

CRYOGENIC VACUUM PUMPING AT THE LBL 88-INCH CYCLOTRON

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Abstract

A cryogenic vacuum pumping panel has been in operation at the 88-inch cyclotron since 1974. The nude pumping panel is located in the acceleration chamber. The pumping surface consists of tubing cooled to 20°K by a closed loop helium refrigeration system. The pumping surfaces are shielded from radiation heat loads and water vapor by liquid nitrogen cooled baffles. The panel was designed for an average pumping speed of 14,000 liters/sec. for air. This approximately tripled the total effective pumping on the acceleration chamber from the existing diffusion pumped system, significantly reducing charge exchange losses of heavy ions during acceleration. Design, installation and performance characteristics will be described.

Introduction

The increased interest in heavy ion research at the LBL 88-Inch Cyclotron brought with it an associated demand for better vacuum in the acceleration chamber, to reduce the charge exchange loss during acceleration. The early light ion program of protons to α -particles normally used fully stripped ions with a negligible charge exchange cross-section for acceleration energies. Since the mean free path of the accelerating particles varies inversely with the pressure times the charge exchange cross-section, this became a serious problem in heavy ion acceleration.

Vacuum analysis showed the background to be air components and some water. The water usually was not significant after 72 hours of pumping from exposure to atmosphere. The known air leaks which remained were of the type which would require a complete dismantling of the accelerator to repair. Known throughput of these leaks was about $18 \mu\text{l}/\text{sec}$. With slightly less than 6000 l/sec. total pumping speed from LN₂ trapped diffusion pumps, the average pressure was 3×10^{-6} Torr. The usual problems of accessibility, space and conductance restricted the options for the type of pumping improvement to be used. It was decided to use a cryogenic pumping panel and a 20°K helium gas refrigeration system in which the support components could be located remote from the radioactive accelerator area, for monitoring and operational maintenance. A 150 watt, 20° K modified helium refrigeration system was purchased from Cryogenics Technology Inc.

Cryopanel

The cryopump was located in the upper corner of the acceleration tank near the beam exit port (Fig. 1) for several reasons. The primary considerations were the best conductance to the overall acceleration volume in an area which would be relatively free from r.f. currents and spurious beam deposits. This location also was chosen to minimize the effect of external beam line pressure bursts on accelerator operation.

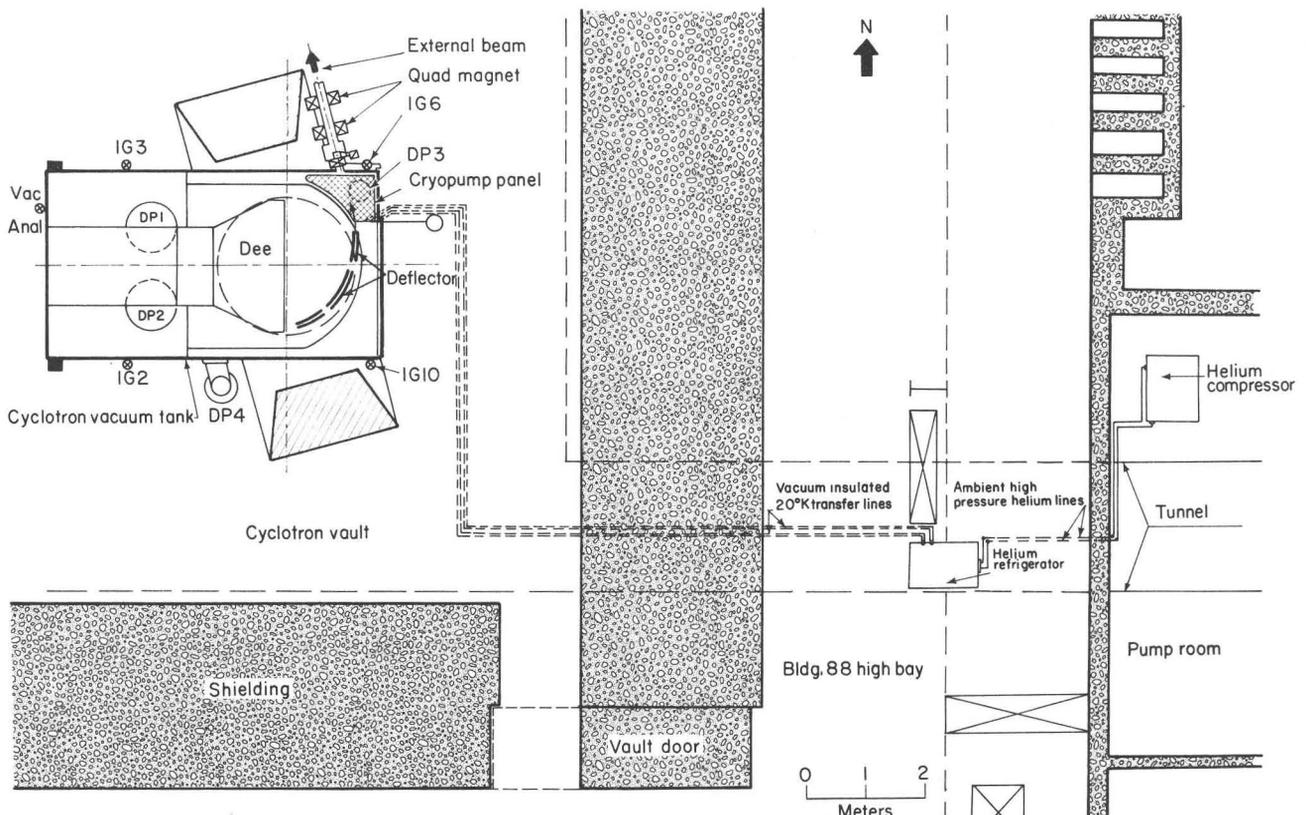


Fig. 1. Layout showing location of helium compressor, refrigerator, cryopanel and transfer lines.

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Figure 2 shows a cross section of the designed cryopanel. The 20°K surface was a .5" dia. copper tube shielded with 80°K LN₂ cooled radiation heat shields and supported and restrained with stainless steel wire. It was estimated that this cross-section would have a pumping speed of approximately 36 l/sec. per inch of length for a total pumping speed of 14,000 l/sec, for nitrogen. Other than chemical cleaning no special preparation was made on the copper surfaces of the 20°K or 80°K surfaces since it was felt that emissivities would change very quickly due to vapor condensates. The total heat load on the 20°K surfaces due to radiation, conductivity and cryopumping was estimated to be slightly over 5 watts.

Transfer Lines

The cryopanel was connected to the refrigeration expansion engine by vacuum jacketed superinsulated transfer lines. Supply and return lines were each approximately 60 running feet long. The lines were designed with removable sections near the cryopanel and expansion engine, with bayonet connectors to allow servicing of these units without breaking the vacuum jackets. The inner 20°K helium line was nominal 3/4" rigid copper line. The inner line was wrapped with 34 layers of double face aluminized Mylar. Alternate layers were embossed for layer separation to improve the insulation factor and promote vacuum pump out. The thermal conductivity value was estimated to be 1.3 μW/cm/°K. The outer vacuum casing was nominal 3" copper line with expansion joints in the straight sections of line where differential expansion exceeded .25 inches. The total heat loss was estimated to be 20 watts, the bulk of which was heat transfer losses at the bayonet connectors.

Refrigeration System

For serviceability and performance monitoring the refrigeration expansion engine was located outside the accelerator radiation shielding vault. (Fig. 1). The system controls and gages were located in this unit. The helium compressor was located in a room outside the normal work areas to minimize noise levels and to be near the required utilities.

Operation

A running log of temperatures and pressures was kept. Readings were taken at least every 8 hours. The log proved to be valuable in maintenance and troubleshooting.

In almost four years of operations, 18 thousand hours of cryogenic pump operation have been logged. The cryo system was turned on only when needed to conserve the 25 kW of power required. Typically, the cool down time to reach 27°K where N₂ pumping takes place has been 8 hours. The relative accelerator pressure drops were in accordance with the increased total pumping speed as estimated.

The nude placement of the cryopanel in the accelerator chamber gave the maximum pumping possible but also changed the operating philosophy in some respects. Since it could not be isolated, inadvertent pressure bursts had to be avoided. Where dynamic pumping swept all gas loads out of the system, cryogenic pumping collected past gas history only to be dumped at another time. If gas loads saturated the cryopanel pumping surfaces the condensates had to be "flushed off" to recover pumping action. This operation usually required heating the helium lines to 35°K to boil off N₂, Ar, O₂ condensates. The total time required to do this operation and recover pumping temperatures was about 30 minutes. Recurrent brief, small water leaks did not seriously reduce cryopumping, since the LN₂ cooled surfaces protected the 20°K surfaces.

Weekly maintenance usually involved cryosorption clean up of the helium gas in the refrigeration system. Vacuum insulating jacket pressures were usually checked, pumped out and isolated at ambient temperatures when required. Lubrication points were checked and lightly touched up only if required. Valve settings were usually checked when the system was running and in the 20°K range of temperatures.

Annual maintenance usually involved an overhaul of the expansion engines. The valve seats and seals were replaced and piston seals checked and replaced as required. Usually lubricants were found to have migrated beyond moving seals, so all parts were thoroughly cleaned and dried. After reassembly, a minimum of vacuum clean up was performed. The final clean up was always performed with warm positive helium pressure purging and cryosorption trapping.

Major breakdowns have not been numerous. Two leaf valve failures in the compressor high pressure stage were traced to faulty valve plate fabrication and corrected by CTi. A faulty weld in the expansion engine counter flow heat exchanger showed up after several thousand hours of operation. An expansion engine connecting rod bearing failure was spectacular and exciting but was not extensively damaging. A compressor high pressure gage rupture roused our fire department another time. One might class most of these failures as educational, in that they have lead to a better understanding of the equipment.

Future plans call for an expansion of cryo pumping and better temperature monitoring of pumping surfaces.

Beam Tests

Several test runs were carried out on beams accelerated in the cyclotron to measure the effect of the cryopump on charge exchange beam attenuation during acceleration. Two conditions were used: "cryopump on" with the helium lines at their normal pumping temperature of 22°K, and "cryopump off" with a heater on the

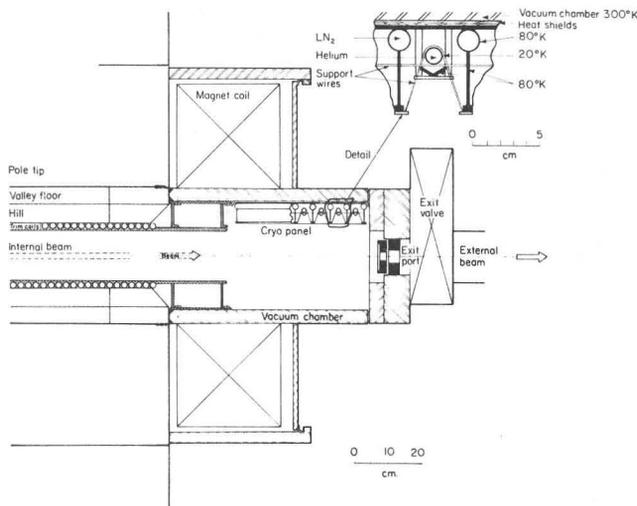


Fig. 2. Cross-section of beam acceleration chamber, showing cryopanel location and construction.

helium supply to the panel, which raised the panel temperature to 40-50°K where nitrogen and oxygen would not be pumped. The liquid nitrogen shields remained cold during these tests. A beam vs. radius curve was first taken with the cryopump on. Then another curve was taken with the cryopump off about 30 minutes later, when the pressure had stabilized after the pressure rises due to nitrogen and oxygen boil off from the panels.

Beam vs. radius data is shown in Fig. 3 for several oxygen beams. The transmission was normalized to 1.0 at 15 inches radius because spurious beams usually masked the true beam at smaller radii. The estimated pressures in the beam region¹ were about 2×10^{-6} Torr with the cryo on and $3-4 \times 10^{-6}$ Torr with the cryo off. The pressure ratios, cryo off to cryo on, were 1.7 to 1. The pumping speed on the dee tank is calculated to increase from 6000 l/s to 20,000 l/s due to the cryopanel, but pressure inside the dee changes by less than this ratio. The cryopanel is seen to increase the full energy intensity by over 30% for the O^{4+} beam and over 2.5 times for O^{2+} . It was found that the ion source is an excellent oxygen pump, pumping 80-95% of the incoming gas, which is fortunate since oxygen has one of the highest flow rates of any gas, 2.5 to >5 atm. $cm^3/min.$

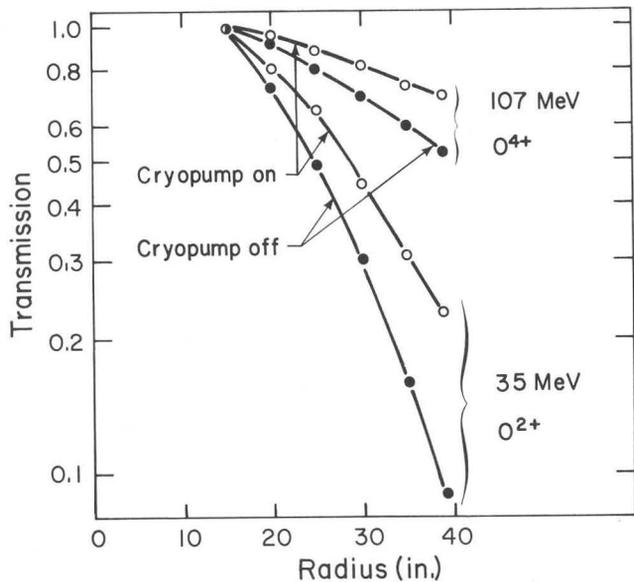
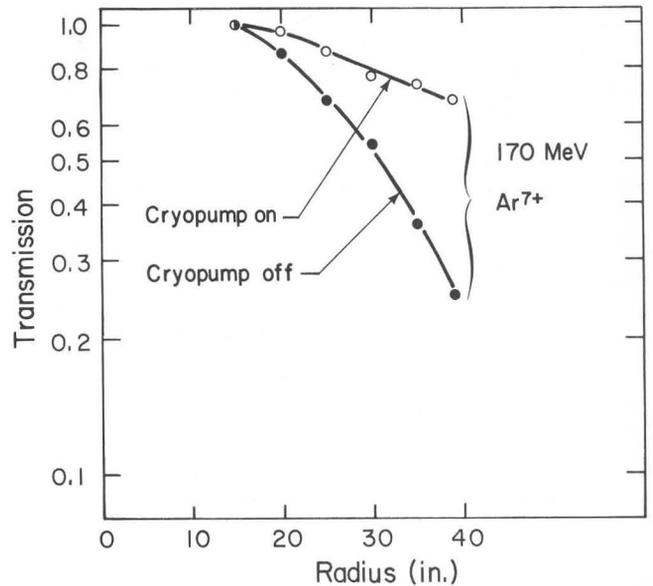


Fig. 3. Beam vs. radius for two oxygen beams, with cryopanel on and off.

In Fig. 4 are shown similar curves for an Ar^{7+} beam. The estimated pressures at the beam¹ are 1.8×10^{-6} Torr with the cryo on and 3.6×10^{-6} Torr with the cryo off, a ratio of 2 to 1. Gas flows in these cases were only .1 atm $cm^3/min.$ The cryopanel increases the full energy beam by over 2.7 times.

The cryopumping system has thus been shown to reduce the pressure in the acceleration chamber by about a factor of 2 and to substantially increase the beam currents of most heavy ion beams.



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Fig. 4. Beam vs. radius for Ar^{7+} with cryopanel on and off.

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