CRYOGENIC PLANTS FOR SRF LINACS

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Abstract

Helium cryogenic plants are a key utility for SRF linac applications. Due to their custom design and long delivery times, they are consistently on project critical path to meet SRF based project technical, schedule, cost and design safety goals requirements This paper outlines an overview of the most common considerations in their development.

INTRODUCTION

The SRF cryogenic plant consists of a modified 4.5K plant coupled with vacuum pumping to lower the operating temperature below 4.5K Common temperatures include 3.5K, 2K, and 1.8K. For plants less than 500W, this is commonly done with ambient temperature vacuum pumps For plants greater than 500W a combination of cold centrifugal and warm vacuum pumps or all cold centrifugal pumps when loads are greater than 2kW.

FUNCTIONAL DESCRIPTIONS

Warm Helium Gas Compressor System

A simplified modified schematic for the 4.5K cold box warm helium oil flooded screw compressors is presented in figure 1. The compressor system based on the Ganni Cycle is designed to maintain constant high efficiency with 20% to 100% 4.5K cold box load variation. The high pressure (HP) and medium (MP) stages compress the 4.5K cold box recycle flow (turbine bypass flow). The low pressure (LP) stages compress return flows cold compressor or other cryogenic loads, that must operate at 100 kPa, into the variable inter stage pressure between the HP and MP compressors.

All of the compressor stage is equipped with bypass valves controlled by its suction pressure. The valves, with the exception of the LP bypass, remain closed unless an extreme off design low suction pressure set point is encountered. The high pressure (HP) and medium pressure (MP) compressor stages are allowed to find their own natural operating pressures based on the charge pressure of the system and their natural tendency to automatically maintain a pressure ratio of 2.5 to 3.5.

For small variations in load during steady state operation, the compressor system charge pressure is self regulating due to the positive displacement compressor design. With increasing load return flow from the LP compressor stage, the charge pressure of the MP and HP stages increases, producing more refrigeration as the discharge pressure.

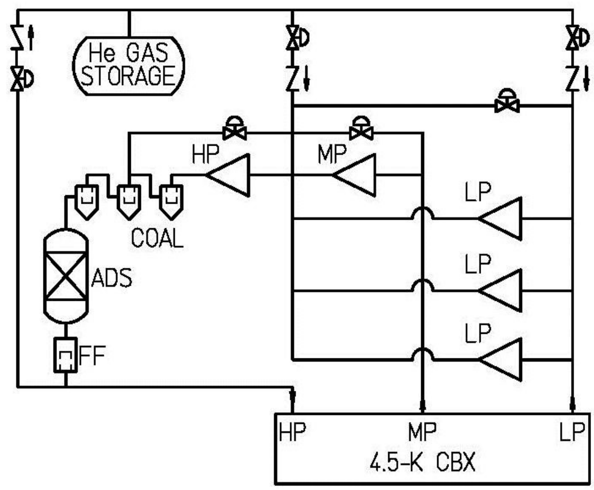

Figure 1: Simplified Warm Helium Compressor System

increases at constant pressure ratio. With decreasing load return flow, the charge pressure of the MP and HP stages decreases. Multiple low pressure compressors are provided to process the large cold compressor flow rate during pump down and normal operation of the linac.

There are also secondary positive effects for this design approach. Since the system provides a fairly constant compressor discharge volumetric flow with variable pressure, the compressor oil removal coalescers and charcoal absorber vessels have constant volumetric flow which maintains oil removal performance at the calculated design. In addition, the operation of the compressors with reduced pressures and increased efficiency has shown an increase of time before major compressor maintenance is required. This time has increased to 74,000 hours from an industry standard of every 35,000 hours.

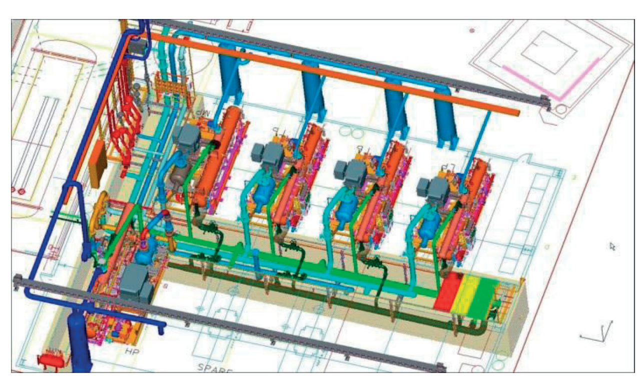

Figure 2: Typical Warm Helium Compressor Layout.

ISBN 978-3-95450-142-7

Large variations of load is monitored by the liquid level within a 4.5K dewar which sub cools the 4.5K supercritical gas leaving the 4.5K cold box with a liquid to gas heat exchanger within the dewar. Besides providing constant 4.5K sub cooled supply, the liquid level is used to control the warm helium compressor charge pressure over time. An increasing liquid level over time decreases the pressure set point for the gas make up into the warm helium compressor MP and HP stage inter stage. A decreasing liquid level results in decreasing the gas mass out valve pressure set point, reducing the charge pressure of the system. As the refrigerator is adjusting to new operating load conditions, the linac 4.5K sub cooled supply remains constant.

4.5K Cold Box Operation

As the linac is being evacuated there is an imbalance of the supply to return flows within the 4.5K cold box with more cold return flow than supply flow to the linac. This would normally turn off turbine operation on safety due to low turbine outlet temperatures. When a turbine is stopped it produces a warm temperature excursion pulse within the refrigerator. Should this warm temperature reach the cold compressors, it will tend to disrupt the pump down of the linac. To counter this, the 4.5K cold box must only produce a minimal amount of refrigeration while maintaining continuous turbine operation and continuity of system temperature control.

This is accomplished by reducing the warm helium compressor charge pressure as described above while maintaining turbine inlet valves fully open. As the system charge pressure is reduced, the 4.5K cold box turbine speeds will naturally decrease. To counter this effect it is important to have variable turbine brake control capability to maintain turbine efficiency at its specific design speed and to avoid critical speed ranges which may be lower than the nominal design speed. To date, months of JLab 12 GeV compressor system at 650 kPa has been demonstrated successfully while maintaining full 4.5K cold box turbine operation during plant turn down.

As the pump down continues, the refrigeration load on the 4.5K cold box refrigeration load increases and the refrigerator is required to adjust to the load increase using the warm helium charge pressure control system.

2K Cold Box Operation

A typical 5 stage 2K cold box is shown in figure 3. With total pressure ratio of ~41, the cold compressor train discharge temperature of ~30K is re-injected into the 110 kPa low pressure return flow of the 4.5K cold box. Five stages of cold compressor provides increased turn down flow capability by reducing the pressure ratio across each stage as compared to 4 stage train designs.

Each stage is equipped with a variable speed motor drive. During the linac pump down, each compressor speed is controlled as a percentage of the 5th stage speed per a prescribed pump down speed vs linac pressure table. After pump down is complete, the speed ratios of all the cold compressor stages is locked as a percentage of the 5th stage. The speed of the 5th stage is controlled the the common discharge flow meter control loop of the compressor train. The set point of the flow control loop is set by the measured linac operating pressure. Until linac RF power is applied, electric heaters within the cryomodules provide the load for the cold compressors. As RF is applied, an equivalent amount electric heat is removed instantaneously. Conversely, if RF is removed, an equivalent amount of electric heat is added. The amount of electric heat for each cryomodule is predetermined by measurement of the cryomodule cavity Q values.

During steady state beam operation, the cold compressor flow is reduced where only 1-2 watts electric heat per cryomodule is applied above the value of applied RF power for positive load control for the cold compressors. Linac pressure regulation has been demonstrated to be +/- 0.01 kPa with slow variance frequency. When beam is not being produced for extended periods of time, the cold compressor train can be bypassed, maintaining the linac at 4.5K. The use of individual 2k to 4K subcooler heat exchangers at each cryostat can decrease the amount of low temperature heat leak to save up to 7% of the refrigerator capacity.

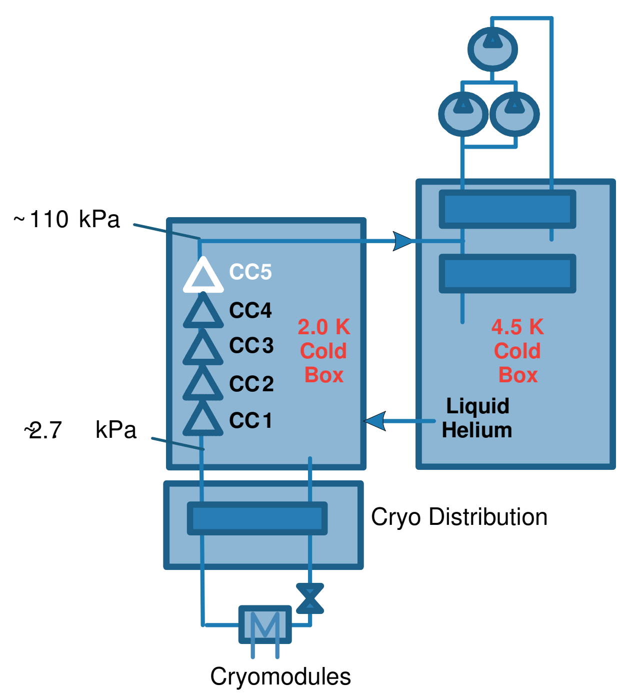

Figure 3: Typical 5 Stage 2K Cold.

Describing Plant Operation

For proper plant design it is important to describe the planned requirements for the system. Below is a representative list of some of the needed information for the design.

- Describe the cryogenic plant and overall accelerator availability goals. 99%+ is common for SRF cryogenic plants and 95% for the sum of all accelerator subsystems.
- Indicate if the SRF linac is designed for pulsed or continuous wave (CW) operation.
- Cryogenic loads for each load component should be calculated and summed for each refrigeration temperature level.
- Each load should include parameters of flow, temperature, and pressure range requirements coupled with maximum allowable working pressures, temperatures and pressure drops. Include cryogen liquid inventory amounts within the cryostats. The assistance of a cryogenic process engineer for this activity can optimize the refrigerator capacity for the loads.
- Once the loads are established, an allowance should be made for calculation error.
- Apply calculation allowances only to the load sums to avoid compounding margins.
- Describe all operational mode requirements inclusive of cool down, warm up, steady state, maintenance or testing modes.
- Describe all cryostat failure modes which may be encountered such as power outage, loss of beam line vacuum, loss of insulating vacuum, etc.

ACKNOWLEDGMENT

This work is funded under JSA/DOE Contract DE-AC05-06OR23177.

ISBN 978-3-95450-142-7