TRIUMF Cyclotron Vacuum System Refurbishing

I Sekachev
TRIUMF, 4004 Wesbrook Mall, Vancouver, BC, V6T 2A3
E-mail: sekachev@triumf.ca

Abstract. The cyclotron at TRIUMF was commissioned to full energy in 1974. The volume of the cyclotron vacuum tank is about 100 m$^3$ and it operates at 5x10$^{-8}$ Torr pressure during beam production. The pumping is mainly based on a Phillips B-20 cryogenerator (Stirling cycle 4-cylinder engine). The cryogenerator supplies helium gas at 16 K and 70 K to cryopanels in the tank. The decreasing reliability of the B-20 and demanding maintenance requirements triggered the decision to completely overhaul or replace the cryogenerator. Replacement with the LINDE-1630 helium refrigerator was found to be the most attractive (technically and economically) option. The details of the proposal with installation of the helium refrigerator and with a continuous flow liquid nitrogen shield cooling system are presented.

1. Introduction
The cyclotron vacuum tank is 100 m$^3$ and it operates at 5x10$^{-8}$ Torr pressure during beam production. The cyclotron with its elevated lid is shown in figure 1. The vacuum is mainly attained by cryopumping with cryopanels cooled by a B-20 cryogenerator and six cryopumps. The tank is also equipped with two turbo pumps, three Roots blowers, and four roughing mechanical pumps [1].

The decreasing reliability of the B-20, which is already over 30 years old, triggered the decision for a complete overhaul or replacement of the cryogenerator. Very intensive maintenance was required to keep the cryogenerator operational. The standard interval between cryogenerator overhauls is 2,000 hours; the time between regenerations (defrosts) is about 600 hours. Due to occasional malfunctioning, the cryogenerator, at times, needs to be repaired after one to two weeks of operation.

The factory reconditioning of the B-20 or replacement with a new cryogenerator of the same type will not change overhaul and defrost schedules significantly. The helium refrigerator LINDE-1630 with RSX compressor was selected as the most attractive option, technically and economically. The required modifications to the nitrogen system for the installation of the new refrigerator were completed in September 2006. Preparation for the new cold box installation is underway. The refrigerator system has been tested at the manufacturer’s site. The commissioning of the refrigerator system at TRIUMF is scheduled for the “fall shutdown” in September 2007.

2. Cyclotron Cryopanels Cooling System before Modification
The cyclotron cryopumping system, as it was organized before the modification, is shown in figure 2. The system consists of two cryopanels, 11 m-long each, located inside the cyclotron vacuum tank; the B-20 cryogenerator with two helium gas circulators; transfer line delivering cryogens to and from the cyclotron, and a nitrogen heat exchanger.
The B-20 is an electrically driven, Stirling cycle 4-cylinder cryogenerator which cools helium gas to 16 K and 70 K. The circulators mounted on the B-20 supply helium gas through vacuum jacketed transfer line to the cryopanels in the tank forming two closed loop helium circulation systems for pumping and thermal shielding. The cryopanel is a form of cryopump, which does the majority of the water vapour, oxygen, and nitrogen pumping in the cyclotron tank. The compression heat of the cryogenerator is carried out by cooling water.

The circulators are driven by three-phase high frequency motors. The running speed is approximately 9500 rpm. The maximum working pressure is 25 kg/cm². The thermal loss on each circulator is about 78 Watts (Phillips manual, PGH 420), which should be subtracted from the total B20 cooling power, leaving only 42 useful Watts at 15 K.

The nitrogen heat exchanger (bath type) was added to the original 70K circulation system to minimize the load on the B-20. The helium flow returning from the cyclotron is cooled from 130 K to 95 K by using about 30 l/hr of liquid nitrogen.

**Figure 1.** The cyclotron with its lid elevated.

**Figure 2.** Cyclotron cryopumping system before modification.
3. Modified System

The new cyclotron cryopanel cooling configuration with LINDE-1630 helium refrigerator and nitrogen circulation system for the shields cooling is shown in figure 3. The helium refrigerator can be replaced with the B-20 in the case of malfunction or unscheduled maintenance. The B-20, in this case, will run as usual but with 70 K cooling capabilities not utilized.

The helium refrigerator LINDE-1630 with an RSX compressor in refrigeration mode has a cooling power of 86 Watts without and 151 Watts with nitrogen pre-cooling at helium flow rate of 22.2 g/sec and an electrical power consumption of 110 kWatts. The RSX compressor requires 57 l/min of 24°C water. A helium buffer tank is installed outside the building.

Three helium transfer lines were manufactured to connect the refrigerator (cold box) to the cryoline on the supply side, the cryoline to the 100 liter helium dewar on the return side, and the dewar back to the cold box. The dewar is equipped with a heater, a level probe, and a sensor in order to maintain a constant helium level.

The nitrogen lines connecting the existing 34 m³ nitrogen supply tank located outside the building to the cryoline and cold box, and the lines carrying the cold nitrogen exhaust gas to the vaporizer, have been manufactured. They are three vacuum jacketed 20m-long lines with a 12 mm inner diameter convoluted process line. There is one 20m-long non-jacketed line with a 25.4 mm inner diameter. The usage of liquid nitrogen is estimated to be about 55 l/h.

The first stage in the new helium refrigerator installation, the new nitrogen system configuration, was implemented during the fall shutdown in September 2006, and has been operational since. The system delivers liquid nitrogen from the supply tank outside the building to the shields of the cyclotron cryopanels through new vacuum jacketed transfer lines. The interface box is accommodating the connections of the nitrogen supply and return lines from the supply tank, and the helium lines between B-20 or 1630 and the cyclotron. The required nitrogen flow is controlled with a manual cold service valve installed on the supply side of the new interface vacuum box. The return flow is vented outside the building.

![Figure 3. The helium and nitrogen circulation schematic, including LINDE-1630 helium refrigerator (Cold Box), replaceable with B20.](image-url)
Nitrogen flow to the cryopanels is controlled by a new vacuum jacketed valve installed on the supply line just before it enters the existing cryoline. The system has established very stable cyclotron cryopanel shielding temperatures. The return flow is vented after the vaporizer outside the building and has been roughly measured at less than 60 l/hr. The system is equipped with 100 psig relief valves. The nitrogen flow monitor is installed downstream of the vaporizer to measure nitrogen usage. Also, a monitor output is used to control the nitrogen flow and to produce warning messages and interlocks. Temperature sensors are installed on the supply and return lines to the cyclotron as well as the cyclotron cryopanels. Thermocouples are installed on the outer surface of the vacuum jacketed sections and on major process line connections to diagnose a loss of vacuum or nitrogen leak respectively. There is a telephone line based system in place to provide information on pressure and level in the tank to the liquid nitrogen supplier. The signals are also used for warning messages and interlocks. Oxygen sensors are installed in a few locations inside the building for safety reasons.

3. Summary

The main goal of the cyclotron cryopanels pumping system refurbishment is an improvement in equipment reliability. The required modifications to the nitrogen system were completed in September 2006, and it has been operational since. There is no venting of nitrogen gas inside the building after the modifications. All equipment (buffer tank, compressor, room temperature piping, helium dewar, and helium transfer lines), but cold box, required for the operation of the new refrigerator system has been installed. The cold box was successfully tested at the factory before shipment to TRIUMF. The commissioning of the system is scheduled for the shutdown in September 2007.

References
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[3] Blakely RG, Moore RW, Harwood VJ 1969 TRIUMF Design Note TRI-69-9