CRYOGENIC SYSTEM FOR THE ENERGY RECOVERY LINAC AND VERTICAL TEST FACILITY AT BNL*

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Abstract

A small cryogenic system and warm helium vacuum pumping system provides cooling to either the Energy Recovery Linac's (ERL) cryomodules, which consist of a 5-cell cavity and an SRF gun, or a large Vertical Test Dewar (VTD), at any given time. The cryogenic system consists of a model 1660S PSI piston plant, a 3800 liter storage dewar, a subcooler, a wet expander, a 50 g/s main helium compressor, and a 170 m^3 storage tank. A system description and operating plan of the cryogenic plant and cryomodules is given below.

INTRODUCTION

The cryogenic system for the ERL and the Vertical Test Dewar has a plant that can produce the equivalent of 300W at 4.5K with the addition of a wet expander 350 W at 4.5K. Along with this system, a sub-atmospheric, warm compression system provides pumping to produce 2K at the ERL cryomodules or the Vertical Test Dewar.

SYSTEM DESCRIPTION

The cryogenic system makes use of mainly existing equipments relocated from other facilities: a 300W 4.5K coldbox, a 50 g/s screw compressor, a 3800 liter liquid helium storage dewar, a 170 m^3 gas storage tank, and a 40,000 liter vertical low pressure liquid nitrogen storage dewar. An existing wet expander obtained from another facility has been added to increase the plant capacity. In order to deliver the required 3 to 4 bar helium to the cryomodules while using up stored liquid capacity at low pressure, a new subcooler was installed to function as the capacity transfer device. A distribution valve box functions as a distribution equipment to supply either the ERL cryomodules or the large Vertical Test Dewar.

Process Description

The liquid helium supply line, a liquid nitrogen supply line, and a cold vapor return line are contained in a 10-inch pipe diameter vacuum jacketed transfer line system. 4.5K liquid helium is supplied to the end loads for use, and the cold vapor can be then returned to the plant or to the warm sub-atmospheric compression system. A 2K to 4K recovery heat exchanger is also implemented for each cryomodule to recover refrigeration below 4K, thus maximizing 2K cooling capacity with the given sub-atmospheric pump. No 4K-300K refrigeration recovery of the returning sub-atmospheric cold vapor is implemented at this time, hence the 2K load appears as a liquefaction load on the cryogenic plant. The Vertical Test Dewar also has a 2K to 4K recovery heat exchanger. The liquid nitrogen distribution system supplies nitrogen to the ERL cryomodule, the Vertical Test Dewar and the cryoplant's 4.5 K cold box thermal shields cooling, plus the superconducting gun's cathode tip cooling.

Part of the plant's cold-end 12 bar 5K helium is throttled via a pressure regulating valve down to the supply pressure of 3 bar. This 3 bar helium is then sent through the subcooler, where it is cooled to 4.6 K. The cold helium is then supplied to the cryomodules. The 3 bar 4.9K flow is used for cooling the intercepts in each cryomodule, and for filling the cavity side 2K volume via a recovery heat exchanger where the 4.9K helium is cooled to below 3K in a counterflow heat exchanger with the returning 20Torr, 2K vapor.

EQUIPMENT

Sub-atmospheric Pumping System

A Roots blower backed by two liquid ring pumps is used to evacuate the liquid helium bath to produce the 2K cooling. The system provides a pumping capacity of 5.5 g/s with the bath held at 2 K. The Roots blower is a Tuthill MB5400, belt geared down to 1900 rpm from the 2400 rpm max using a 40 HP motor. The blower is backed by two Kinney KLRC-525 two-stage liquid ring pumps with 50 HP motors. A high to low by-pass valve controls the suction pressure at the pump from dropping below its setpoint. Coalescing element at the discharge of the each liquid ring pump prevents oil carryover to the discharge line. The vacuum pump discharge will go to the low pressure (suction side) of the main helium plant. The liquid ring pumps are matched to allow the Roots blower to operate at a maximum pressure ratio of 4. Cooling during compression in the Roots blower is done by oil injection at the inlet of the blower flange. UCON LB-170X oil is used for the oil injection cooling and liquid ring pumps. Because of air contamination from the vacuum pumps, a small compressor and purifier will be added in the future to process the vacuum pump flow.

4.5K Coldbox Plant

The Process Systems International 300 W @ 4.5K model 1660S built in 1993. It has 2 pairs of 76 mm (3 inch) diameter piston expanders configured as a Collins cycle with liquid nitrogen precooling. The first expansion stage operates at an inlet of 50K, and the second expansion stage at an inlet of ~19K in full liquefaction mode.

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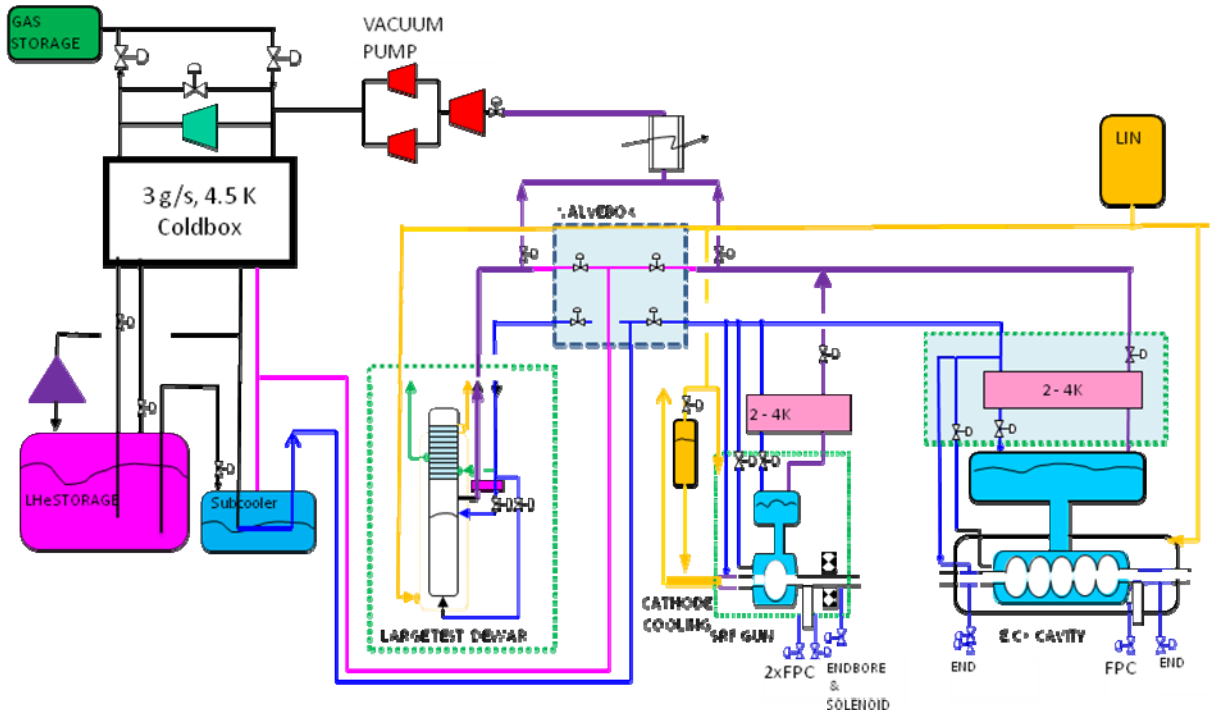

Figure 1: Process flow diagram of cryogenic system for Energy Recovery Linac and Vertical Test Facility.

Wet Expander

A 1985 Koch Process System wet expander consisting of a pair of 2 inch (50 mm) diameter piston has been added to the system, expecting to provide an additional 0.6 g/s liquefaction capacity to the plant.

Main Compressor

The main helium compressor is a 1975 Sullair C20LA4.8-400HP screw compressor complete with bulk oil separator. The oil demisting system consists of 2 parallel banks of 4 stage Balston coalescing vessels in series: DX, BX, BX, BX filters. Each vessel contains four of each filter type. An 18 inch diameter charcoal bed is used for oil vapor removal. Flow throughput of the compressor is 45 g/s @ 1.05 atm.

Liquid Helium Inventory

Liquid helium inventory will be stored in an existing 3800 liter liquid helium storage dewar manufactured in 1992 by Cryofab. The dewar has 3 liquid fill lines and one vapor line as interface.

Gas Storage Tank

An existing 170 m^3 horizontal warm gas storage tank rated to 18 bar is used for inventory storage when the system is warm.

Subcooler

Because helium at 3 to 4 bar is required for the intercept flows in the cryomodules, the plant's high pressure flow is used to supply the cryomodules instead of low pressure liquid from the storage dewar. The subcooler serves to cool the plant's helium supply to 4.5K and simultaneously serves to consume liquid helium inventory from the main low pressure 3800 liter storage dewar.

Distribution System and Valveboxes

A distribution valvebox near the cryoplant can supply either the Vertical Test Dewar or ERL cryomodules via independent multi-line jacketed transfer bundle. The jacketed transfer bundles contain the helium supply line, the liquid nitrogen supply line, and the cold vapor return line. The cold vapor can be returned either to the 20 Torr vacuum header or to the plant's 1.2 bar, 4.5K cold end return. Local valveboxes containing the 2K-4K recovery heat-exchanger and cryogenic valves provide distribution to the cryomodules.

CONNECTED LOADS

ERL Cryomodules

The ERL cryomodules consist of the eCX 5-Cell Cavity and a superconducting RF (SCRF) gun. In the eCX 5-Cell Cavity Cryostat System, the cavity is cooled to 2K by the cryogenic system. The cryostat has a liquid nitrogen-cooled heat shield. The system consists of the eCX cavity and a large 500 liter reservoir above the cavity. The eCX cavity is a 5-cell 704 MHz superconducting RF cavity with an expected dynamic load of 40W and a static load of 5 W at 2 K. The reservoir

was engineered to have a static load of 2W. Intercepts and heat stations: 3 bar, 5K helium is used to intercept heat along the fundamental power coupler outer conductor, the beam tube thermal transitions from the cryogenic end to the ambient temperature end, and the tuner push/pull joints on the cavity.

The Superconducting RF (SRF) gun consists of a half-cell RF cavity inside a titanium helium vessel with a cathode gun at one end of the cavity. A 140 liter helium reservoir is connected above the cavity helium bath via a 75 mm (3 inch) tube. The cavity is powered using two 500 kW Fundamental Power Couplers (FPCs), which require 3 bar, 5K cooling intercept flow. One separate helium stream intercepts, in a series arrangement, the heat leak on each end of the cavity flange interface to the beam tube and the high temperature superconducting solenoid. The gun's cathode tip is liquid nitrogen cooled. Liquid nitrogen is supplied from a nitrogen separator to provide high quality liquid to the cathode tip. The boil-off is returned back to a heater and vented.

Vertical Test Dewar

The cryogenic system also supports a large Vertical Test Dewar operation. The Vertical Test Dewar has a working volume of about 0.95 m diameter by 2.4 m height and is described elsewhere [1]. Liquid helium is supplied from the plant via the subcooler or directly from the liquid storage dewar. Cold vapor from the Vertical Test Dewar can be returned to the cold end of the plant's low pressure side. For 2K operation the cold vapor is returned via a 250 mm line to a natural draft air exchanger for warmup and return to the sub-atmospheric pumping system. A liquid nitrogen line supplies the shield and intercept of the test dewar.

Control System

The control system for the cryogenic system, cryomodules, and vertical test dewars consists of an RTP 2200 series PLC and I/O modules and is tied in with RHIC's main cryogenic supervisory controls system. HMI, Supervisory Control and Data acquisition is accomplished using Indusoft's SCADA product. Local HMI stations are located in the ERL main control room for operation along other ERL system controls.

OPERATIONS

When the cryomodules cryogenic requirements exceed the cryoplant's capacity, the cold loads cannot be operated continuously, rather operations at 2K has to be halted to allow the plant to reliquefy helium, stored in the warm gas storage tank during the run, back into the liquid helium storage dewar. With a 2K load of at least 75 W, the vacuum pump flow will be 4.3 g/s, and with a 0.8 g/s liquefaction load from the intercepts, the total liquefaction demand load is 5.1 g/s, which is more than the net 3.0 g/s liquefaction capacity of the plant. The additional 2.1 g/s capacity will come from the low pressure liquid helium storage dewar, using the subcooler as the transfer device. With 2000 liters the system can operate 24 hours before stopping. If the cavities operate at the full capacity of the vacuum pump, 5.5 g/s, then the total demand is 6.3 g/s. The run time will last only 16 hours. Reliquefaction of the equivalent of 2000 liquid liters from warm storage while keeping the cavities cold at 4.5K requires 50 hours.

SUMMARY

The cryogenic system for ERL and the Vertical Test Dewar makes use of existing equipment for putting a system together. It can supply either the ERL side or the Vertical Test Dewar side, but not both at the same time. Double valve isolation on the liquid helium supply line allows one side to be warmed to room temperature and worked on while the other side is being held at operating temperature. The cryogenic system maintains the end loads from 4.4K to 2K or colder depending on capacity.

Liquid helium storage dewar capacity allows ERL or the VTD to operate above the plant's capacity when required; and the ERL cryomodule ballast reservoirs and the VTD reservoir allows the end loads to operate on full vacuum pump capacity when required.

REFERENCES

[1] R. Than, A. Burrill, M. Grau, D. Lederle, C.J. Liaw, G. McIntyre, R. Porqueddu, T. Tallerico, J.Tuozzolo, I. Ben-Zvi, and D. Pate, "Cryogenic vertical test facility for the SRF cavities at BNL", these Proceedings.