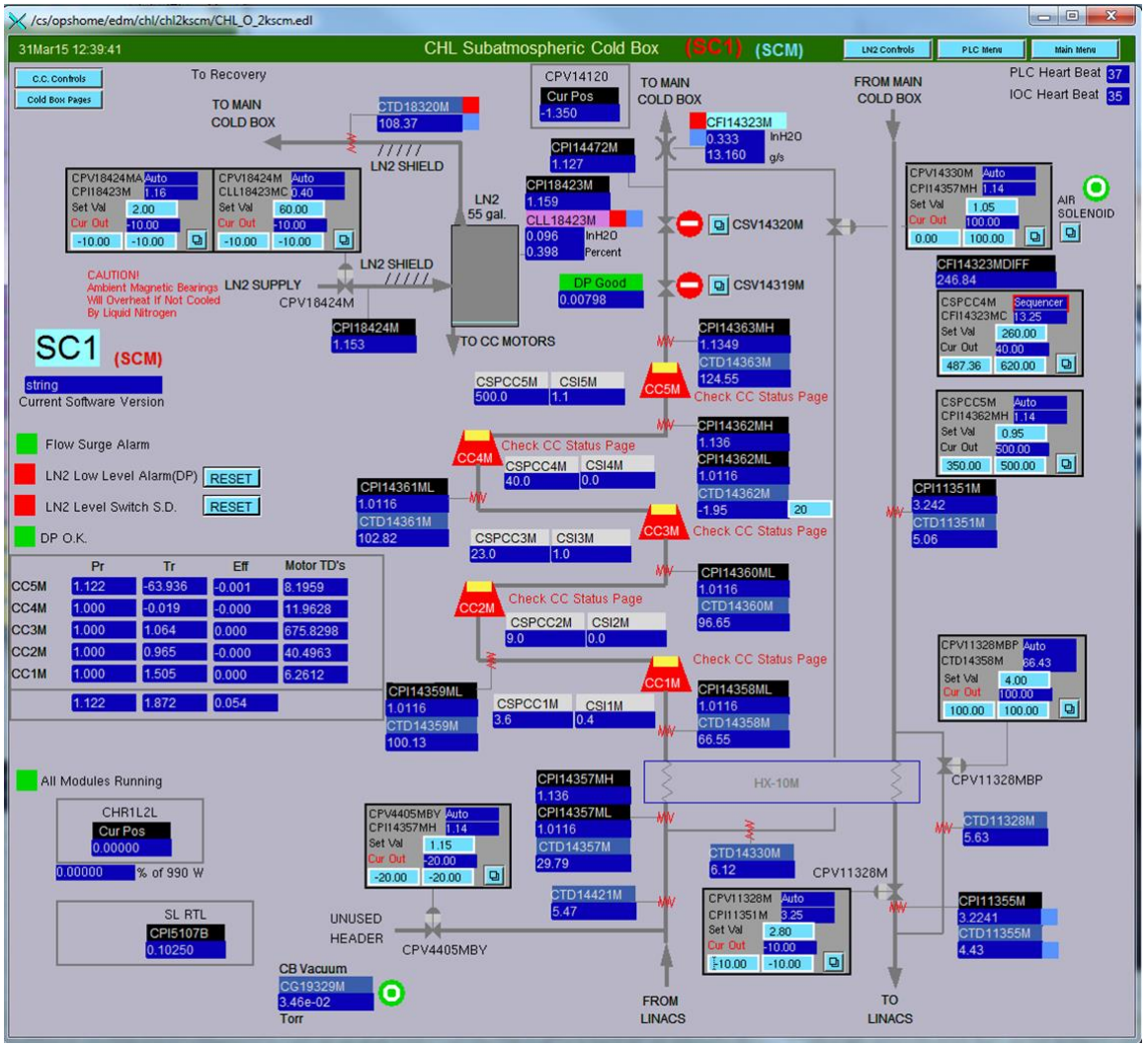
System Overview

2K Cold Box is a cold vacuum pumping system that contains cold compressors, heat exchanger, piping, valves, sensors, etc.

- Uses centrifugal compressors
- Motors mounted inside vacuum space are liquid nitrogen cooled
- Two motor sizes and four wheel sizes
- Use analog actively controlled magnetically levitated bearings (3-Axis)
  - Each has a “backup” ball bearing for hard landings (undefined)
- Driven by variable frequency drives at speeds up to 640HZ (38,400 RPM)
- Manufactured by S2M France



System Flow Diagram



Cold Box Details

Parameter	SC1 v1.0	SC2 v1.0	SC1 v2.0
Years Operated	1994-1999 Took 2.5 years to commission	1999-Present Built to replace SC1 v1.0 Took 1 week to commission	2014-Present Originally rebuilt as backup to SC2 v1.0 but became part of 12Gev project
Designed and Built by	Air Liquide & Cvl	Ganni, JLab	Ganni, JLab
Compressors Max Speed Wheel size rpm=(f/60*3600)	CC1a, 150Hz, W1 CC2a, 270Hz, W2 CC3a, 470Hz, W3 CC4a, 640Hz, W4	CC1b, 150Hz, W1 CC2b, 270Hz, W2 CC3b, 470Hz, W3 CC4b, 640Hz, W4 CC5c, 640Hz, W5	CC1a, 150Hz, W1 CC2a, 270Hz, W2 CC3a, 470Hz, W3 CC4a, 640Hz, W4 CC5d, 640Hz, W5
Characteristics	Square piping, small innerstage coupling volumes	Round piping, larger innerstage coupling volumes, flow straighteners	Same as SC2 v1.0
Stability	Unstable	Stable	Stable
Capacity	Below specification	+10%	+10%
Failures	Multiple. Major redesigns to coils and stators delayed program 2 years	None	CC4 (UPS/backup bearing) CC5 (under investigation)

Order #1, ~1990 Two-sets of 4 cold compressors CC1a-CC4a and CC1b-CC4b
Order #2, ~1995 Two cold compressors CC5c and CC5d
Wheels: W1 largest, W2, W3, W4 smallest. W4 and W5 are identical
Motors: 2 pole

Progression

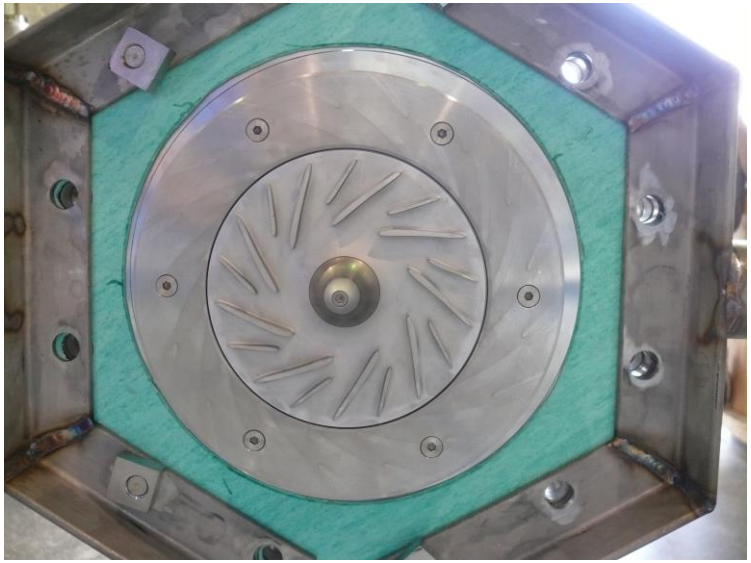
- 6Gev Era
  - CHL1 4K cold box and SC2 2K cold box on North and South LINACS
  - SC1v2.0 2K cold box was assembled but untested
  - Tunnel pressure 0.0395 atm nominal CC4 speed ~500Hz

- SNS Project (circa early 2000's)
  - JLab designed and built 2K cold box using same two cold compressor motor sizes but with different wheel sizes to match SNS flow requirements
  - SNS ordered four compressors to install and one spare of each of the two sizes as backup

- 12Gev Era
  - Added 5 C100 modules to North and 5 C100 modules to South
  - CHL1 4K cold box and SC1 2K cold box on South LINAC
  - CHL2 4K cold box and SC2 2K cold box on North LINAC
  - No backup 4K or 2K cold boxes
  - Tunnel pressure was lowered from 0.0395 atm to 0.0350 atm to compensate for performance issues with C100's. Raised nominal CC4 speed ~560-570Hz
  - Ops was executing a controlled program of raising the pressure in steps while monitoring C100 performance when failure occurred

SC1 CC4a Event

- Site wide power outage 3-25-2015
- Systems passed restart checks and procedures
- Compressor operated normally at first but locked up during pumpdown at high speed
- Problem traced to failure of magnetic bearing UPS resulting in hard landing
- Backup ball bearing failure led to extensive compressor damage
- JLab borrowed one spare compressor from SNS
  - Details of loan to be worked out by Lab Directors
- Damaged unit sent to S2M for 2 year repair using only set of spare parts
  - Expect CC4R return by end of May 2017
- S2M indicated they would not build more parts or compressors of this design



CC5d Event Summary

- Operations noticed occasional rotor displacement alarm flickering
  - Cabinet controls two levels of protection: alarm and shutdown
  - Most frequently encountered alarms/shutdowns are flow surge and rotor displacement
- Visual inspection of bearing cabinet during operation seemed normal
- Only item noted was Z2 coil operating near its minimum control current and was interpreted as contributing to the intermittent alarm
- Plan formed to adjust the balance of Z1/Z2 at the next 2K shutdown
- Cold compressor was operating normally until 10:24pm on March 9, 2017
- Cold box tripped on CC#5 rotor displacement
- Technical staff saw no problems and equipment appeared to function normally
- Planned adjustment made to the axial control loop card
- LINAC backfill started and compressors operated normally at low speeds from 12:00am until 12:34am
- Pumpdown started 12:35am March 10, 2017 and progressed with no issues
- Pumpdown completed 1:25am March 10, 2017
- SC1 tripped again on rotor displacement at 3:31am March 10, 2017
  - CC#5 mag bearing alarms would not clear
  - Investigation started

Steps Following Event

- Visual inspection of magnetic bearing cabinet
  - Rotor not floating
  - Coil currents unstable
  - W4 and V4 were pegged at high current
- Techs unsuccessfully attempted adjustment to recover rotor position
- Magnetic Bearing #5 backup battery function passed load test
- Magnetic Bearing #4 cabinet was plugged into cold compressor #5
  - Non-functional with same results as magnetic bearing cabinet #5
- Magnetic Bearing #5 cabinet was plugged into cold compressor #4
  - Functioned correctly in all aspects

- Several conference calls with Air Liquide
  - Discussed CC4 return date
  - Discussed CC5 failure and their participation in investigation
  - Reiterated that S2M is not likely to support any further repair actions

Immediate Path Forward

- Contract Air Liquide technicians come to JLab
  - Visually inspect CC5 compressor wheel and nose piece
  - Disassemble lower end of CC5 and perform visual inspection of backup bearings
  - Perform measurements on all cold compressors in SC1 and SC2 to determine backup bearing clearances, check position sensors, etc.
  - Recommend and carryout any maintenance procedures on any of the existing cold compressors based on the measurements taken
    - Might effect repair schedule for SC1 and restart schedule for SC2

- Return LINACS to 6Gev era LINAC pressures
  - Slow compressors and reduce trip impulses when outlet valves close

Immediate Path Forward

- Option #1 for SC1
  - Perform warm testing to determine viability of CC4R repair
  - Install CC4R in CC5 slot and prove it works
  - Operate cold box for the physics program
  - Deal with a failure at JLab or SNS when it occurs
- Option #2 for SC1
  - Bypass CC5 and learn to run on 4 stages
  - Use CC4R as spare for JLab and SNS
- Option #3 for SC1
  - Install CC4R in CC4 slot
  - Perform warm testing to determine viability of CC4R repair
  - Bypass CC5 and learn to run on 4 stages
  - Use CC4 as spare for JLab and SNS
- Each option should not take more than approximately 3 months

Long Term Path Forward

- Design a new replacement 2K cold box for SC1 (the oldest)
  - JLab is currently doing this for FRIB and LCLS2
  - Utilizes latest cold compressor and magnetic bearing technology
  - Design uses two motor sizes and multiple wheel sizes
  - Could be adapted to replace the SC1 cold box
  - Cold compressor manufacturing interval is approximately ~1 year
  - Production pipe line currently producing FRIB and LCLS2 compressors
  - ~ 3 year design and build effort to incorporate into existing system
  - Approximately $8M (working to refine this number based on actual LCLS2 projections)

- Use parts from old SC1 to maintain SC2