ION PUMP OPERATION ON A 5.5 MEV AND 12 MEV VAN DE GRAAFF ACCELERATOR

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Summary

An improved vacuum system, using combined Ion and Cryo-pumping techniques has been successfully used on Van de Graaff accelerator beam tubes. The pumping through-put of the Ion pumps has proved more than adequate in handling tube discharges. Base pressures are in the mid 10^{-7} torr range, while operating pressures have been improved by factors of 2-9 over Hg. diffusion pumped systems. System maintenance has been virtually eliminated. This paper describes Ion pump starting techniques, roughing systems and characteristic operation of Ion pumping and combined Ion and Cryo-pumping on a C.N. and E.N. accelerator.

Introduction

A program to change the vacuum pumping system from Hg. diffusion pumps, that were supplied with the accelerator, to Ion pumps on the Tandem Accelerator was undertaken during installation of the machine. There were several reasons for doing this:

1. Improve operating pressures
2. Eliminate maintenance
3. Avoid damage to accelerator from vacuum or power failures
4. Eliminate refrigeration units
5. Eliminate Hg. as a health hazard.

C. N. Accelerator Vacuum System

Description

Initially, a 400 ℓ/sec. (800 ℓ/sec. for Hydrogen) Varian Ion pump was installed in parallel with the Hg. diffusion pump, on the C.N. or 5.5 MeV section of the accelerator. The vacuum valve between the Hg. pump and system was left closed. Fig. 1 shows the arrangement of the accelerator vacuum system.

Portable Rough Pump

The vacuum roughing system is a portable unit that can be attached to various sections of the accelerator vacuum plumbing. It utilizes a VPR-150 positive displacement Rootes type blower manufactured by the Hereaus-Englehard Co., rated at 73 cfm, and backed by a 15 cfm mechanical pump (Fig. 2). Both the input line and foreline are trapped by liquid nitrogen cold fingers. This unit is capable of pulling down a vacuum in the beam tube of 5×10^{-5} torr.

Ion Pump Starting

Starting the Ion pump requires a rough pressure that ranges from 8×10^{-4} to 8×10^{-5} torr depending on the past history of the gases pumped. These pressures are readily attainable with the rough pump within 15 minutes, if the beam tube has been let up to dry nitrogen.

Our experience on the C.N., in which the gas load is Hydrogen from the Terminal Ion source, has been a worsening in the time required to start the pump. On starting the pump the pumping elements heat up regurgitating previously pumped hydrogen gas from the cathode surfaces.[1] In actuality, the pump becomes a source of gas.

In practice, the pump is left on for about 1/2 hour with the roughing pump on the system. During this time the Ion pump is periodically fluctuating from glow discharge to a pumping condition. The temperature of the pump body rises to $\approx 80^\circ$C, power is then turned off. As the pump outgasses the pressure drops and after 20 to 30 minutes the pressure is around 8×10^{-5} torr. The Ion pump is then started and the roughing pump valved off from the system. Immediately the pressure drops and within 15 minutes the vacuum reaches 5×10^{-6} torr, at which time the accelerator may be started. Base pressure in the C.N. tube is 2.5×10^{-6} torr and operating pressures with the Ion source on are 4.5×10^{-6} torr.

Accelerator Tube Discharge

There was concern in the ability of the Ion pump to handle the dynamic gas load due to accelerator tube sparks that are characteristic with Van de Graaff accelerators.

During 2 years of C.N. operation tube sparks have been negligible. Very rarely has the pressure gone above 2×10^{-5} torr, which is well within the operating limits of the tubes. It is interesting to note here that the C.N. tubes sparked less frequently than the E.N. (Tandem) accelerator tubes, which were pumped by Hg. diffusion pumps.

Recovery of the vacuum, after a tube spark, took longer for the Hg. pumps than for the Ion pump, all things being equal.

Pump Lifetime

After one year's operation on the accelerator the Ion pump was removed from the system. The interior of the pump body was cleaned and the pumping elements replaced.

An examination of the pump elements revealed that there was, at least, another 4 or 5 years' life left in them.

E.N. Vacuum System

Low Energy Beam Tube

Successful operation of the Ion pump on the C.N. beam tube encouraged us to replace the Hg. diffusion pump at the low energy base of the accelerator with a 400 ℓ/sec. Ion pump and cryo-pump (Fig.3). The liquid N_2 cryo-pump was added to the system to clean up the residual Hg. vapors in the low energy beam tube.

After several weeks of operation the cryo-pump was cleaned and Hg. was found collected on the walls. Traces of Hg. were always present until the high energy vacuum system Hg. pump was finally replaced with an Ion pump.

Pump Starting

In starting the Ion pump the beam tube was first roughed down to 20 microns before liquid N_2 was added to the cryo-pump. At a pressure of 8×10^{-4} torr the Ion pump was turned on and the pressure dropped to 2×10^{-5} torr. The roughing pump was valved off the system and within 3 minutes the pressure was in the mid 10^{-6} torr region. After overnight pumping the pressure was 5×10^{-7} torr as measured by the pump current. This was a factor of 3 improvement over Ion pumping alone, and better than an order of magnitude less than the base pressure attainable with the Hg. pumping system.

During subsequent pumpdowns where the system had been let up to a dry nitrogen atmosphere the pump has never failed to start at 8×10^{-4} torr, reaching a pressure in the low 10^{-6} torr range within minutes. Final base pressure was 4×10^{-7} torr.

Operational Gas Pressures

The gas load in the E.N. beam tubes is from the stripper canal located in the high voltage terminal of the accelerator where the conversion of negative to positive ions takes place. Oxygen gas is leaked into the stripper canal at a rate of up to .0053 atm cc/sec.[2] The gas flow into the low energy beam tube is conductance limited by the geometry of the vacuum plumbing in the terminal. Therefore, most of the gas flows into the high energy beam tube.

Under normal operating conditions the pressure measured at the low energy 'Tee' section is as high as 1×10^{-6} torr depending on the amount of gas leaked into the stripper canal. Operating pressures with the Hg. pump was in the $5\text{-}12 \times 10^{-6}$ torr region.

At the high energy 'Tee' base pressure varied between $6\text{-}8 \times 10^{-6}$ torr. For optimum beam currents the stripper gas flow was adjusted to read as high as 3.4×10^{-5} torr, measured at the Tee, for a proton or deuteron beam. The He^{3++} beam required pressures as high as feasible without shorting the beam tube. Typical values were 3.8×10^{-5} torr for terminal voltages above 5 M.V. and as high as 4.5×10^{-5} torr at lower energies.

High Energy Vacuum System

Vacuum measurements made on the low energy vacuum system were used to determine the Ion pumping requirements for the high energy vacuum system.

A 400 ℓ/sec. Ion pump has an effective pumping speed for oxygen of only 70% of that for air, or 280 ℓ/sec. For optimum beam currents the stripper canal gas flow was adjusted for a $Q \approx 5.3 \times 10^{-3}$ atm cc/sec. Gas flow into the low energy beam tube was determined by the following relationship.

$$Q_1 = \Delta P \times S$$

$$Q_1 = (8-4) \times 10^{-7} \text{ torr} \times 280 \text{ } \ell/\text{sec.}$$

$$Q_1 = .112 \text{ } \mu \text{ } \ell/\text{sec.} = .15 \times 10^{-3} \text{ atm cc/sec.}$$

where ΔP is the change in pressure from the gas flow and S is the speed of the pump for oxygen.

From this we find the gas flow Q_2 into the high energy tube to be 5.2×10^{-3} atm cc/sec. Assuming a 1000 ℓ/sec. Ion pump (700 ℓ/sec. for oxygen) for the high energy vacuum system the change in pressure due to gas flow will then be:

$$\Delta P = \frac{Q_2}{S} = \frac{5.2 \times 10^{-3} \text{ atm cc/sec.}}{700 \ell/\text{sec.} \times 1.32 \frac{10^{-3} \text{atm cc/sec.}}{10^{-3} \text{torr } \ell/\text{sec.}}}$$

$$\Delta P \approx 5.5 \times 10^{-6} \text{ torr}$$

If a base pressure of $\approx 6 \times 10^{-7}$ torr is anticipated at the high energy 'Tee' then operational pressures should be $(6 + 55) \times 10^{-7}$ torr $= 6.1 \times 10^{-6}$ torr. These assumptions proved to be in good agreement with actual conditions (Fig.6).

On the basis of the above calculations a 1000 ℓ/sec. Ion pump vacuum system was installed on the high energy beam tube (Fig.4). A cryo-pump pump of the same size as the low energy one was also added. The cryo-pump has a speed of 850 ℓ/sec. for condensable gases and vapors.

Vacuum System Assembly

At the time the high energy vacuum system was being converted a complete new set of beam tubes was installed in the accelerator. An improved beam injector transmission system was also installed.

An attempt was made to usė Viton 'O' rings in the vacuum flanges. Flange spacers were machined to give added compression on the 'O' rings. Initial pump downs were unsuccessful with leaks appearing two and three times in joints that had been carefully assembled. The use of Viton 'O' rings was finally abandoned for the conventional type.

After the system was found tight the base pressure measured at the 'Tee' was 6.5×10^{-7} torr. With the 25 ft. flight tube valved off after the 'Tee', base pressure was 4×10^{-7} torr. The Ion pump current gave a pressure reading at 1.8×10^{-7} torr.

Operational Characteristics

Evaluation of the beam injector transmission system and new Mark II beam tubes afforded us the opportunity to run a series of performance measurements on the new vacuum system.

The most significant test was a series of measurements where maximum analyzed beam versus accelerating tube pressure at different energies was made. All runs were taken with 30 μa of protons injected into the accelerator.

The stripper gas in the terminal was adjusted to optimize the analyzed beam. At lower terminal voltages the beam peaked at a particular gas pressure (Fig.5). As the terminal voltage was increased the stripper gas target thickness had to be increased for optimum beam as would be expected, since the stripping cross section of the gas target decreases with increasing particle energy. Over the energy range covered the variation in stripping cross section σ_{-1+1} was found to be $\propto 1/E$ where E is the energy of the ions.

At the higher gas pressures the accelerator stability suffered. Tube sparking and voltage collapse would occur with tube pressures of 1×10^{-5} torr at medium voltages, and 9×10^{-6} torr at the higher voltages. From this it was deduced that, although vacuum pressures along the lower part of the beam tube had been improved by a factor of 4-9 over the measured energy ranges, the pressure in the tube near the terminal was still high due to the conductance limitations of the tube itself. Therefore, the gas stripper target thickness is limited by the tube pressure-voltage breakdown characteristic. Under these circumstances, maximum beam can never be attained at higher energies.

Accelerator Performance

With the original Mark I tubes we had never experienced running out of target thickness in the stripper canal. When it became clear what was occurring with the Mark II tubes we conferred with High Voltage Engineering Corp.[3] on the matter. They readily confirmed that the terminal high-energy tube conductance had been reduced by approximately 30%.

This loss of beam at higher energies is not serious with a proton or deuteron beam since there is more than adequate beam current at reduced stripper gas pressures (Fig.6). It does become a matter of concern when accelerating a He^3 beam. At terminal voltages above 4 M.V. the analyzed beam is still increasing when the voltage across the tube collapses as the pressure rises.

There is no immediate solution to this problem at the present time unless one installs terminal pumping. This would entail a major modification in the terminal and is not looked upon favorably. One alternative is to install the older Mark I tubes which are capable of operating at higher vacuum pressures.

The greatest singular improvement, due to the reduced vacuum in the low energy beam tube, has been a marked increase in the He^{3-} beam injected into the accelerator. The analyzed beam of He^{3++} had been improved by almost a factor of two. Other vacuum modifications along with the new beam injector transmission system has increased the analyzed He^{3++} beam to .140 μa. With a detailed program, we hope to have upped this to .250 μa by the end of the year. This will be a subject for another paper.

E.N. Tube Discharges

In the time the Ion pumps have been in use on the E.N. accelerator tubes they have never been overcome by gas bursts due to tube discharges. Occasional tube sparks in the high energy beam tube have caused the pressure to rise, at times, into the 10^{-4} region. Recovery of the vacuum would be in the order of several seconds. This pressure recovery time constant has been observed to be due to the conductance limitation of the tube itself and not the throughput of the pump at these working pressures.

Conclusions

Ion pumping on a C.N. or single ended Van de Graaff, where the predominant gas load is hydrogen, has been proven effective. Pressures are as good, if not better, than a Hg. diffusion pumped system. Maintenancewise, they are trouble free and are not a source of contamination to the beam tube if the system vacuum should go up to air.

Starting the pump can be troublesome due to hydrogen re-evolution from the pump elements. This trouble could be largely eliminated if a cryo-pump or titanium sublimation pump[4] were added to the system to aid pump downs. Care has to be exercised so as not to run the pump for prolonged periods in the mid 10^{-5} torr region where pump heating takes place, finally stalling the pump.

On the Tandem Accelerator, starting the Ion pumps offers no problems. This is primarily due to the stable compound that chemisorbed oxygen makes with sputtered titanium in the pump. The pump is capable of starting at 8×10^{-4} torr. Cryopumping greatly enhances the pump down time and the ultimate base pressure.

Improved operating pressures in the low energy tube has greatly enhanced the He^{3-} beam. This is not too critical with the H^- and D^- beams since the source yield is more than adequate.

Overall performance of the Ion pumps on the Tandem is far superior to Hg. pumps. There is no lost time in warming up the traps. Pump maintenance is practically eliminated and the system is virtually foolproof. The pumps are immune to tube discharges and recover rapidly.

Acknowledgement

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References:

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2) T.Von Zweck,H.V.E.C. Private Com.
3) C.Goldie,H.V.E.C. Private Com.
4) Manufactured by Ultek Corp. & Varian Associates.

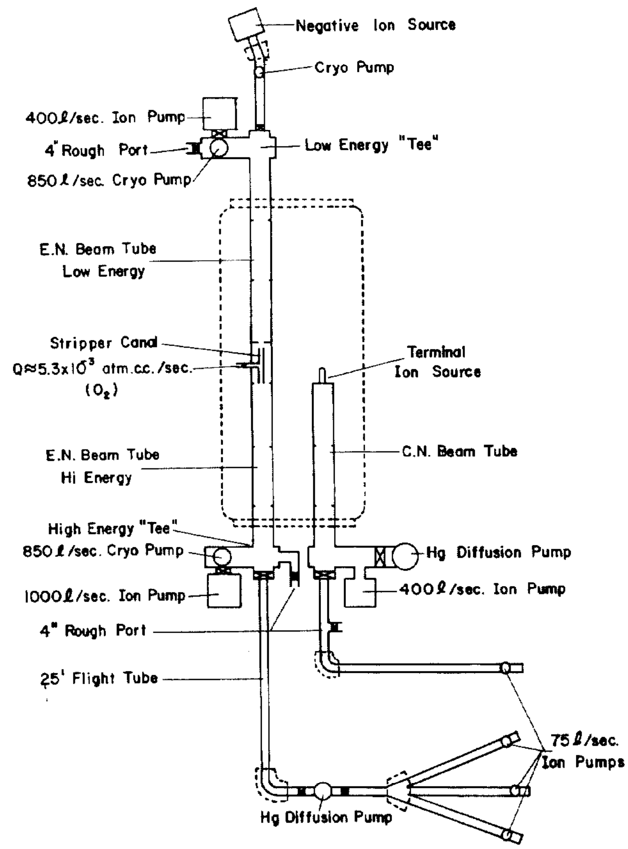

Fig. 1. A schematic diagram of the Tandem Accelerator showing the block diagram of the vacuum system. The C.N. portion of the accelerator was later removed.

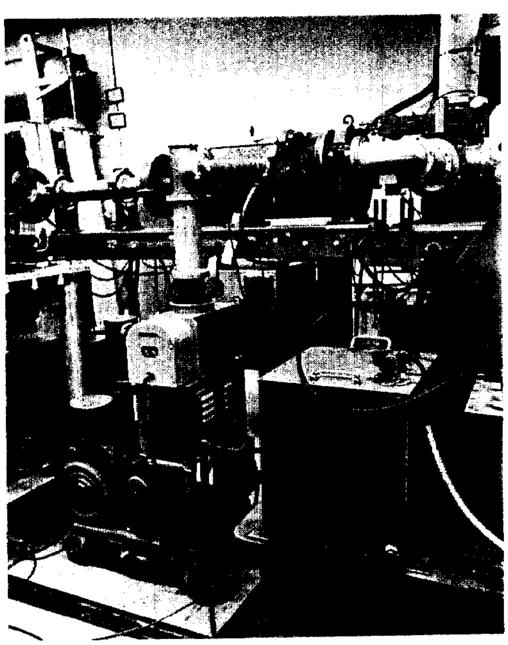

Fig. 2. Portable vacuum rough pumping system. Rated at 73 c.f.m., it is capable of reaching a pressure of 5×10^{-5} torr.

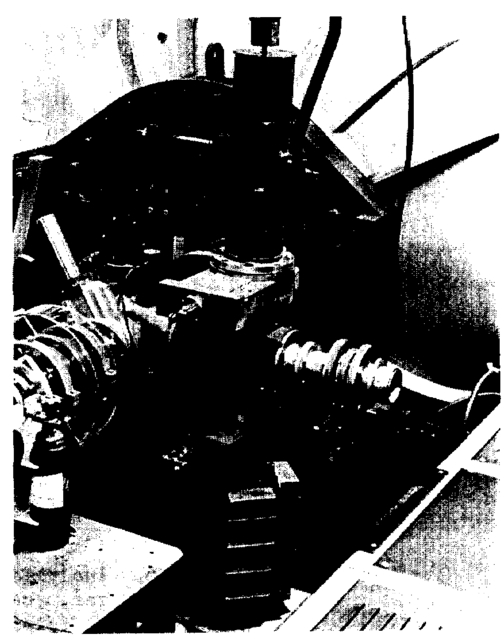

Fig. 3. The low energy vacuum system showing the 400 ℓ/sec. Ion pump, cryo-pump and roughing port.

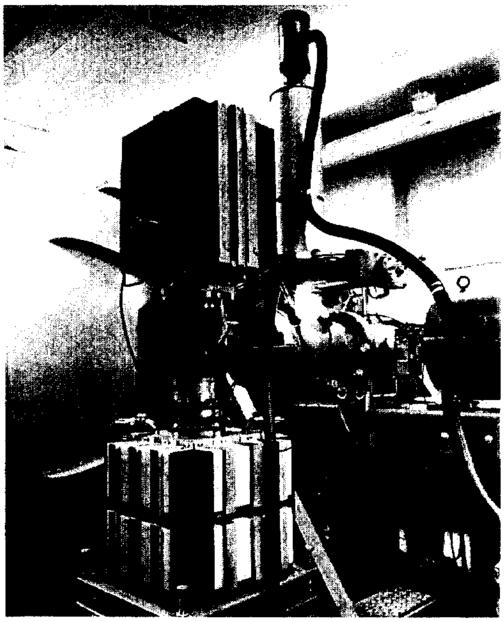

Fig. 4. The high energy vacuum system showing 400 ℓ/sec. and 600 ℓ/sec. Ion pumps in parallel.

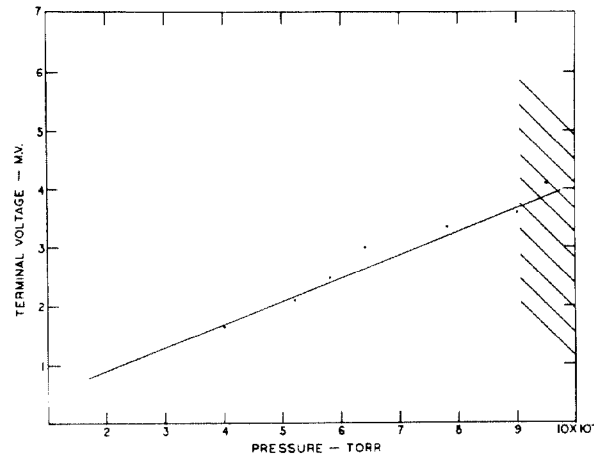

Fig. 5. The curve represents the maximum beam line at different terminal voltages with the corresponding stripper gas pressure in the beam tube. Voltage instability and eventual tube collapse is indicated by the hatched area.

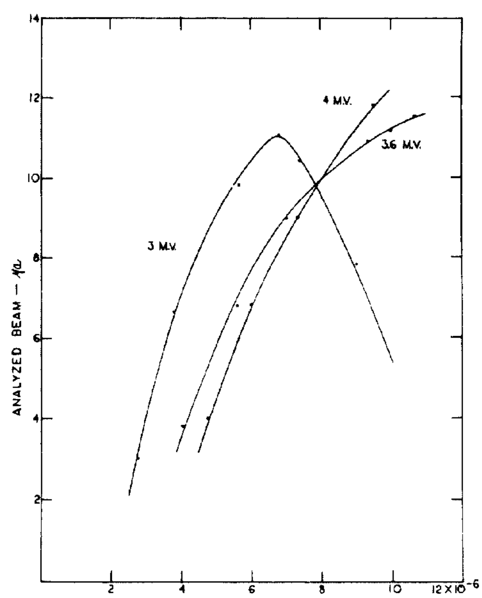

Fig. 6. Analyzed proton beam as a function of stripper gas pressure in the high energy beam tube for different terminal voltages. The injected beam was 30 μa for all runs. The broken curves are incomplete because of high tube pressures.