Title
VACUUM CRYOPUMPING A HEAVY ION SOURCE IN A HIGH VOHEAGE TERMINAL

Permalink
https://escholarship.org/uc/item/10r1157f

Author
Wolgast, Richard C.

Publication Date
1971-02-01

Presented at the Particle
Accelerator Conf., Chicago,
IL., March 1-3, 1971

UCRL-20620
Preprint c.2

VACUUM CRYOPUMPING A HEAVY ION SOURCE IN A HIGH VOLTAGE TERMINAL

4-7

Richard C. Wolgast

February 1971

AEC Contract No. W-7405-eng-48

UCRL-20620

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

28

c.2

VACUUM CRYOPUMPING A HEAVY ION SOURCE IN A HIGH VOLTAGE TERMINAL*

Richard C. Wolgast

Lawrence Radiation Laboratory
University of California
Berkeley, California

Summary

Two coldfingers differentially cryopump the heavy ion source of the SuperHilac 3-MV injector. One coldfinger near the source freezes most of the source gas load and provides adequate clean vacuum for source operation. The second coldfinger near the beam entrance into the high voltage column produces high vacuum to reduce ion beam loss through charge exchange and accidental electrical discharges. The 20° K temperature is produced by a small refrigerator in the terminal, and is transmitted to the coldfingers by hydrogen-charged heat pipes. The effective system pumping speed for air at the source measures 180 ℓ/s. While running beams of argon ions, pressures are 8×10^{-5} mm Hg at the source and 5×10^{-6} at the column entrance. The integral of pressure with distance along the terminal beam path is 1.8×10^{-3} mm Hg-cm.

Introduction

The SuperHilac ion source, charge state analyzing magnet, and the associated beam transport elements are located in the 3-MV terminal whose overall size is 4 ft diam x 6 ft long, which contains the electrical generators, electronic power supplies, and telemetry equipment as well. The terminal operates in an ambient atmosphere of 250 psi of 80% N_2, 20% CO_2.

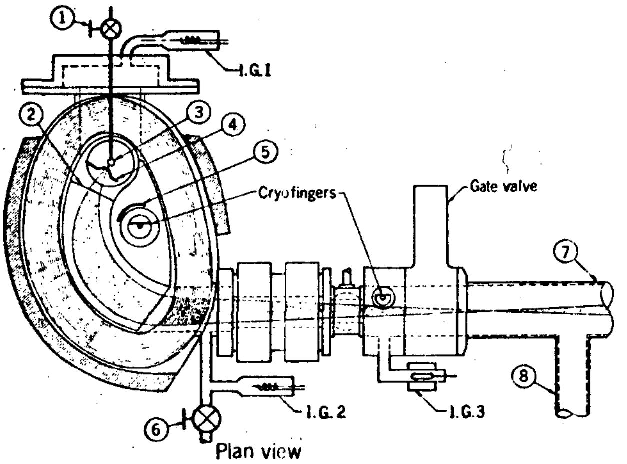
The heavy ion source uses gas flows of about 0.3 cm^3/min. It operates in a 3-kG magnetic field with an extractor potential difference of 25 kV. A minimum requirement of the vacuum system is that it provide low enough pressures to prevent glow discharges. In our source under clean conditions this limit is above 5×10^{-4} mm Hg. Another requirement is that ion beam loss through charge exchange with ambient gas molecules be minimized. This loss increases with the atomic number of the ion (Ref. 1). This means we want the best vacuum we can get, subject to the practical limits of space, electrical power, and budget.

A surface at 20° K will hold all gases at less than 10^{-10} mm Hg vapor pressure except hydrogen, helium, and neon. There is no substantial steady load of these gases in the system, so they can be left to pass down the accelerating column to pumps at ground potential. The conductance of the column is about 33 ℓ/s for air (for hydrogen, 125 ℓ/s; helium, 88; neon, 39). If these light gases are needed as a source of ions they will be run in the low voltage (750 kV) injector with its own pumping system. The next most volatile gas is nitrogen, with a vapor pressure of 10^{-7} at 25.2° K, closely followed by several other gases, which sets an upper limit on the coldfinger operating temperature.

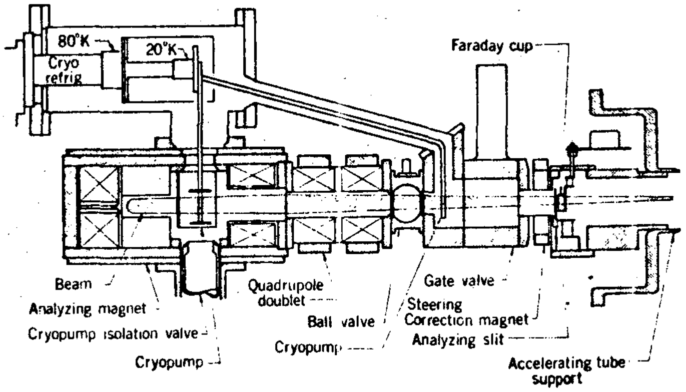
This paper describes what has been accomplished with a cryopump based on a 3.3-W, 20° K refrigerator. Feasibility tests of various cryopump configurations using this refrigerator were conducted by N. Milleron. Other features of the 3-MV injector are described in Ref. 1.

Description

Figure 1 shows a layout of the ion source and beam transport system in the terminal. The ion source vacuum chamber in the magnet is all welded construction using the magnet poles as part of the envelope and .25-in. stainless steel plate. Welded rectangular ducts pass through cutouts in the magnet coil to provide for insertion of the ion source and the beam exit.



Plan view



Section

The plan view shows the system as set up for vacuum tests and beam focussing measurements. 1: leak valve; 2: step in the magnet pole from 2.9-in. gap on the ion source side to 1.42-in. gap; 3: ion source anode; 4: ion source extractor (0.8 in. high); 5: radiant heat shield; 6: roughing valve; 7: tube-to-beam measuring slits; 8: outlet to 2-in. diffusion pump. Ion gages I.G. 1 and 2 are model VG-1A. I.G. 3 is a Penning type model GPH-001. The elevation view in section shows additional components to be installed for operation in the injector.

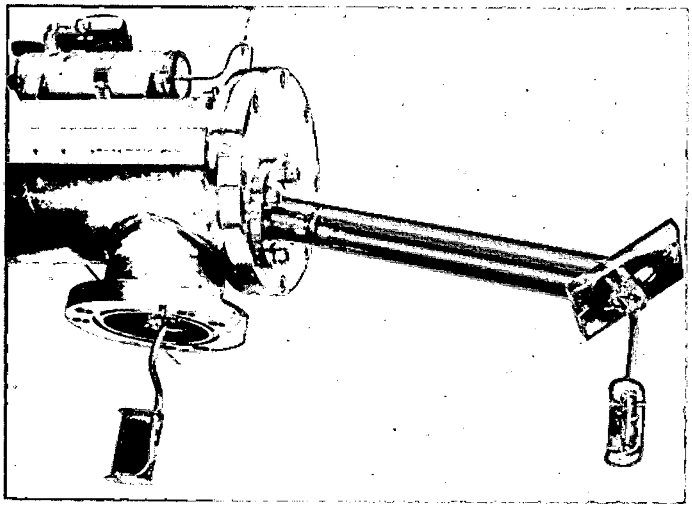
Figure 1

A 2-in. diffusion pump was mounted temporarily onto the system to stand-in for the pumping capacity to become available through the accelerating column. It is partially baffled by a 2-in. opaque water-cooled elbow. To our regret we did not provide the DP with fail-safe valves and interlocks. Elastomer seals are used throughout the system.

The first coldfinger is inserted into the deep crescent-shaped space between the magnet poles and coil. The finger was formed by the .25-in.-diam copper-tube heat pipe to which two 1.5-in.-diam copper discs are soldered. The discs are mounted above and below the magnet gap to avoid intercepting stray beam and thermal radiation from the ion source. The tantalum anode of the ion sources operates at a bright orange temperature and radiates about 500 W. A liquid-Freon-cooled radiation shield intercepts the direct radiation from the source. The walls of the crescent-shaped space are lined with cooled copper to intercept as much as possible of the diffuse radiation without impeding the molecular gas flow. Both shields are chemically blackened. The coolant temperature is about 10° C.

The second coldfinger was just the .25-inch-diam heat pipe. Our initial operation showed there was some excess refrigeration capacity so the coldfinger areas were increased. A vertical copper sheet was added between the discs of the first, and a 1.0 x 3.25-in. sheet to the second. The total exposed areas now are 15.6 in.^2 and 7.3 in.^2.

Each gravity flow "heat pipe" is supplied with hydrogen through a fine tube from a separate 15-in.^3 reservoir at room temperature. The hydrogen liquefies at the cold head of the refrigerator and runs down the coldfinger, hastening the cooldown and maintaining a low temperature drop under the heat load. The reservoir is initially charged to 100 psi to provide enough hydrogen to make about 1 in. of liquid in the .25-in. tube. Each reservoir is fitted with a bourdon gage to serve as a vapor bulb thermometer after some liquid has formed, at pressures below 60 psia in our case. The reservoirs are also fitted with pressure transducers so the pressures can be monitored during injector operation. Figure 2 shows the two coldfingers and one of the hydrogen reservoirs mounted on the cold head vacuum jacket.



Coldfingers attached to the refrigerator cold head in its vacuum jacket.

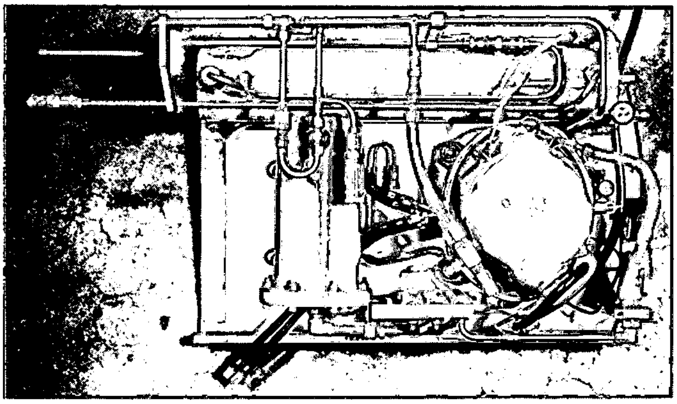
Figure 2

Five layers of aluminized Mylar are wrapped over the 20° K cold head and the heat pipes to the point where they enter the vacuum chamber. A copper shield from the 80° K cold head shields the 20° K head. Five more layers of aluminized Mylar are wrapped over the copper shield.

The cryopump isolation valve and the ball valve allow us to isolate the cryopump so it can be kept in operation while the source chamber is let up to atmosphere (which may in the future be the 250-psi insulating gas atmosphere) for changing the ion source. The gate valve allows us to keep the accelerating column under vacuum while the cryopump is thermally cycled to remove the accumulated gas load.

The cryogenic refrigerator, the Cryodyne Model 350 (Cryo. Tech. Inc.), uses helium as the working fluid and has two stages at 80°K and 20°K. According to the production check, with a 5-W load on the first stage, the second stage capacity is 4 W at 21.8°K, 2 W at 16.7°K, and 0.0 W at 13.6°K. The production check is run with the cold head bare.

The compressor assembly was adapted from air to liquid cooling by putting liquid-cooled straps around the compressor and putting liquid-gas heat exchangers in the discharge line. A plan view of the assembly, ready to install in the terminal, is shown in Fig. 3. The short tank is the oil separator and the long tank is the oil vapor charcoal absorber trap. Space occupied by the assembly is 13 x 19 x 27 in.^3. Space occupied by the refrigerator expander and cold head in its vacuum jacket is 9 in. diam x 22 in. long. The refrigerator system uses 1800 W of 60-Hz power.



Plan view of the modified compressor assembly.

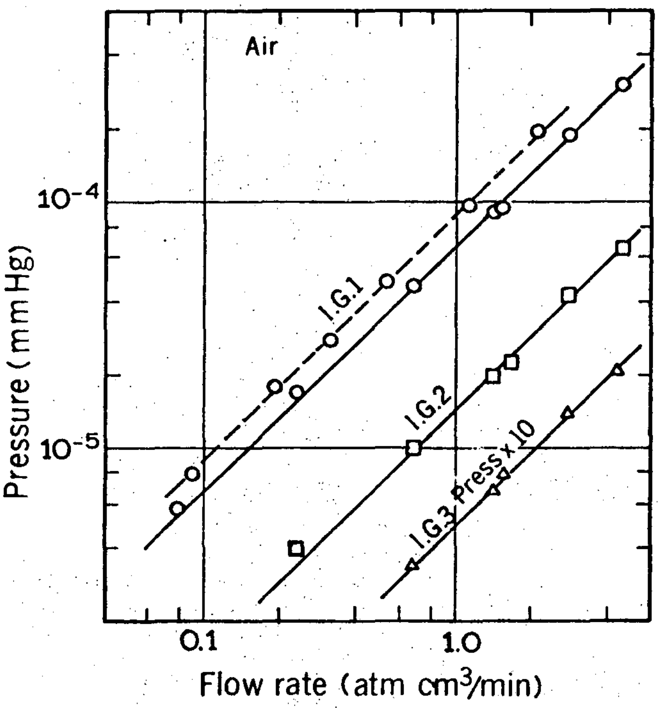
Figure 3

The operational system in the injector will provide for remote reading of the coldfinger pressures, compressor suction and discharge pressures, an ion gage, and a thermocouple vacuum gage. Remote control of the valves will be provided subject to interlocks from the gages. Plans call for the changing of ion sources through a pressure lock so the tank insulating gas need not be dumped. This would shorten the source change time from about 1 1/2 hr to 20 min.

Performance

Pumping Speed Measurements

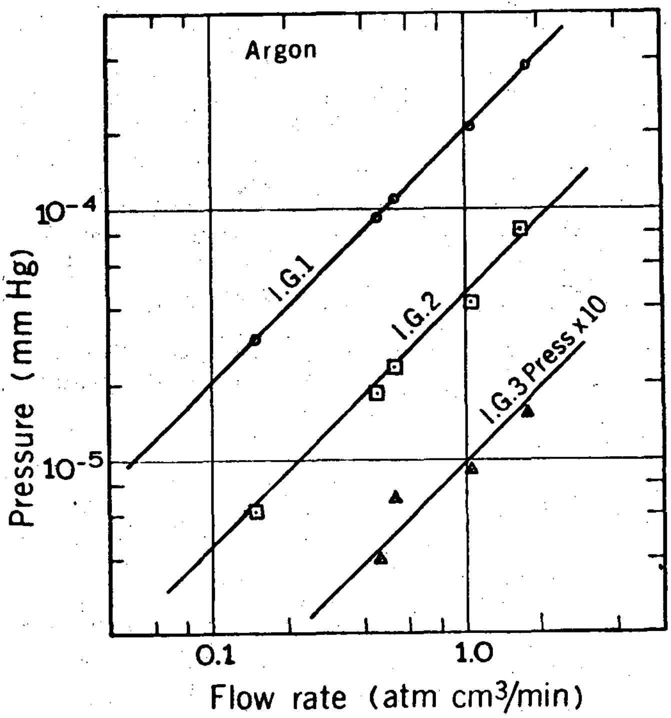
During the air speed measurements the diffusion pump was throttled to a measured speed of less than 3 ℓ/s. Gas was admitted to the system through the operational ion source by using the ion source valve to control the flow. In making the measurement for air, a burette-and-stop-watch flow measurement was used in series with a Hastings thermocouple flowmeter. The two flowmetering methods agreed within 5%. Pressures at the three ion gages were recorded. The base pressures with no flow were subtracted and the pressure rise due to the flow was plotted in Fig. 4. Using the values from Ion Gage 1, the effective system speed for air at the source was found to be 186 ℓ/s. The speed before the coldfinger areas were increased was 140 ℓ/s.



Air pumping speed data: pressure rise due to flow vs flow rate.

Figure 4

Pumping speed for argon was measured in the same way, except only the Hastings flowmeter was used. The data is plotted in Fig. 5 before applying the sensitivity factors for argon relative to air for the flowmeter and the ion gages. (Meter reading) x (1.43) = flow of argon. (Ion gage reading) x .617 = pressure of argon (Ref. 2). Applying these factors, we find the effective system speed for argon to be 143 ℓ/s. This value may be used to predict the speed for air if it is multiplied by the ratio of the average molecular speeds of air relative to argon (i.e., 1.18) and possible small effects of differences of sticking coefficients are neglected. Doing this, we predict an air speed of 169 ℓ/s, slightly less than our measured speed of 186 ℓ/s. This difference (if real) cannot be due to differences in sticking coefficient because published data show argon to have a higher sticking coefficient than nitrogen.

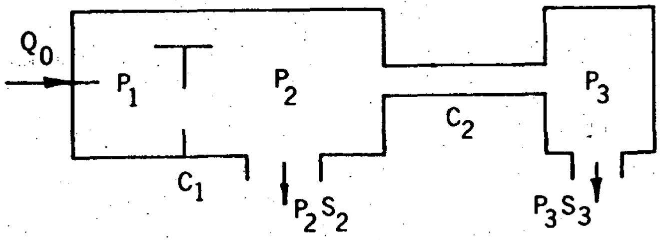


Argon pumping speed data: pressure rise due to flow vs flow rate (ion gage and flowmeter readings not corrected for sensitivity factors for argon).

Figure 5

A Calculation of the System Pressures

In spite of the intractable geometry, we can try a rough calculation of the pressures by using a lumped conductance model of the system as shown in Fig. 6.



Lumped conductance model used for pressure calculation.

Figure 6

Q_o is the air flow admitted at the source: 0.5 atm cm^3/min = 6.3×10^{-3} mm Hg ℓ/s.

C_1 is the parallel conductance of the duct formed by the magnet gap, 1.4 in. x 3.2 x 2.8 long, and the aperture around the radiant heat shield 4.75 in.^{2}. C_1 = 520 ℓ/s.

C_2 is the conductance of the quadrupole bore tube and ball valve port, 1.75-in. diam x 10 long. C_2 = 36 ℓ/s.

S_2 is the local pumping speed of the first coldfinger with a total area of 15.6 in.^{2}. Because this area is not in full view of much of the chamber and because it is strongly concave, we take only half the area to be the effective pumping area. S_2 = 580 l/s.

The second coldfinger has a total area of 7.3 in.^{2}. We take .75 of this area as effective, to allow for some inaccessibility of the wall side of the finger. S_3 = 410 l/s.

The flow equations are:

$$Q_o = C_1 (P_1 - P_2),$$
$$Q_o = P_2 S_2 + P_3 S_3,$$
$$P_3 S_3 = C_2 (P_2 - P_3).$$

Calculated values of the pressure, in units of 10^{-6} mm Hg, are:

$$P_1 = 22.2, \quad P_2 - 10.3, \quad P_3 = .8.$$

Measured values from Fig. 4 are:

$$P_1 = 34, \quad P_2 = 7.3, \quad P_3 = .25.$$

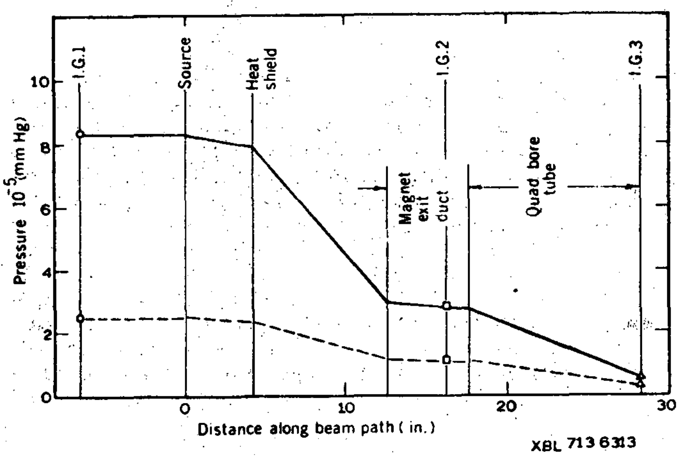
Having gone this far it may be worth trying a calculation with the Monte Carlo molecular-flow computer program available at LRL (Ref. 3).

Vacuum Performance with Operating Ion Source

A momentary high gas flow is required to start the ion source arc, which causes no operational difficulties. After the arc is started it heats the tantalum anode to a bright orange, and the cathodes become still hotter. At this time large quantities of hydrogen are evolved, raising the vacuum pressure sometimes in excess of 10^{-3} mm Hg. This gas load quickly begins to fall until after a half hour or so this gas amounts to 10 or 20% of the gas flow being supplied to the source. Since the gas is largely hydrogen it increases the pressures along the entire injector beam path and could cause a noticeable loss of beam operating time for heavy high-charge-state ions. We may want to pre-bake new source parts.

Another gas load appears when the extractor voltage is applied, sending ion beam through the system. Only one ion charge state is focussed cleanly through the system. All other charge states produced by the arc bombard the walls with 20-kV ions. This load also decreases with operating time but toward some steady value not zero. Much of this gas load is cryopumped. During our limited operation so far this gas seems to increase system pressures by about 3 x 10^{-6} mm Hg.

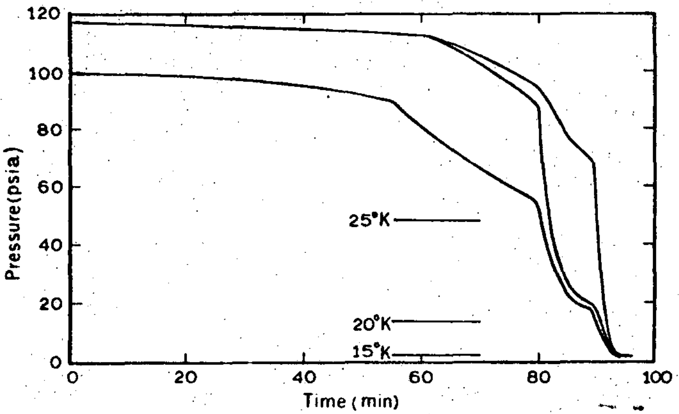
Of major interest to the heavy ion beam is the amount of gas it must pass through. To make our best estimate of this quantity we made the plot shown in Fig. 7, where the estimated pressure distribution along the beam line is drawn, based on the three ion gage readings and the geometry. The solid line represents source operation with a large slit in the source anode (.05 x .47 in.); the dashed line represents operation with a one-third smaller slit (.05 x .16 in.). Both sets of readings were made after several hours of operation. The integrals of pressure with distance from the curves as drawn are 2.8 x 10^{-3} and 1 x 10^{-3} mm Hg-cm for the two slit sizes. Correcting these values for the gage sensitivity for argon they become 1.75 x 10^{-3} and .6 x 10^{-3} mm Hg-cm.



Pressure along the beam line during with Ar^{3+} beam. Dashed line: small ion source slit.

Figure 7

During day-to-day operation without thermal cycling of the cryopump to remove accumulated gas, we have observed each day an increase in the coldfinger temperature. The temperature rise is caused by the increase in radiant heat absorptance caused by the thickening frost deposit. Experience so far doesn't tell us how often we need to purge the cryopump except that it will not be more frequent than every four operating shifts. A typical cool-down history is plotted in Fig. 8. The lowest curve is the pressure of the vapor bulb thermometer mounted on the cold head flange. The middle curve is the shorter coldfinger pressure and the highest curve is the longer coldfinger pressure.



Cool-down history of the coldfingers. Lowest curve is the vapor bulb thermometer pressure.

Figure 8

It should be possible to purge the cryopump with only a partial warm-up. Xenon, for instance, has a vapor pressure of 1 mm Hg at 104°K. We have made one partial warm-up with a turnaround time of 1 hr, but have not yet tried for shorter purges. The cold head is equipped with 20-W and 10-W heaters on the first and second stages respectively, to speed the process.

Acknowledgments for excellent work are due to Y. Maruyama, T. Lauritzen, and E. Chuck for design and to K. Ransdell for assembly and testing.

References

1. D. A. Spence et al. A 3-MV Injector for the SuperHilac, Paper at the 1971 Particle Accelerator Conference (also UCRL-20452, LRL, Berkeley, Cal.)

2. Consolidated Vacuum Corp. Ionization Gage Tube-Type VG-1A, Bulletin No. 9-55.

3. L. Levenson, N. Milleron, and D. Davis, Optimization of Molecular Flow Conductance, 1960 Seventh Nat. Symposium on Vacuum Technology Transactions (Pergamon Press, 1961).

*Work supported by the U. S. Atomic Energy Commission.

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720