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SUMMARY

The Omnitron[1] (Fig. 1) is a synchrotron (120 ft. diam) accelerator with a concentric storage ring (130 ft. diam) that will deliver beams of light and/or heavy ions at different energies and currents. Storage of heavy ions in a high-charge state for 25 msec requires that the vacuum[2] be specified more carefully than is common in everyday speech. (Reference to "air" and "pressure" serve well enough, if not taken too literally.) Thus in place of a pressure specification, a conservatively crude figure of merit, $10^{14} \leq N\Sigma n_i Z_i^2$ is used where: $N = 3\times10^7$ turns around the accelerator, n_i = the concentration of atoms of the i^{th} atomic number Z_i. Cryopumping is done by cold fingers inserted in each gap between magnets on both the synchrotron and storage rings (190 pumping stations total - see Fig. 1). Each finger, consisting of an 80°K jacket around a 4°K core, is cooled at one end by metallic attachment to nitrogen and helium distribution rings. Pump-down tests of one full size pumping station (Figs 2 & 3) comprising an alumina beam tube brazed to stainless steel are reported using "heat pipes" (thermal siphons)[3] and metallic heat conductors in the cold finger design. Superior pumping performance is achieved, i.e., pump down requires 7 hrs to the Omnitron figure of merit. A garden variety oil sealed mechanical pump[2] and an oil (convoil 20) diffusion pump[2] provided with fail safe LN trap-valves[2] are used.

INTRODUCTION

The following design requirements on the Omnitron[1] vacuum system have been chosen:

(i) At least 90% of injected beam, such as U^{+12}, Xe^{+10}, etc., goes through acceleration, storage, and extraction without interacting with the residual gas. (Charge exchange is the interaction of primary importance.)

(ii) Pump-down time after exposure to air is 12 hours or less.

(iii) Loss of operating time traceable to vacuum-system function, malfunction or foreseeable accident (i.e., rupture of beam exit windows, power failure, etc.) is negligible.

(iv) The initial cost of the vacuum system will be ~ 1/20 of the machine cost, and the operating cost, both direct and indirect, will be ~ a few percent of running costs.

PUMPING SYSTEM

Referring to Fig. 1, the main elements of the pumping system are shown. Cold fingers are brought up between each magnet and wherever else required. The principal reason for using heat pipes and metallic conductors stems from the number of high-integrity vacuum-tight joints that would be required if cryogenic fluids were circulated between each magnet gap. A fluid circulating system would have hundreds of joints and bends that could not be pre-tested easily before installation. A much simpler, more reliable and cheaper design avoids the bugaboo of vacuum tight joints that must be fabricated in place. The first element of the system is the cryogenic pumping loop shown as the heavy dark line between the synchrotron and storage rings. This loop is a temperature distribution system consisting of a 3°K or less, 1" diam liquid helium line shielded by an 80°K, 1" diam liquid nitrogen-carrying line. These two fluids systems are each about 400 feet long, have no kinks, bends or changes in elevation, can be welded in place by automatic equipment, can be precisely and easily leak checked, and are both fed from liquid reservoir systems located outside the radiation shielding. Each cold finger is attached to this temperature distribution system by metallic non-vacuum joints. Each cold finger extends radially outward or inward a distance of about 5 feet. The length of the finger, its cross sectional area and the heat load applied thus establishes the temperature drop between the cryogenic pumping loop and the pumping end of the finger. Two diameters of the highest purity copper available were tried for the 3°K system. The heat conductivity was so high that the temperature drop in 1/16" diam copper was comparable to the temperature drop in 3/8" diam copper. Tests of these copper rods for lengths up to 87" gave temperature drops of a few hundredths of a degree Kelvin. These temperature drops were determined by hydrogen adsorption.

Metallic copper works fine for the low temperature part of the cold finger but was heavy and gave sluggish performance for the 80°K shield. Fig. 4 illustrates this point. At 80°K the highest purity copper has essentially the same thermal-conductivity as ordinary grades. While this was acceptable and in certain respects commendable, a so called heat pipe was tested. By definition a heat pipe utilizes capillary phenomenon in a wick to move liquid against gravity. High rates of heat transfer are achieved by utilizing the heat of vaporization of an appropriate liquid. In our case, oxygen, due to its higher density, higher surface tension, higher heat of vaporization and acceptable boiling point gave better results than nitrogen. However, we could not make a true heat pipe work. We tried wicks of various materials and geometries. None of these tests were successful. We then turned to a heat pipe consisting of two separate, but connected, functions.

Referring to Fig. 3, parts 7, 8 and 9 are parallel with and connected to part number 11. Part number 9 is the condensing end of a thermal-siphon (9 is clamped to a liquid nitrogen-carrying tube). Oxygen gas initially at 200 psi is cooled and condensed to a liquid. Acting as a thermal-siphon this liquid runs under gravity to the low point directly under end number 7. For a stainless steel tube .020 wall by 5/16 diam by 5 feet long the end-to-end temperature difference was consistently less than a few hundredths of a degree Kelvin. The second part of the heat pipe requires work against gravity. Since we could not contrive a true heat pipe we turned to a geysering principle. Liquid oxygen runs down into a 1/8" diam by 16 mil wall stainless steel tube in the form of a U. Part number 8 is a heavy copper connection communicating to room temperature. Liquid entering this U-tube is in part vaporized in passing point 8. A geysering effect is created shooting a stream of liquid and gas upward toward end 7. This geysering effect is effective for heights up to about 5 feet. In our case we require a vertical rise of about 15". The geyser of oxygen gas and liquid falls down through copper wool to the bottom condensing end. In point of fact the oxygen condensed at 9 communicated freely to end 7. Careful measurements showed that the temperature fluctuations at 7 were again only a few hundredths of a degree Kelvin. Temperature difference between 7 and 9 was also only a few hundredths of a degree Kelvin.

As anticipated in Reference 3, various tricks can be played with this sort of heat pipe. The temperature at the condensing end can be raised enough to prevent formation of liquid or the gas can be withdrawn through connection 8. In either case the temperature at 7 can be raised to room temperature almost independently of the temperature at 9. A cryopumping diode is thus created permitting accumulated gasses of a particular class to be desorbed at 7 and adsorbed again on surfaces connected to 9.

The system 7, 8, 9 is used to cool a tube housing the 3°K system 6, ultimately attached to the liquid helium-carrying system. For cryopumping purposes this system functions almost independently of the diam of the metallic heat conductor used. 1/16 wire gave comparable performance to 3/8 diam rod. End 6 has an appropriately enlarged surface to give required speed and pumping capacity. Gas communicates to the condensing surface 6 through the louvred passages at LN temperature. Fig. 6 shows a photograph of this louvred shield around the 3°K system. In this photograph a 3/16 wall by 1-5/8" heavy copper tube was used for a shield around the 3°K system. Figure 7 shows a test of a more elaborate 3°K surface. Instead of a set of louvred passages to allow gas to communicate with the 3°K system, the 3°K system encircled the path of the Omnitron beam. To eliminate problems with eddy-currents this ring of high purity copper was interrupted. Figure 7 shows a calibrating orifice plate rotatable through a bellows from outside the vacuum with one of the small diameter orifice holes in register in the beam line aperture. Note that the plate could be rotated so that a full aperture hole, a blank spot or any of three small diam holes could be used to define the gas flow in the system. Figure 6 shows the same orifice calibration plate in a different position.

PUMP DOWN RESULTS

Referring to Fig. 3 and to Fig. 5, the residual gas analyzer (RGA in Fig. 3) can be seen at extreme top of Fig. 5. The high alumina beam tube (in round cross section to save expense) can also be seen connecting the RGA house to the pill box in Fig. 5. This alumina beam tube had the same charge dissipating coating inside that is used by the Cambridge Electron Accelerator group. The cold resistance of this coating for a length of 17" and inner tube diam of 2-7/16" was 1000 ohms. The coating had a very pronounced negative coefficient of resistance. Stainless steel coatings produced by vacuum evaporation were also tried. In Fig. 3 the Baird Alpert nude ionization gauge is traceable to the upper part of Fig. 5. Figure 3 part number 4 is the rotatable calibration plate also seen in the other figures. In Fig. 3 the position of the RGA corresponds to a mid-point in a magnet. Thus the average concentration in terms of atomic number could be measured. Figure 3 part 2 is also a nude Baird Alpert type gauge. Figure 3 part number 1 is a leak valve; leaks as low at 10^{-9} liter torr averaged over a period of 10 seconds could be metered using a diaphram instrument.

Pump down proceeded as follows: The test apparatus shown in Fig.'s 2, 3, 5, 6 and 7 could be used to give a good indication of the pump down time for the entire Omnitron since all pumping occured in parallel. At the RGA station shown in Fig. 3., the diffusion pump system, not shown, had a speed of 1/2 liter/second. Within a half hour from air at the ion gauge reading of 10^{-4} torr, the 80°K shield system was cooled. In less than 1 hour BAG number 2, indicated 1×10^{-6} torr. Liquid helium was added to the system. Omnitron conditions were achieved within 7 hours from the time pump down started. This was facilitated by heating the charge-dissipating coating to a temperature of 200°C for a few minutes.

CONCLUSION

A comprehensive report covering the details of cryopumping in terms of kind and amount of gasses, capacities and a host of other pertinent details will be forthcoming in the future.

ACKNOWLEDGEMENT

We owe a special debt to Leon Archambault, Phil Batson and Gary Webster for craftmanship and perservance under fire.

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1) The Omnitron, A Multipurpose Accelerator, July 1966, UCRL 16828.

2) N. Milleron, IEEE Trans., June 1967, p. 794.

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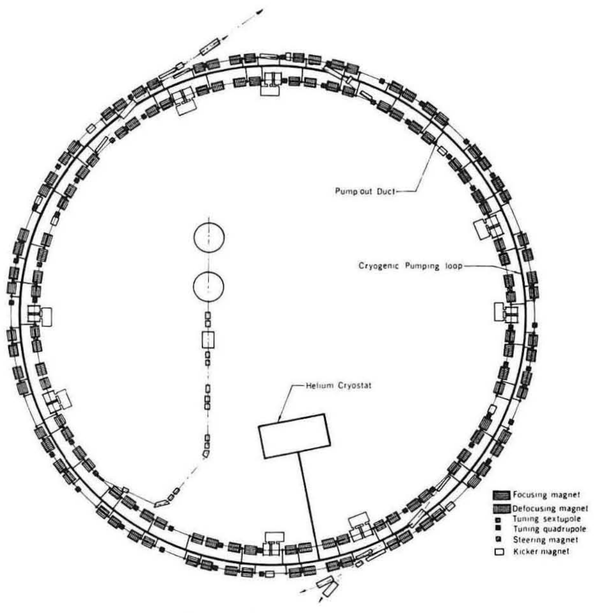

Vacuum System Schematic

Fig. 1. Vacuum System Schematic of the Omnitron Cryopump.

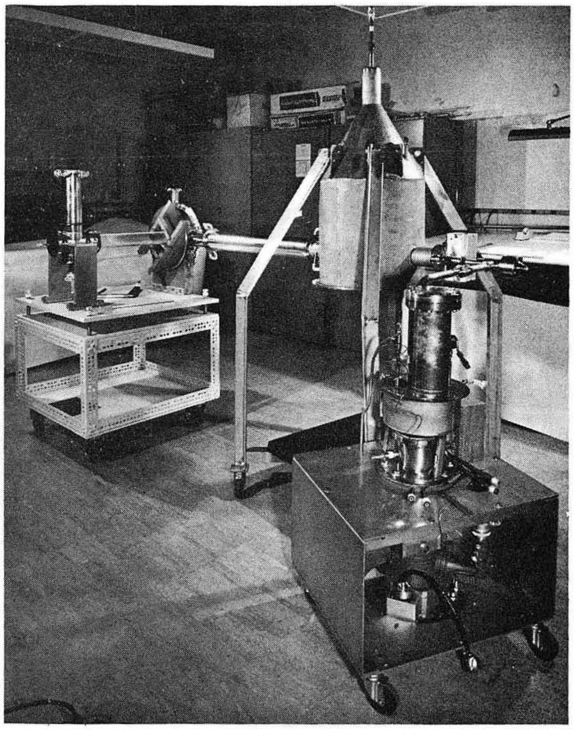

Fig. 2. Overall view of the Test Cryopumping Station.

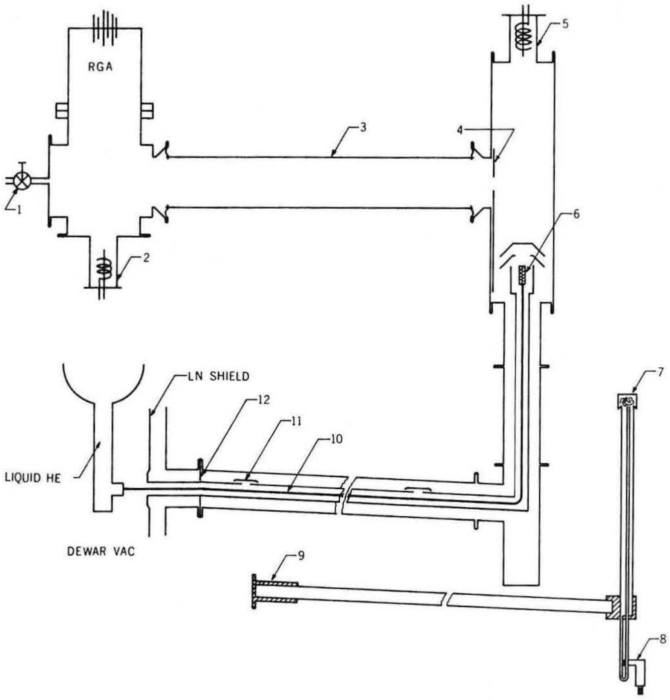

Fig. 3. Schematic Drawing of the Test Cryopumping Station.

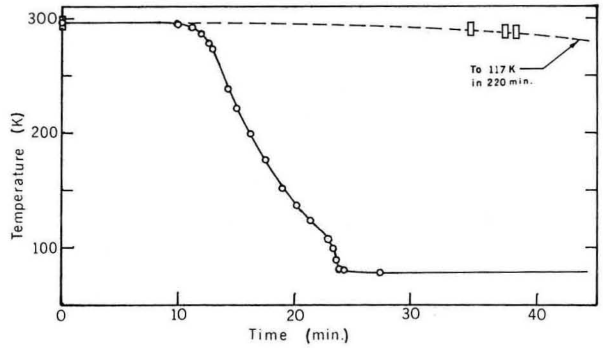

Fig. 4. Cool-down of Liquid Nitrogen Cooled Elements.
Solid line: Sloping, gravity "heat pipe" 58" long with vertical geyser tube 15" high.
Dashed line: Heavy wall open end copper tube 3/4" diam 54" long (in good agreement with calculation).
At time = 0, liquid nitrogen filling of 1" transfer line begins.

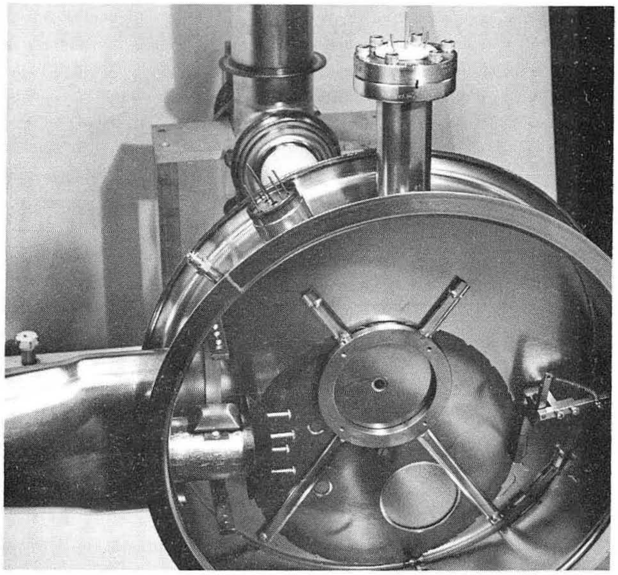

Fig. 5. Test cryopump connection at the beam line with aperture plate for flow rate measurement. Sample ceramic beam tube and RGA connection in the background.

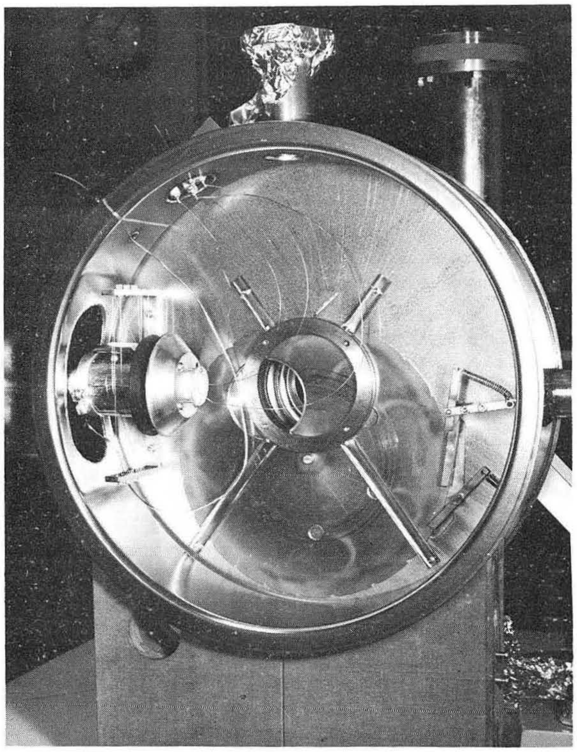

Fig. 6. Test cryopump with liquid helium cooled 3/8" diam copper rod within louvered LN-cooled shield.

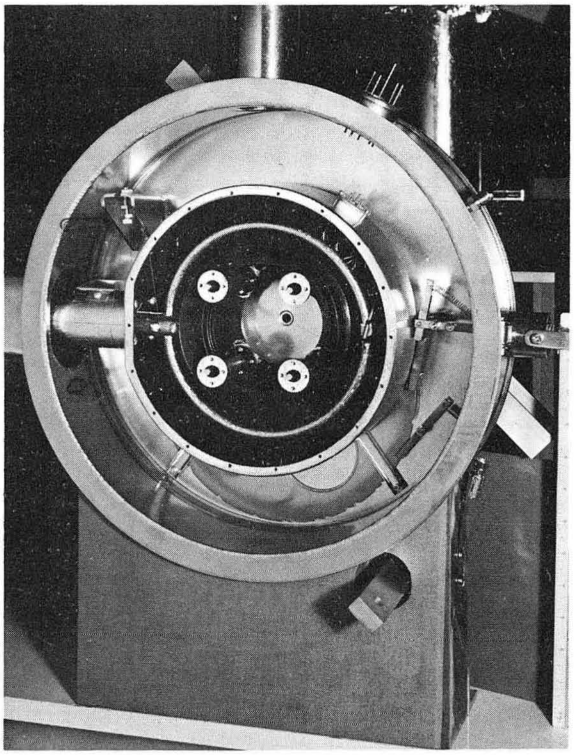

Fig. 7. Test cryopump with liquid helium-cooled ring of 3/8" diam copper rod around the beam line.

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