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FLOATING PRESSURE CONVERSION AND EQUIPMENT

UPGRADES OF TWO 3.5 kW @20K, HELIUM REFRIGERATORS



Jefferson Lab
Thomas Jefferson National Accelerator Facility





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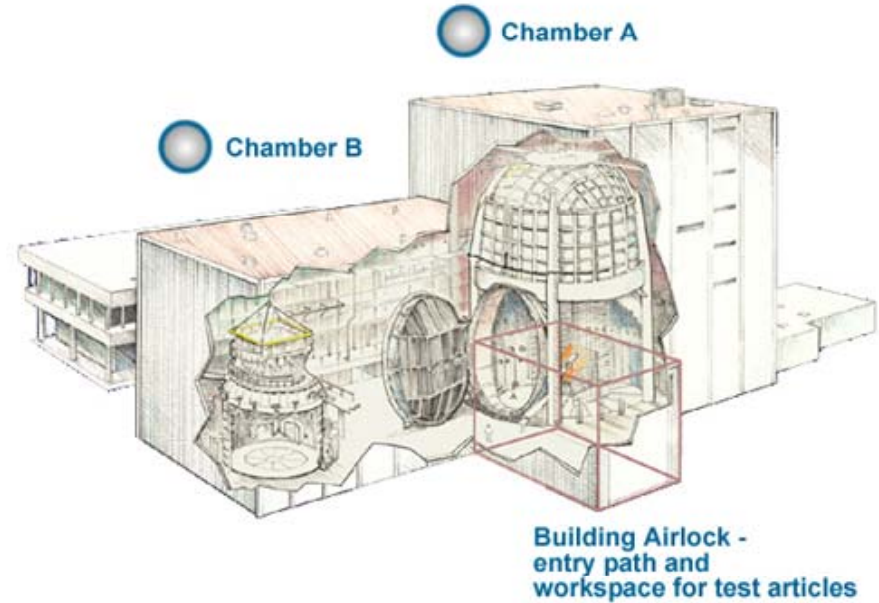
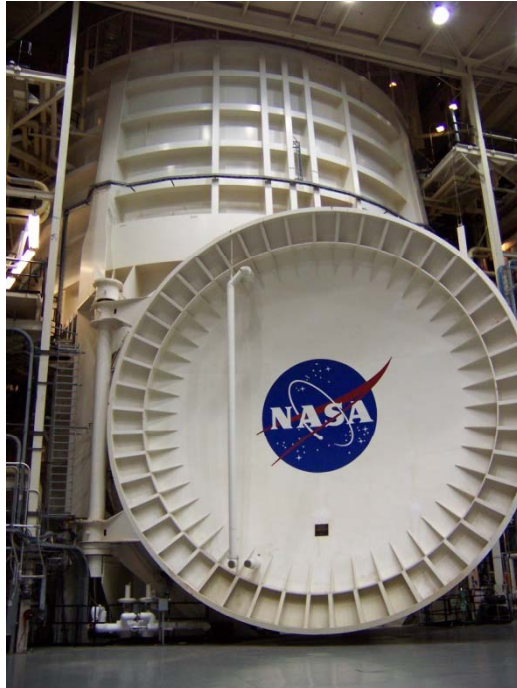
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Brief History of SESL use of Helium Refrigeration

- » 1960's Five CVI refrigerators of 1.75 KW @20K were installed for chamber cryo-pumping
Chamber A was supported by four and one for Ch-B
- » 1990's Combined all units with common transfer line
 - Very beneficial to have the ability to use refrigerators on different chambers through common manifold
- » 1997 Commissioned two Linde modified TCF50 units rated at 3.5 KW @20K each to redundantly support testing in either Chamber A or B

Future:

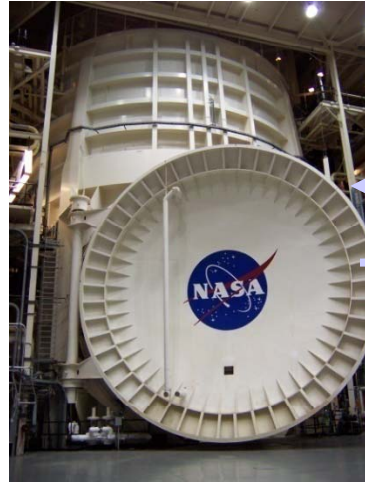
- » Preparing to add a new 12.5 KW @20K refrigerator to support JWST testing in Chamber A



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Since the initial commissioning of SESL (1965), large scale helium refrigerators and helium shrouds within Chambers A & B have been used to provide cryo-pumping to high vacuum conditions

Chamber Shrouds



Cold Box
3.5 KW
@ 20K

Compressor

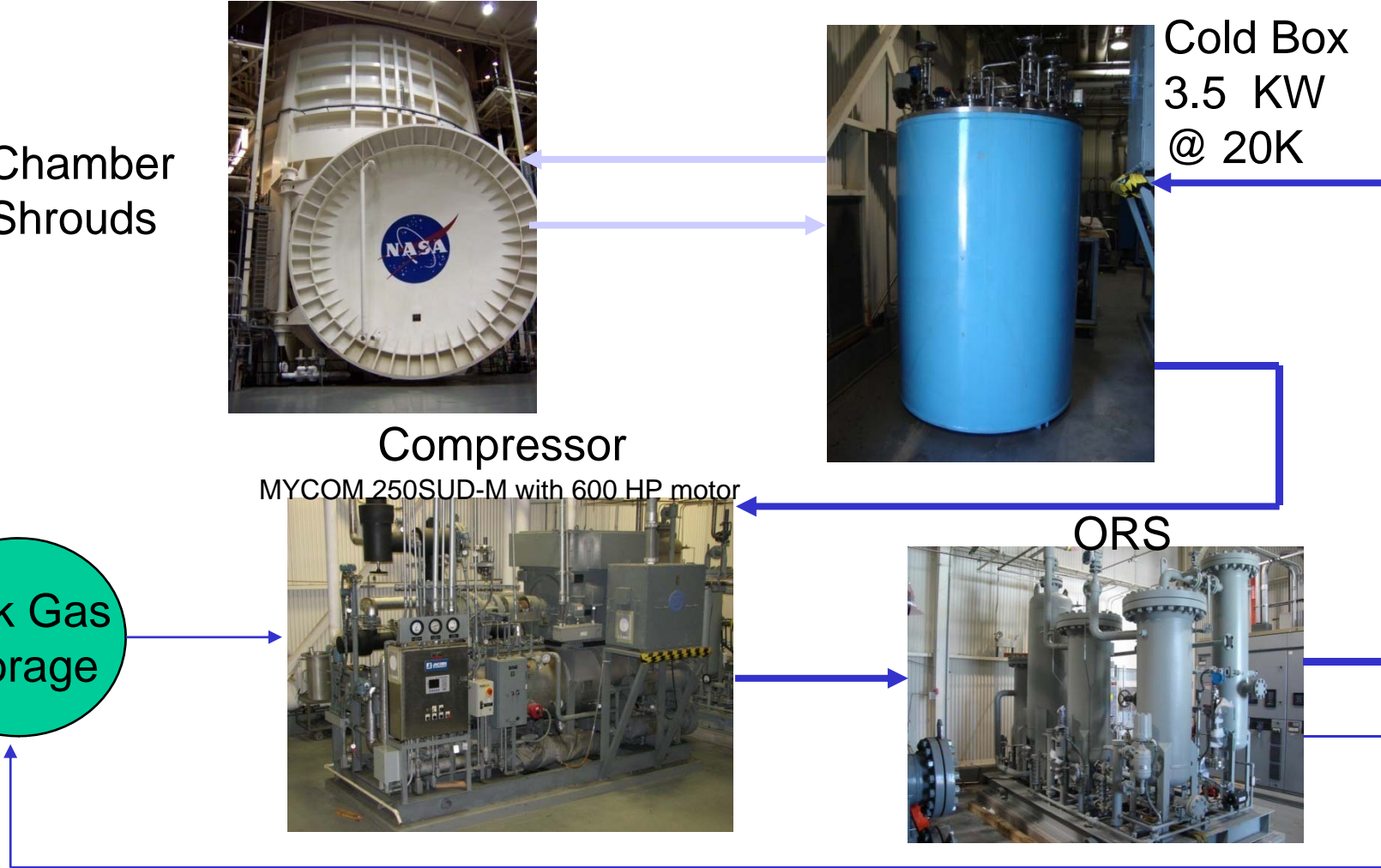
MYCOM 250SUD-M with 600 HP motor



ORS



Bulk Gas Storage





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Why did JSC go away from the original CVI units?

- » In the late 1980's realized the CVI units were no longer maintainable
- » Moved to newer technology of turbine expanders and oil-injected screw compressors
- » Issued a contract through NASA's Construction of Facilities (CoF) program to procure two new helium refrigerators, a building wing, and utilities to support the upgrade



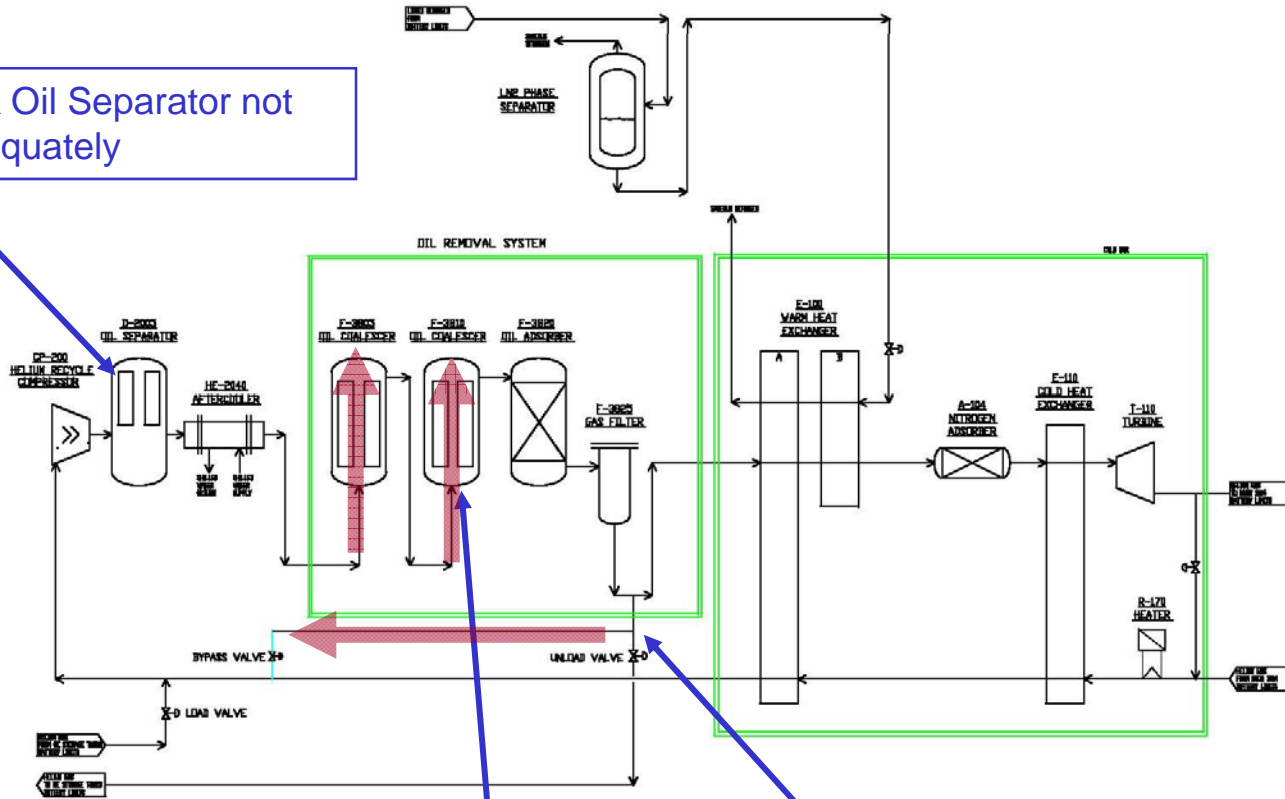
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- **The system performance was good once up and running, but three problems lead to much headache**
 - » Oil Carry-over past the oil removal system
 - » Controls system lock-up with no discernible cause
 - » The chamber panel temperatures varied by 2.5K
- **As a result of the oil carryover, the cold boxes were contaminated**
- **The problem was partially mitigated by the compressor contractor, but not corrected**
- **Linde Cryogenics of Tulsa was contracted to determine the cause of oil carryover, and implement solution**



Original system arrangement and issues:

Horizontal Bulk Oil Separator not performing adequately

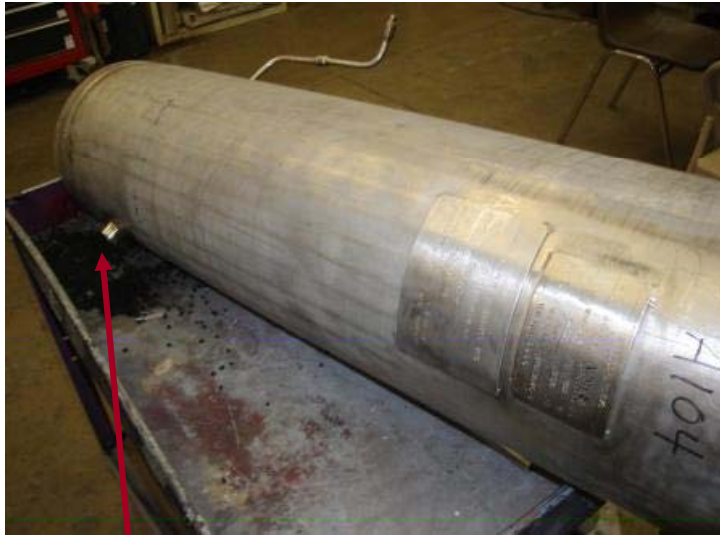


Flow through coalescers was bottom to top

Compressor recycle valve downstream of ORS



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Cold Box 80K Charcoal Adsorber
Contaminated with compressor oil



Cold Box VJ Bayonet to load
Compressor oil found downstream of turbine



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Modifications / refurbishment project (Linde):

Changes made to the ORS

- Replaced the coalescing elements to Monsanto type elements
- Modified helium flow path to flow from top to bottom and center to out through the side of the coalescing element
- Added a new vertical bulk oil separator between the helium after-cooler and the two downstream coalescer vessels
- Added a check valve on the line from helium buffer tank to reduce possibility of oil contamination of the helium buffer tank
- Changed the compressor bypass valve inlet from downstream of the ORS to upstream of the ORS



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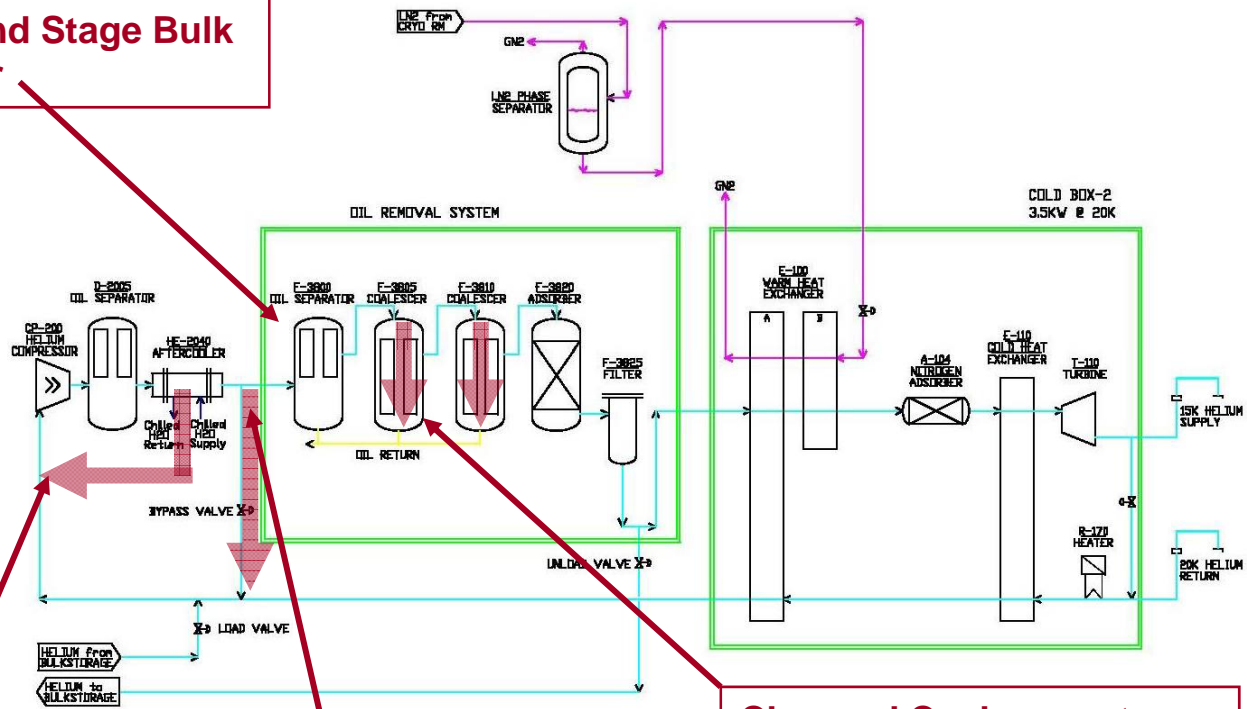
Changes made to the ORS (cont.)

- Added new oil return path to the compressor from the helium after cooler heat exchanger
- Cleaned all system lines of oil residue
- Changes made to the cold box
 - » Replaced and added redundant instrumentation within Cold Box
 - » Cleaned Heat Exchangers and Cold Box internal lines of oil residue
 - » Replaced internal filters and adsorbers
 - » Replaced other damaged components like heaters



Current Arrangement

Added Second Stage Bulk Oil Separator



Added after-cooler oil return

Compressor recycle moved to upstream of ORS

Changed Coalescers to Monsanto top enter, side discharge



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ORS before modification

ORS after modification





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Control System Modifications

- » Original configuration was a SATCON PLC and a LINKS human machine interface (HMI)
 - Had to “catch” a curser to enter commands
 - Commands were all typed
 - Screens commonly “froze”
- » December 2006, re-wrote the PLC software to incorporate modifications to the 2003-NASA-JSC reverse engineered control system code from the SATCON PLC and reprogrammed the same controller logic to operate on an Allen Bradley PLC and also integrated the PLC with an ICONICS HMI
- » Developed new HMI screens to operate the system
 - Software based on Jefferson Labs “Floating Pressure Control”
 - HMI on ICONICS platform
- » In 2006, NASA JSC contracted the Cryogenics department at Thomas Jefferson Laboratory (DOE) for assistance with the project
- » Implemented Jlab control and operators interface techniques on the 3.5KW Systems on Allen Bradley and ICONICS platforms



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Control Philosophy Changes

- » Modified the process control to allow the compressor discharge pressure to vary with the load, i.e. to “Ganni Cycle floating pressure”
- » Basically the “Ganni cycle floating pressure” balances the input power of the refrigeration to the refrigeration demand by the load
 - Analogous to using gas pedal for primary speed control
- » Most refrigerators control to a T-S design point and trim the load with makeup heat
 - Analogous to driving with the gas pedal fully depressed for peak power and controlling speed with the brake



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What does it mean?

- » Instead of the compressor operating to a set point pressure and the system temperature controlled by a trim heater, the high pressure system set point is determined as function of the load return temperature
- » No new equipment required to implement the floating pressure control



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Other controls re-writes that proved beneficial

» Compressor startup

- Implemented changes that reduce risk to oil carry over and hardware damage

» LN2 Controls

- Changed LN2 control valve from nitrogen vent temperature control to control of temperature difference between the helium high and low pressures
- This gave much better temperature stability and reduced LN2 consumption



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Operator Interface:

- The original HMI was a LINKS HMI
 - » The controls were archaic even in the 1990's and the HMI would often lock up not allowing the operator to see the system performance or health
- The first phase of the HMI portion of the project copied the screen appearance of the LINKS and put that format on ICONICS platform on a PC
- During the second phase the JLab "Floating Pressure Control" theory is implemented and changed the screens to show the process and the operating conditions of the key components.



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Example of old control screen philosophy

Train 2 Coldbox Analog Readouts

Coldbox Status	<input type="text"/>	
T110 Speed	SI111	***** rps
T110 Inlet Temp.	TI110	***** deg K
T110 Inlet Press.	PI110	***** psig
F110 Dif. Press.	DPI110	***** psi
A104 Inlet Temp.	TI102	***** deg K
A104 Reg. Temp.	TI106	***** deg K
Port Supply Gas	FI140	***** lb/hr
Port Return Press.	PI172	***** psig
T110 Inlet Valve	CV110	***** %
T110 Outlet Temp.	TI130	***** deg K
T110 Outlet Press.	PI130	***** psig
T110 Brake Temp.	TI111	***** deg F
GN2 Outlet Temp.	TI605	***** deg K
Port Return Temp.	TI172	***** deg K
Totalizer	<input type="text"/>	
Adsorber Inlet	GI+102	NOT OPEN
Adsorber Outlet	GI+104	NOT OPEN
T110 Inlet Valve	GI-110	NOT CLOSED
T110 Bypass	GI-112	NOT CLOSED
Port Supply Valve	GI-140	NOT CLOSED
Port Bypass Valve	GI+152	NOT OPEN
Port Return Valve	GI-160	NOT CLOSED



Typical Pop Up for New HMI

PC201A ●

10.00 ATM
Actual Setpoint

20
15
10

PV 3.6 SP 10.0
-2.0 %
Requested Manual Position
10.00 ATM
Requested Setpoint

100%
Valve Info

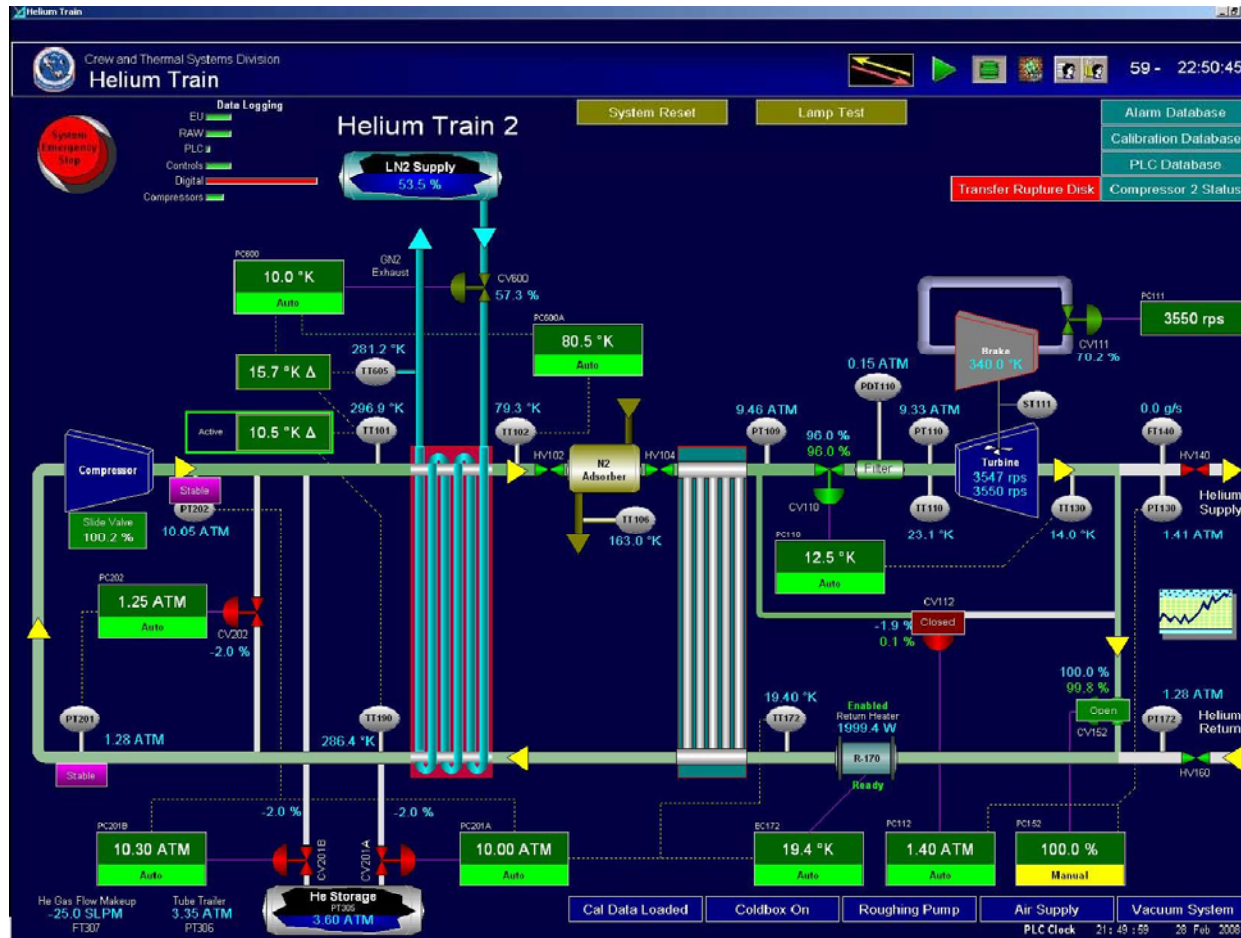
70.0 %	Valve Max	70.0 %
-2.0 %	Valve Min	-2.0 %
1.0 %/s	Valve Close Rate	1.0 %/s
1.0 %/s	Valve Open Rate	1.0 %/s
1.000 s	Update Time	1.000 s
20.000	Proportional Gain	20.000
5.000	Integral Gain	5.000
0.000	Derivative Gain	0.000
20.0	Output Load Temp	20.0
13.0	Output Exp. Temp	13.0
0.1	Allow. Temp Error	0.1
0.200	Error Correction Gain	0.200
30.0	Time Increment	30.0
18.0	Max Discharge Press	18.0
10.0	Min Discharge Press	10.0

Staged ➔ Write PLC Values



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Example of new system screen





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New Turbine Information Pop-Up

Turbine

On
Off

Off

Trip

Conditioning

Interlock

Speed > 400 rps

Speed High

CV110 > 1% at Startup

Inlet Pressure	1.35 ATM
Outlet Pressure	1.32 ATM
Inlet Temperature	175.45 °K
Brake Temperature	292.00 °K
Outlet Temperature	102.03 °K
Turbine Mass Flow	3.42
Isentropic Eff	0.61
Pressure Ratio	1.03
Isen Temp Ratio	1.02
Actual Temp Ratio	1.72
Ref Flow Speed	67.46 m/s
Optimal Speed	698.73 rps
Mass Flow Crit m_c	12.72 g/s
Mass Flow A m_a	3.42 g/s
Power	0.00 J/s
PT Inter Pressure	1.47 ATM
T0 Trans Inlet Temp	25.10 °K
T3 Trans Outlet Temp	24.84 °K
Intermediate Density	2.88 x
Temp Diff Isen	0.44 °K
Thrust Speed Limit	10000.0 rps
Speed Setpoint	380.0 rps
Current Hi Speed Limit	3550.0 rps
Hi Speed Plus	3612.5 rps
Hi Speed Plus Plus	3675.0 rps
Ax Thrust	0.00
Ax Thrust Limit	1.00
Inlet Valve Increment	0.0300 %

Settings

Speed High Limit	3800.0 rps
Speed Low Limit	400.0 rps
Speed SP High Limit	3550.0 rps
Pressure Low Limit	0.89 ATM
Max Start Press Ratio	1.70
Min Oper Press Ratio	1.30
Temp Low Limit	11.00 °K
Brake Start Position	70.00 %
Ax Thrust Gain	1.00
Temp Stop Time Limit	7200.00 s
Temp Stop Max No	3.00

Brake	Temp High
Housing Water	Brake High
Cooling Water	Overspeed

00100C0400

- 1 Trip - Low Speed
- 2 Trip - High Speed
- 3 Trip - Turbine Not Started
- 4 Trip - Brake Temp High
- 5 Trip - High Num of Stops
- 6 Turbine Outlet Not Open
- 7 Undefined
- 8 Undefined
- 9 Undefined
- 10 Trip - Circuit Breaker
- 11 Trip - Speed Hi Delta
- 12 Trip - Emergency Stop
- 13 Trip - High Pressure
- 14 Undefined
- 15 Turbine Off Command
- 16 No Instrument Air Press
- 17 Compressor Not Running
- 18 Trip - Outlet Press Low
- 19 Trip - Temperature Low
- 20 Undefined
- 21 Trip - Brake Temp Switch
- 22 Trip - Hardware Interlock
- 23 Compressor Not Ready
- 24 No Brake Cooling Water
- 25 No Housing Cooling Water
- 26 CV110 > 1% at Startup
- 27 Turbine Hardwired Overspeed
- 28 HV102 & HV104 Not Open
- 29 Undefined
- 30 Undefined
- 31 Undefined



Conclusion

- The system performance is greatly improved with the controls change-over to the Ganni Cycle floating pressure control
- Improved system operational stability
- Operator intervention requirement is substantially reduced
- Power savings and reduced LN2 consumption
- Improved load temperature stability (2.5K to 0.25K)
- Maintenance requirements on the system are expected to be reduced, especially on the compressor
- Improved system reliability



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3.5 KW Refrigerator System

