CRYOPUMPING TESTS FOR THE INDIANA UNIVERSITY 200 MeV CYCLOTRON BEAM LINE*

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ABSTRACT

Tests to examine cryopumping the 10 cm. beam line have been completed using 180 liter/sec., 18°K refrigerators (cryopumps) without thermal radiation shielding. Full pumping speed (18°K) is reached in less than 20 minutes after pump start. Without supplementary pumping for the non-condensable gases, pressures in the low 10^{-6} Torr range were very easily achieved close to the pump. Vibration imparted to beam line from the pump is minimal. The cost is comparable to other methods of beam line pumping.

INTRODUCTION

Preliminary cryopumping tests on the section of beam line between the ion source and injector stage of the Indiana University Cyclotron have been described.[1] Further tests have now been made using a nominal 20°K refrigerator (cryopump) having a drive improved so that mechanical vibration is minimal.

BEAM LINE DESCRIPTION

The same section of beam line was used as for previous tests but now having more elements to impede pumping. Fig. 1 shows the situation schematically and gives the location of pumps and gauges. TC_1 is a thermal gauge. IG_1, IG_2, and IG_3 are Bayard-Alpert ionization gauges located at the cryopump, bending magnet, and diffusion pump respectively.

CRYOPUMP DESCRIPTION

The refrigerator cold head provides 1 watt of cooling at approximately 18°K on the second stage. Cryopumping speed is proportional to the surface area exposed to the free molecular flow of condensable gases. The governing equation is:

$$\text{Speed} = (11.6\ \text{liter/sec. cm}^2)\left(\frac{28.7}{M}\right)^{\frac{1}{2}} (A\ \text{cm}^2)\ C \qquad (1)$$

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Where M = Gas Molecular Weight and C = Sticking Coefficient; 0.62 for 300°K N_2 on 20°K Surface.[2]

The allowable surface area for continuous cryopumping is limited by the amount of radiation absorbed by the molecules condensed on the cold surface. Water, in particular, with its 0.9 absorptance peak absorbs the incident radiation very rapidly.[3] For 1 watt of refrigeration, the surface area limitation is

$$\frac{1}{(0.045)0.9} = 25 \text{ cm}^2 \text{ approximately.}$$

(0.045 watts/cm^2 is the radiant heat load between a "black" 300°K or much larger "grey" enclosure and a surface below 100°K.) Limiting speed is thus (11.6) (25) (0.62) = 180 liter/sec. watt. Higher speeds require a low temperature shield. Typically, this would be a water pumping surface cooled by the refrigerator first stage or LN_2.

TEST PROCEDURE

At all times, the beam line pressure was reduced by means of a mechanical pump to approximately 6×10^{-2} Torr before either starting the cryopump or opening the valve which exposed the operating cryopump to the beam line.

With one exception, all tests were made at the basic cryopump speed of 180 liter/sec. One 400 liter/sec. configuration (added surface area) was tried and predictably overloaded with radiation.

TEST 1

Table 1 gives pressures at various locations and the time taken to reach these pressures.

At the start, (time 0 min. in Table 1) the line pressure (air) was 6×10^{-2} Torr, the diffusion pump valve closed, the cryopump valve was open and the cryopump started.

At 55 minutes, the vacuum was fairly stable with the pressure falling at a very slow rate and this test was terminated. The valves of the operating cryopump and diffusion pump were closed and the beam line filled with argon to a pressure of 760 Torr.

In the earlier tests, the pressures along a 3 meter section were 2.6×10^{-6} and 1×10^{-6} Torr after running overnight. This pressure is commensurate with a reported 60% survival of Xe ions transported 70m.[4] The current higher pressure gradient is due to shorter pumping time and lower beam line conductance.

TESTS 2 AND 3

Tests 2 and 3, identical to each other were a repeat of Test 1 with two differences. Prior to tests 2 and 3, argon was used instead of air to break the vacuum, reducing water contamination of the beam line wall and lowering the background non-condensable hydrogen, helium and neon present in air.

At the start of these tests, the refrigerator was cold, isolated by a valve. The diffusion pump valve was closed throughout the entire test.

Five minutes after opening the operating cryopump valve, the pressure at G_2 was 3 X 10^{-6} Torr and 9 X 10^{-5} Torr at G_3. Both tests were terminated after 22 minutes with the pressure slowly decreasing.

Table I Test 1 Results

Time (Min.)	Cryopump G_2(Torr)	Bend. Mag. G_3(Torr)	Diff. Pump G_4(Torr)	Remarks
0	-	-	-	Cryopump Started
17	7 X 10^{-5}	2 X 10^{-4}	-	Cryopump in 20°K Region
25	4 X 10^{-6}	8 X 10^{-5}	-	
40	8 X 10^{-7}	6 X 10^{-5}	-	Situation Stable
45	8 X 10^{-7}	6 X 10^{-5}	-	Diff. Pump valve opened to check for H_2 load.
45.6	1.5 X 10^{-6}	2.5 X 10^{-5}*	-	Diff. pump valve open
55	3.5 X 10^{-6}	1.8 X 10^{-5}	3 X 10^{-6}	Diff. pump valve open

*The very quick drop in pressure at G_3 indicates the removal of H_2. The small increase in pressure at G_2 is difficult to explain. The tendency of this gauge to drift is the most likely explanation.

TEST 4

In this test, the argon was removed from the line using only the 15.2 cm diffusion pump. The cryopump valve was kept closed. After 17 min., the line pressure read at G_3 was 5 X 10^{-5} Torr and then continued to fall at a very slow rate.

This test was made as an afterthought and only to give some rough comparison, bearing in mind the difference in location and speed between the diffusion pump and cryopump.

TEST 5

With no beam line pumps in operation, the amplitude of the background vibration was measured using a dial indicator. Measurements in both vertical and horizontal directions never exceeded 0.0005 mm. This was at the center of the largest unsupported span (3 m.). When repeated with the cryopump operating, they never exceeded 0.0007 mm.

200 MEV BEAM LINE PUMPING SYSTEM

There will be approximately 150 m of 200 MeV beam line leading from the cyclotron final stage through a beam corridor to the experimental areas. Initially, approximately 75 m will be installed, with an estimated 16 pumps required.

One helium compressor, identical to those used for the cyclotron final stage vacuum system can supply through common piping, at least twenty beam line cryopumps. This redundancy due to the additional compressor would be very advantageous and also leave sufficient reserve for further cryopumped systems, e.g., the 150 cm scattering chamber presently in the design stage.

Since 20°K pumping by itself will not remove the helium, hydrogen, and neon present, suitable pumping means will have to be added for these gases. By rule of thumb, about 2% of the total speed (60 liter/sec) is needed. Modification to the cryopumping surface will allow such moderate pumping speed for hydrogen and neon.

PUMP INSTALLATION

Installation is very easy; each cryopump is a completely self-contained unit, flange mounted into a tee in the beam line. Two lines supply and return the ambient temperature helium; line voltage operates the drive motor.

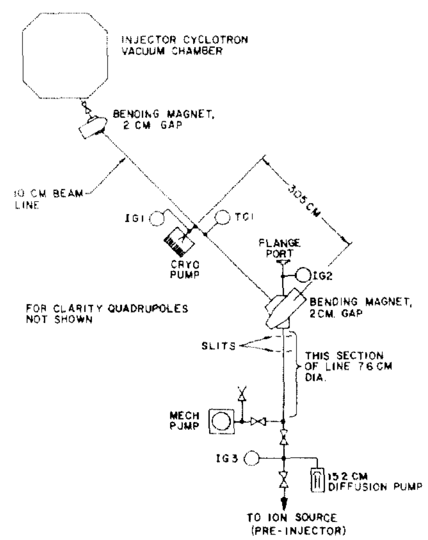

Fig. 1. Diagram of Beam Line used for tests.

It is not necessary to have a valve between every cryopump and the beam line. The preliminary tests showed that a few continuously operating pumps have the capability to reduce the line pressure to an acceptable figure in a few minutes.[1] Simultaneous with opening the valves of the operating pumps, the non-operating ones could be started, taking approximately 17 min. to reach 20°K.

The pumps have inherent fail safe features making control and interlocking a very simple matter. Mechanical pumps are needed for very short periods only - to reduce the line pressure to the 60 micron range.

COST

For a given air speed, a cryopumping system of this magnitude is similar in cost to one using ion pumps. By judicious use of 80^oK shrouds at certain locations, the speed for water vapor will be considerably higher.

A diffusion pump system would be about 25% cheaper initially but LN_2 consumption and added complexity makes these less attractive. Other systems have been considered and rejected.

CONCLUSION

Cryopumping the beam line is attractive. The decision to go this way will depend mainly on experience gained in operating the cyclotron vacuum system.

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