Nitrogen Precooling Heat Exchanger replacement and control system upgrade in Superfluid Cryoplant at CMTF

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CEC/ICMC 2023
07/12/2023
C3Or4B-01
FERMILAB-SLIDES-23-159-TD

Contents

Introduction

- Cryomodule Test Facility (CMTF) at Fermilab is a cryogenic test facility which is supported by state-of-the-art Linde superfluid cryogenic plant (SCP) to supply 40 K, 5 K and 2 K Helium.
- 2 K operations is achieved either by string of cold compressors or a vacuum pump utilizing booster and a ring pump.
- It supports
  - LCLS II project which is used to test 1.3 GHz and 3.9 GHz cryomodules.
  - PIP-II injection test stand program to test front end of future PIP-II Linac and production cryomodules.
- Nitrogen pre-cooling is used in this Cryoplant to cool down Helium to around 80 K.

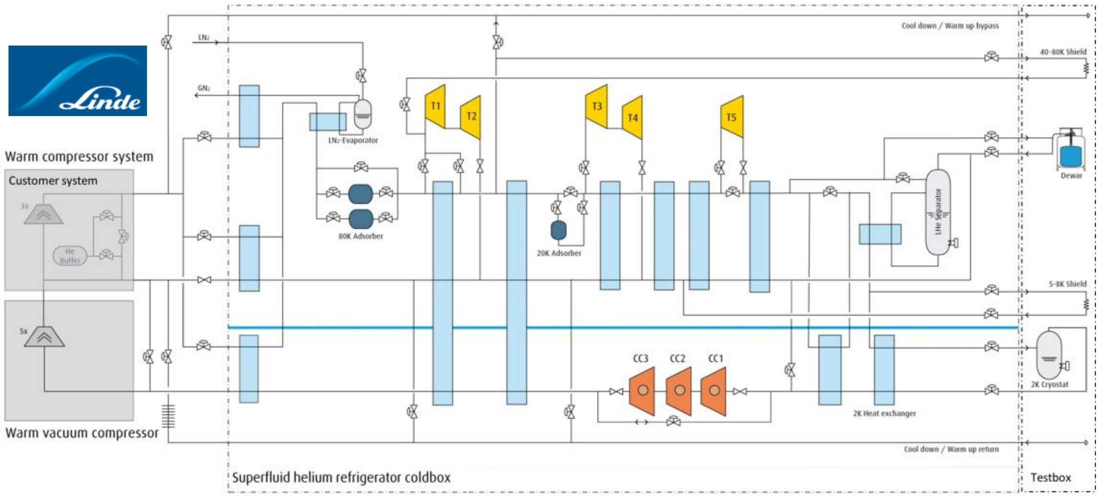

Figure 1: Simplified schematic showing CMTF Cryoplant (Image courtesy: Linde)

Figure 2: Pictures showing cryogenic distribution box, coldbox and Helium dewar at CMTF.

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Incident

- On 30th March 2018, operational issue caused the Helium storage pressure to go down.
- 3000 L liquid Helium dewar heater was set at manual setting of 1000 W to force recovery of gaseous Helium back to storage and recover the system.
- Superfluid Cryoplant coldbox shut down due to low storage pressure even with manual intervention.
- Dewar heater was left in manual after coldbox shutdown.

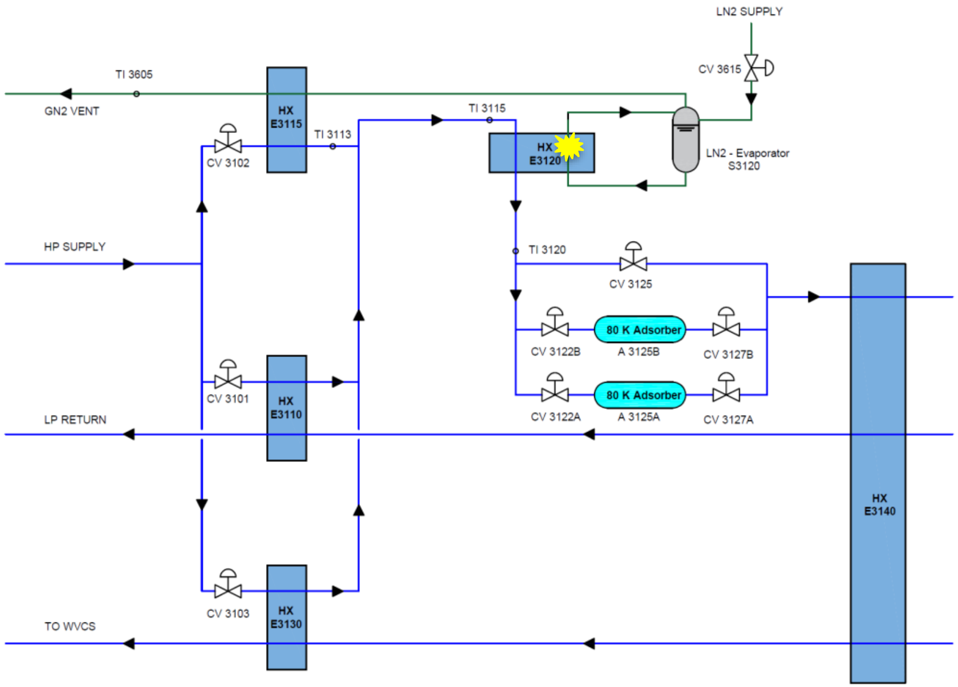

Figure 3: Schematic of Nitrogen precooling at SCP before incident.

- With various high pressure Helium valves programmed to close after coldbox shutdown and uniform flow from cold end due to 1000 W heater, imbalance of flow occurred.
- Due to flow imbalance, rapid cooldown of high-pressure Helium leaving E3110 heat exchanger occured and it entered Nitrogen precooling heat exchanger E3120 at temperature lower than Nitrogen freezing temperature (<63 K).

Incident

- Nitrogen within heat exchanger channel started freezing.
- The issue was not identified immediately and Nitrogen remained below freezing temperature overnight resulting in Heat exchanger channels being frozen solid with Nitrogen.
- In preparation for startup, valves configuration was modified next day to flow warm Helium gas through Helium side of heat exchanger E3120.
- Frozen Nitrogen evaporated non-uniformly and gas pockets developed in middle of frozen channels with no path to escape.
- Local over pressurization due to the gas pockets resulted in rupture of heat exchanger channels of E3120 causing Helium to Nitrogen leak.

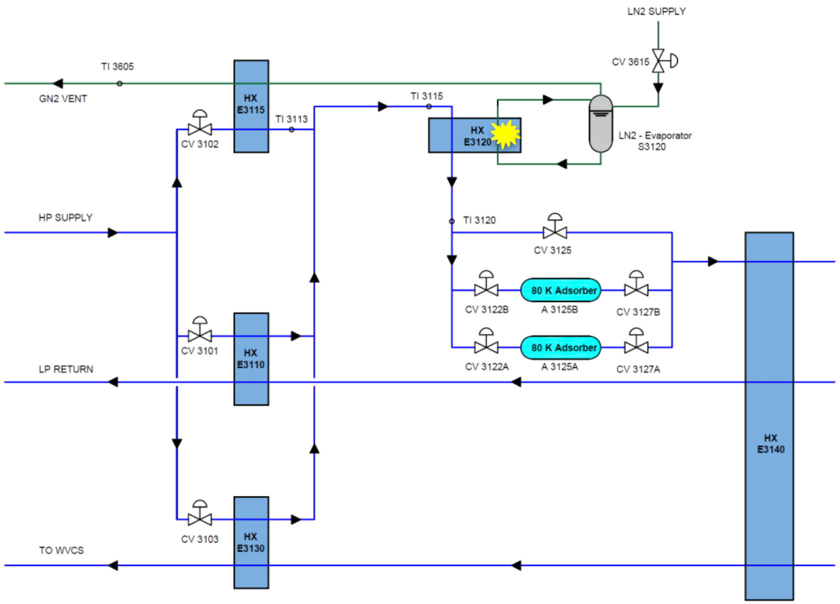

Figure 4: Schematic of Nitrogen precooling at SCP before incident.

Figure 5: Picture of a damaged heat exchanger.

Modification before transition to upgraded system

Figure 6: Removal of coldbox heat exchanger E3120

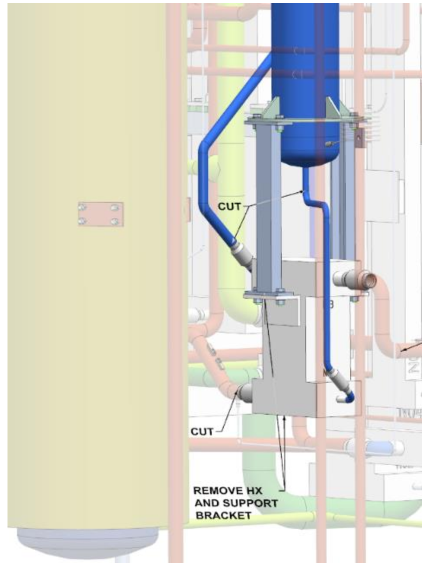

Figure 7: 3D model showing configuration before incident

Figure 8: 3D model showing configuration after installation of heaters

Figure 9: Picture showing actual configuration after heaters installation.

- Heat exchanger was removed from coldbox once the leak was confirmed.
- Due to significant lead time of new heat exchanger and operational support requirement of projects, modification was made in the system to operate without Nitrogen precooling heat exchanger.
- In place of heat exchanger, 4000 W inflow heater and two 1425 W band heaters were added on Nitrogen circuit which would generate Nitrogen vapors to cooldown Helium in recuperative heat exchanger E3115.

Capacity comparison of Cryoplant with and without Nitrogen precooling

Configuration	40 K shield capacity	5 K shield capacity	Liquefaction capacity
With precooling heat exchanger	735 W	105 W	19.8 g/s
Without precooling heat exchanger	400 W	75 W	7.64 g/s
With 7 kW heater	400 W	75 W	11 g/s

Table 1: Table showing 40 K shield, 5 K shield and liquefaction capacity of Cryoplant at different configurations.

- Over-temperature protection was used for the heater bands and temperature sensor was installed in the heat exchanger Helium outlet.
- While not an efficient solution, the configuration provided a way to get the system operational with acceptable capacity to keep cryogenic test programs on schedule.
- Addition of these heaters generated about 44 % more liquefaction capacity than without use of Nitrogen precooling.
- The Cryoplant was operated in this configuration for 2 years until the replacement heat exchanger was delivered and shutdown window became available to install final replacement.

Heat Exchanger replacement and control system upgrade

- Heat exchanger of similar effectiveness as original damaged heat exchanger E3120 was procured from the vendor and was installed as its replacement.

- Mere replacement of heat exchanger would not have prevented the catastrophic incident from reoccurring.

- Series of pipe reconfiguration and control system upgrades were made to ensure that the incident did not repeat.

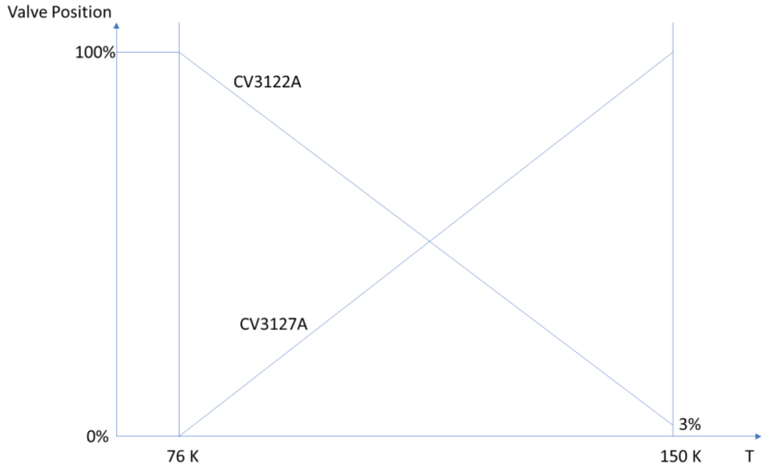

Figure 10: E3120 bypass control valves configuration with assumption of linear PID controller response.

- Due to spatial constraint and valves requirement, one of the 80 K adsorbers in SCP coldbox was removed and its inlet and outlet valves were repurposed to be used to bypass Helium flow around heat exchanger.

- These valve CV3122A and CV3127A are controlled by single controller TC3115 and regulates Helium inlet temperature to heat exchanger.

- The inverse PID controller TC3115 has following control logic
  - CV3122A position = controller output
  - CV3127A position = 100 % - controller output

Configuration and controls upgrade

- In addition to the controller, when heat exchanger inlet temperature TI3115 is less than 76 K, LN2 bypass interlock is activated.
- CV3122A fully opens and CV3127A fully closes when bypass interlock is activated..
- The LN2 bypass interlock resets when TI3115 and TI3120 are greater than 76 K.
- When LN2 bypass interlock is not activated, the controller TC3115 is enabled.

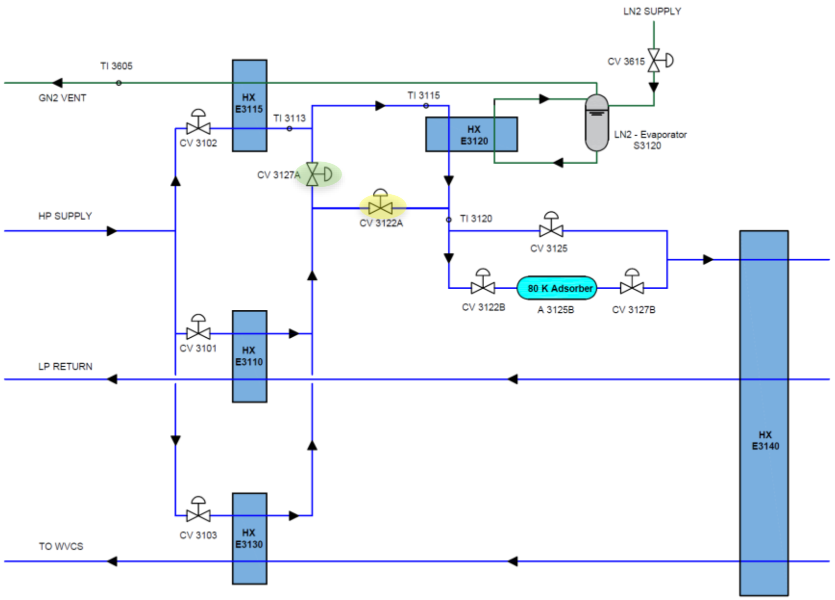

Figure 11: Schematic of Nitrogen precooling at SCP after heat exchanger replacement.

- Helium dewar return valve to coldbox was configured to be 0 % after coldbox shutdown. Cooldown valve for dewar instead opens which directly returns Helium gas to suction.
- The dewar heater was configured to be interlock off in case of coldbox shutdown.
- This piping configuration and controls upgrade prevents heat exchange between cold Helium and Nitrogen at values close to Nitrogen freezing temperature.

Conclusion

- Modification of system to use of heaters during heat exchanger downtime provided way to keep system operational to support critical project requirements.

- Piping configuration change and controls upgrade in Cryoplant has ensured that catastrophic incident of heat exchanger damage does not occur in future.

Acknowledgement

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

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