5. VACUUM SYSTEM

5.1 Description

The vacuum system consists of three different systems, each with its own particular characteristics and requirements:

1. Cold beam tube, vacuum sections in which the beam tube is at cryogenic temperature (about 4.6 K).
2. Warm beam tube, vacuum sections in which the beam tube is at room temperature.
3. The cryostat insulating vacuum which is completely separate from the two systems above.

The beam tube is, of course, continuous around the ring, approximately 6 km in length. The beam-tube vacuum around the ring is conveniently divided into 24 sections which coincide with the 24 cryoloops. Each section terminates in a turnaround box at either end. At each of these points there is a short (about 10 cm) warm section of the beam tube with isolation valve (section valve).

The beam tube is cold except in the six long straight sections and the twelve medium straight sections at locations 17 and 48. Additional warm space will be provided between the quadrupole doublets at the ends of the long straight sections where necessary. Each of these warm sections of the beam tube has an isolation valve at each end. Vacuum barriers built into the superconducting quadrupoles subdivide the insulating vacuum into approximately 200 sections, each about 30 m long. The following is a separate description of the details for each of the three vacuum systems.

5.2 Cold Beam Tube

5.2.1. Pumpdown. Prior to cooldown the beam tube is pumped out via "sniffer" ports located near each section valve and at each cryogenic feed box, which is approximately mid-way between section valves. The pumping is done with a slightly modified version of the standard pump station. (A description of the standard pump station is given in Sec. 5.5) Assuming normal surface phase contamination for clean but unbaked stainless steel, it should take a few hours to reach a pressure of 10^{-5} torr. This roughing is done with the section valves closed. When the beam tube is cold external pumping is no longer required and the pump stations are valved off. Calculations and measurements show that at 4.6 K there are essentially no gas phenomena in the tube. This is true even for helium if the coverage of helium on the beam tube wall is a small fraction of a monolayer. Assuming a pressure of 10^{-5} torr at the start of cooldown and assuming that the gas is condensed on the wall more or less uniformly during cooldown, the resulting wall coverage would be about 10^{-3} of a monolayer. If the residual gas were all helium (the worst case, and very unlikely), this would result in an equilibrium pressure of less than 10^{-11} torr at 4.6 K.[1]

Furthermore, if there is a small leak, the helium admitted into the beam tube through that leak would also be pumped onto the wall very near the leak. As the buildup of helium on the wall increases, the equilibrium pressure in that region also increases and the gas migrates to a previously clean region close by and is again pumped onto the wall. This phenomenon is very slow, taking hours or perhaps even days for leaks as large as 10^{-7} torr·liters/sec to move the distance of a half cell. In other words, it is impossible to give a practical definition of the conductance for the cold tube and very difficult to pump the cold tube effectively with lumped or periodic pumps.

5.2.2. Pressure measurements. The pressure in the beam tube is difficult to measure for at least three reasons, first, for the same reason that it is difficult to pump the cold beam tube, second, because any penetration into the tube will have a high pumping speed of its own, since it is also cold and probably has a higher wall-area to cross-sectional area ratio than the beam tube itself, and third, because the measurement will be dominated by the outgassing of the warm parts of the measuring device.

We have tried to solve some of these problems by the use of what is called the "sniffer" shown in Fig. 5-1. During the beam-tube pumpdown, the sniffer is baked at 200° C to decrease the surface contamination. When the magnet is cold, the copper sleeve in the sniffer is at 80 K so that it is not pumping helium or hydrogen. To decrease the background further, the warm parts of the sniffer are outgassed in a vacuum furnace at 900° C before assembly into the cryostat. The conductance of the sniffer is about 10 liter/sec for hydrogen.

Sniffers will be located at each quadrupole, as shown in Fig. 5-2. Every sniffer will be equipped with a Bayard-Alpert gauge, capable of measuring pressures down to about 2×10^{-11} torr. The sniffers used for pump-out will have low and medium vacuum gauges useful for monitoring the pumpdown. All connections are made with Conflat type copper gasket flanges. All the devices connected to the beam tube except the gate valve are all-metal.

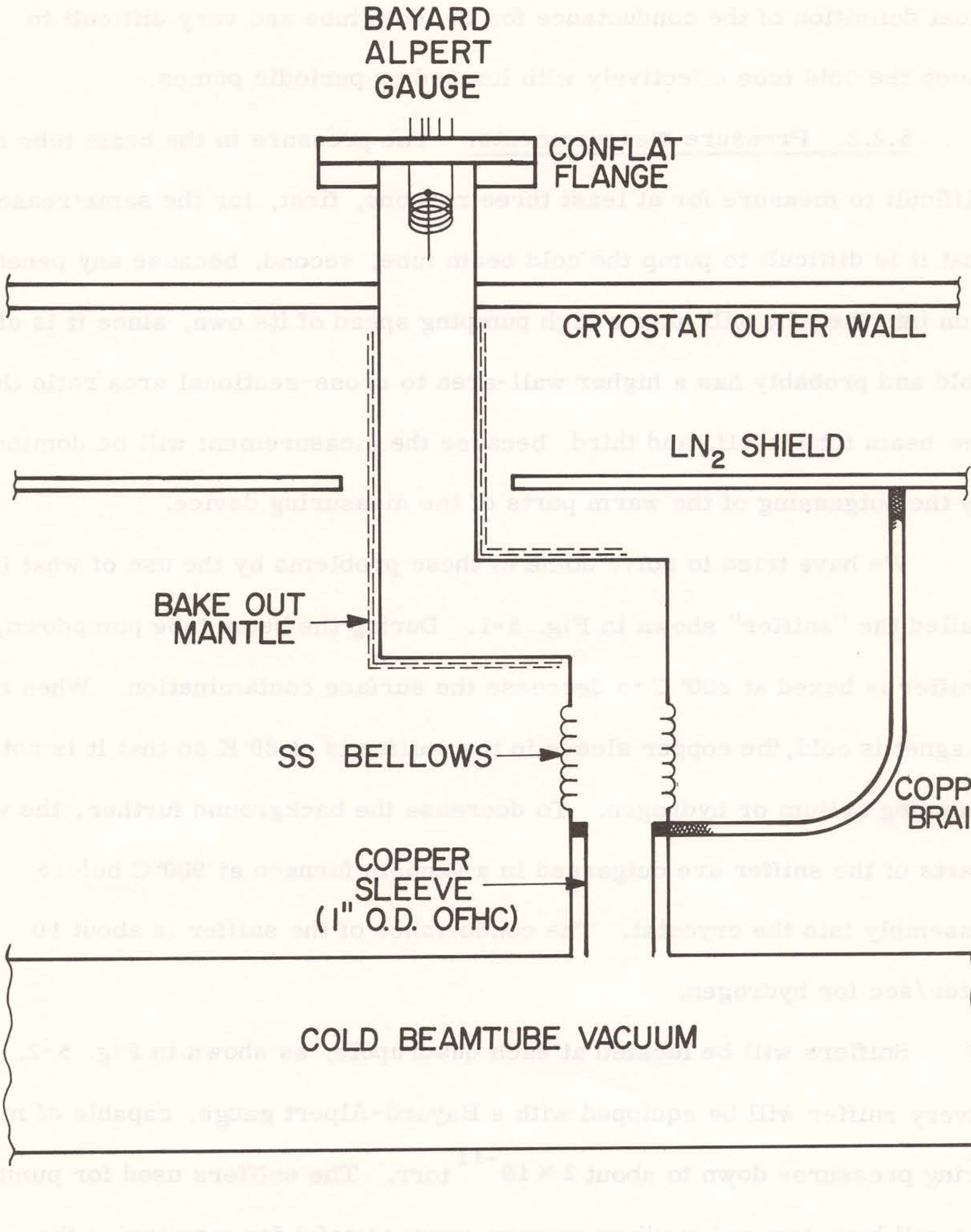

Fig. 5-1. Schematic of the "sniffer" port to the cold beamtube vacuum.

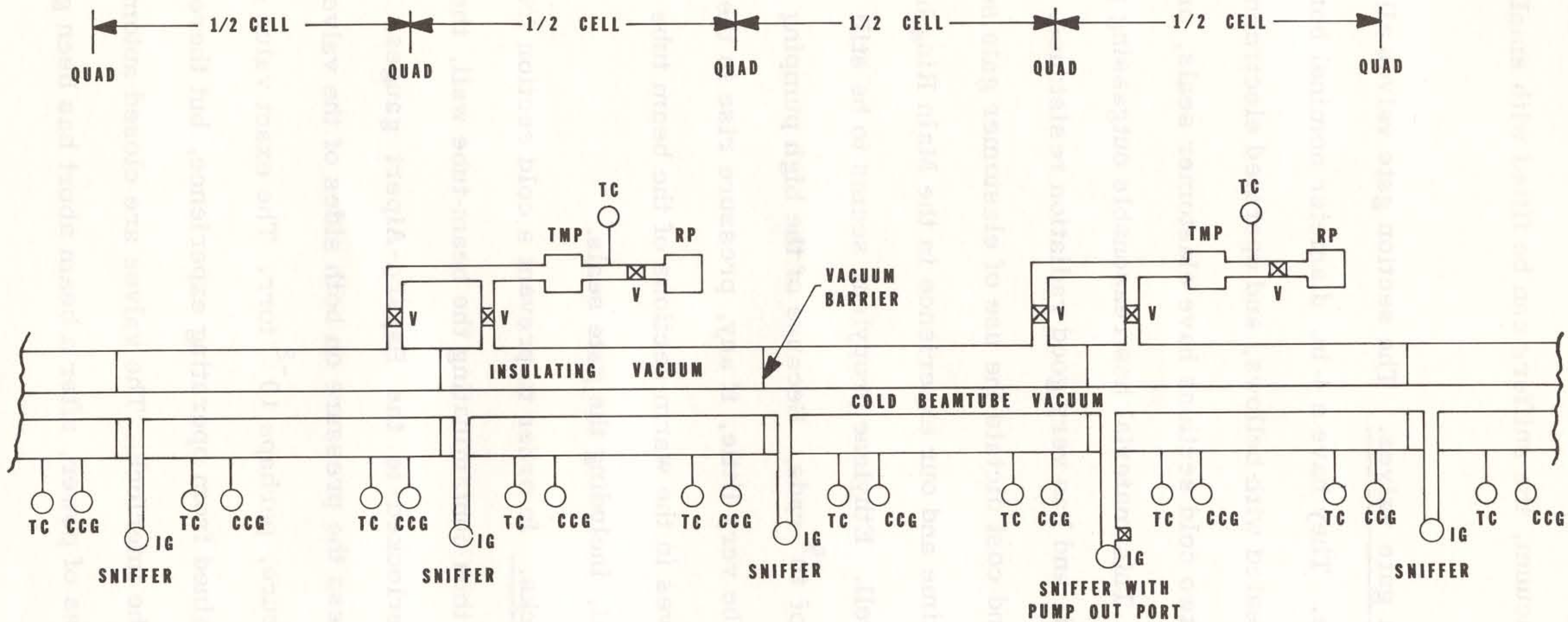

Fig. 5-2. Typical section of cold beamtube and insulating vacuum.

At a later time, if it proves necessary to have more pumping capacity for the beam tube vacuum, the sniffers can be fitted with small sputter ion pumps.

5.2.3. Section gate valves. The section gate valves all operate at room temperature. They have a 4-in. diameter nominal bore and are made of stainless steel, sealed with bellows, and operated electropneumatically. The valves between two cold sections have elastomer seals, probably of ethylene propylene. This material has reasonable outgassing properties, takes a minimum set, and has very good radiation resistance. Reliability, space limitations, and cost dictate the use of elastomer gate seals. They are open almost all the time and our experience in the Main Ring has been that they stand up very well. Ethylene propylene seems to be still flexible enough to seal after a dose of 10^9 rads. Because of the high pumping speed of the cold bore, there will be very little, if any, pressure rise in the vicinity of the valve. The gate valves in the warm sections of the beam tube vacuum will probably be all-metal, including the gate seals.

5.2.4. Interlocks. In order to prevent a cold section from pumping on a warm section, thus contaminating the beam-tube wall, the section gate valves are interlocked to the Bayard-Alpert gauges. They cannot be opened unless the pressure on both sides of the valve is less than some specified pressure, perhaps 10^{-8} torr. The exact value of the set points will be determined from operating experience, but there will be no manual override of the interlock. The valves are closed automatically upon pressure rise, or loss of power, after a beam abort has been generated.

5.2.5. Beam-tube design and quality control. Because of the difficulty of pumping on a cold beam tube, it is extremely important that there be very few leaks. On the other hand, because there is no outgassing of the tube when it is cold, it seems unnecessary to bake the tube in situ or otherwise degas it. The only treatment is to wash the tube in a caustic degreasing agent and a nitric acid pickling bath and maintain a clean environment for it.

The tube material is 316 L stainless steel sheet with a matte 2-D finish. This finish is chosen because it has a high ratio (>3) of real surface area to apparent surface area and thus a high capacity to pump helium and hydrogen on its surface. The tube is rolled to approximate shape, machine TIG welded, drawn to final shape, and annealed.

A key point in the design of the cryostat is that, apart from the seam weld, there are no welds made on the beam pipe that face liquid helium. All the welds, bellows, and seals are in the insulating vacuum. This means, for example, that a leak in a beam tube seal must be very large to be of any consequence because the insulating vacuum is usually better than 10^{-7} torr. The seal between the beam tubes of adjacent magnets is made with a lead-coated C-seal, trapped in a rotatable, bolted flange set.

In addition to the final leak check of the completed cryostat, each magnet is to be leak-checked cold during and after field measurement at the Magnet Test Facility. When the magnet is connected in the tunnel, the seal and bellows are again checked with a helium leak detector by evacuating the beam tube and bagging and flooding the seal area with helium gas. The leak check is then completed by pressurizing the single-phase helium loop.

5.2.6. Miscellaneous points relating to beam stability.

(i) The pressure-bump instability. This instability is due to runaway of gas desorption from the beam tube walls. It is a function of beam current, geometry, pumping speed, temperature, and pressure, at least. Calculations and measurements[2, 3] indicate that the ring could circulate 5 to 10A before wall desorption would be a problem. This is true even for large wall coverage of hydrogen or helium and arises from the very high pumping speed of the cold wall. We conclude that the pressure-bump instability will not be a problem in the cold sections of the ring.

(ii) Trapped electrons in the beam. Ionization electrons produced by the beam can be trapped in its potential well and cause beam instabilities. We do not consider this a serious problem because of the large gap (1.9 μs) in the circulating beam, which must be there to accomodate the risetime of the abort kicker. This gap, together with rf bunch structure, should give sufficient time for electrons to be swept from the beam region.

5.3. Warm Beam Tube

The warm sections of the beam tube vacuum are the six long straight sections (50m long) and the twelve medium straight sections at locations 17 (approx. 14 m long) and 48 (approx. 8 m long). These sections must contain all devices not incorporated in the main magnet system such as kickers, injection and extraction magnets, dampers, separators, and so on. The vacuum system in these regions will be an integral part of this equipment. The average pressure required in these warm regions is 10^{-8} torr. At the interfaces between the warm pipe and the cold pipe, we must provide high pumping capacity in order to prevent the cold region from pumping gas from the warm sections and contaminating the walls. Titanium getter (sublimation) pumps will be added at these interfaces. The sublimation pump plus gate value assembly will use 24 in. of drift space at each interface, as shown in Fig. 5-3.

5.4. Cryostat Insulating Vacuum

In order to decrease the static heat load, the insulating vacuum should be better than 10^{-5} torr. Below this pressure, heat transfer by radiation and conduction across the layers of superinsulation dominates. Our experience has been that in a good leak-tight system the vacuum is much better than that; in fact, it is usually less than 10^{-7} torr. The major difficulty in achieving a good insulating vacuum is the location and elimination of leaks. To facilitate this task, the insulating vacuum has been subdivided into approximately 200 sections by permanent vacuum barriers in each of the quadrupoles, as shown in Fig. 5-2.

5.4.1. Pumpdown. We have chosen to use turbo-molecular pumps to pump out the insulating vacuum (see Section 5.5). Even though the conductance in the insulating space is extremely low, if there are leaks it is advantageous to pump on the space even when the magnets are cold, because a large number of layers of the superinsulation are relatively warm and gas which migrates to those areas can be effectively pumped. Pump stations will be placed at every other half-cell boundary, each station pumping on two half-cells. The number of pumps (approximately 100) can be increased as experience warrants.

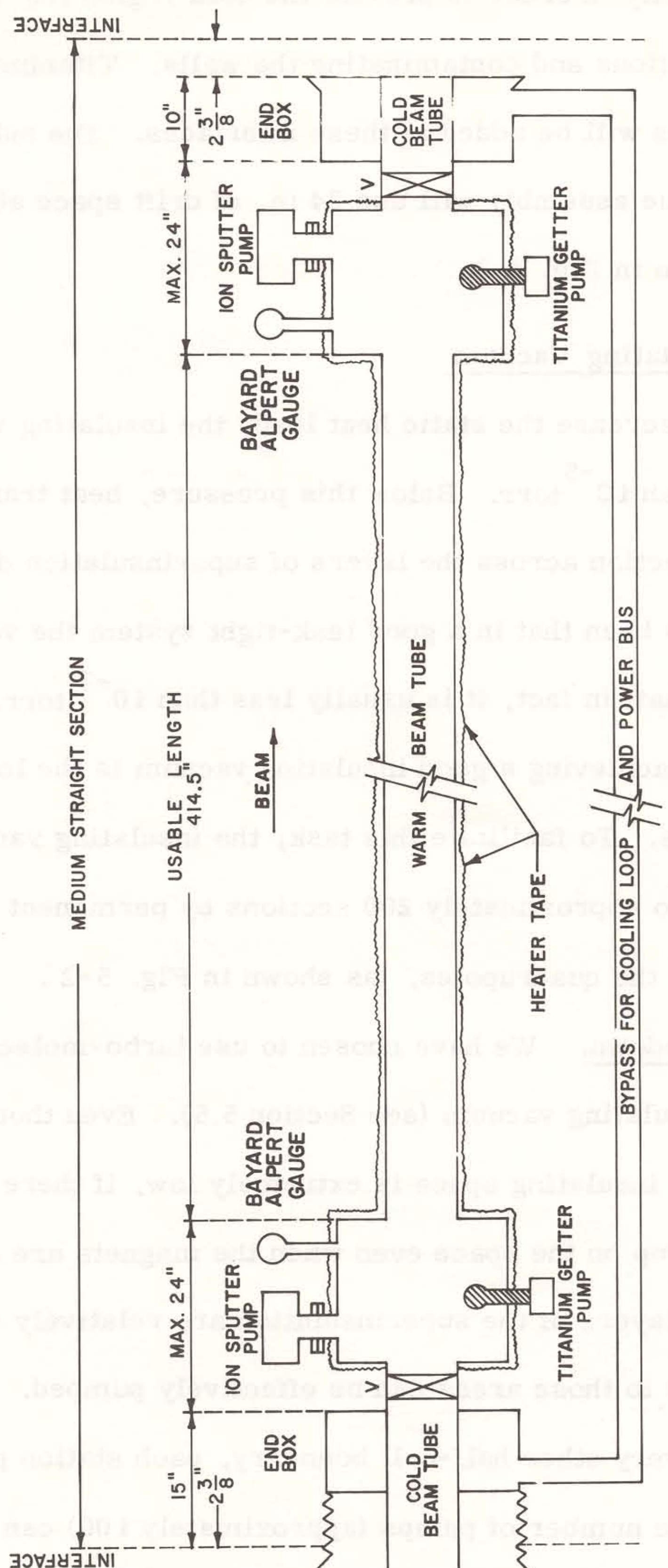

Fig. 5-3. Warm beamtube with cryogenic bypass in medium straight section.

When roughing begins, the turbopumps are started at the same time as the rotary-vane pumps, with the gate valve open. In this mode the turbopump acts as a trap for oil vapor backstreaming out of the rotary-vane pump. (The first time a region is pumped it is advisable to purge it a few times with dry nitrogen to remove water vapor.) Cooldown is started after a final leak check with the pressure less than 10^{-3} torr. If there are no leaks the pumpdown takes about 6 to 8 hours. If the superinsulation has been pumped previously and let up to dry nitrogen, the pumpdown time is much faster, taking only 1 or 2 hours. If the cooldown is started at too high a pressure, water vapor and other gasses condense on the superinsulation, degrading the emissivity and thereby increasing the heat load.

5.4.2. Pressure measurement. The pressure gauges are shown in the diagram of Fig. 5-4 and explained in Section 5-5 along with valves and interlocks.

5.5 Pump Stations

All the pump stations are essentially identical. A standard insulating vacuum pump station is shown schematically in Fig. 5-4.

5.5.1. Pumps. The pumps are a small turbo-molecular pump of approximately 100 liters/s capacity, backed by a direct-drive two-stage rotary vane pump of approximately 5 ℓ/s capacity.

The turbo-molecular pump is mounted with its axis in the horizontal direction by means of a 4 in. ID Conflat flange. The roughing pump is mounted near the pump and connected with a flexible stainless-steel hose.

5.5.2. Valves. Each pump station has two electropneumatic gate valves of 4 in. ID with Conflat flanges. These are all-stainless bellows-sealed valves with elastomer O-rings of ethylene propylene. In addition, there are two hand-operated valves between the roughing pump and the turbopump. They are used during leak checking, when the leak detector is used as the roughing pump for the turbopump and the normal roughing pump is valved off. This gives very good pumping speed to the leak detector and increases the sensitivity.

5.5.3. Pressure measurements. There are five gauges at each roughing station:

1. A thermocouple gauge with fast response (Pirani gauge) monitors the roughing line.

2. A Pirani gauge and a cold-cathode high-vacuum gauge, sensitive to pressures down to 10^{-6} torr, measure the insulating vacuum on each side of the vacuum barrier.

5.5.4. Interlocks. The gate valves automatically close when power is lost. In addition, they are interlocked to each Pirani gauge in order to protect against loss of vacuum on either the high-vacuum side or the backing-pump side. This protects the turbo-molecular pump (TMP).

Other interlocks protect against overtemperature of the TMP and power loss to either pump. A sudden rise in the insulating vacuum will also cause a beam abort and closing of the beam section valves, in addition to closing the roughing gate valves and turning off the TMP.

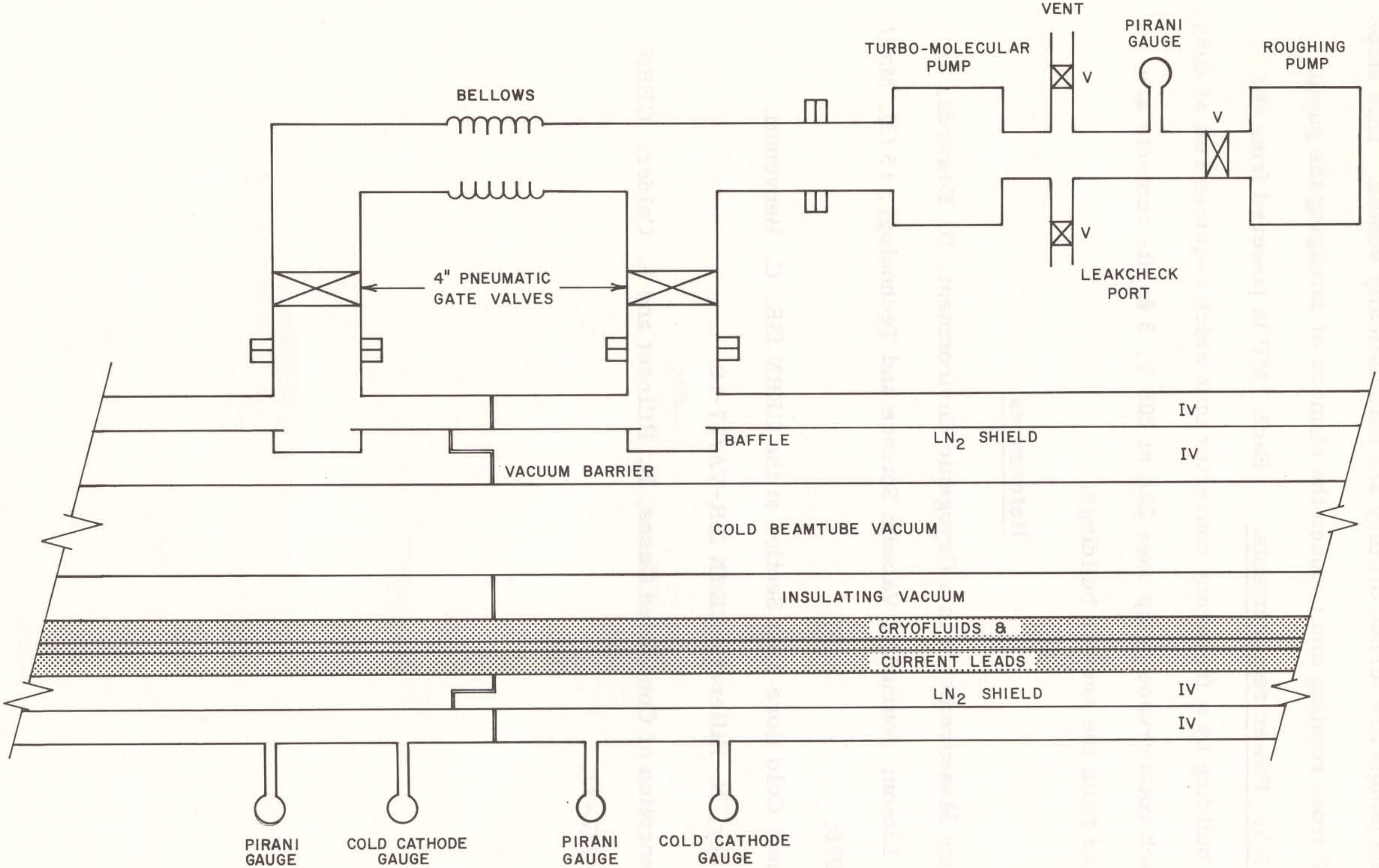

Fig. 5-4. Pump station for insulating vacuum.

When the pumps are turned off they are automatically vented. This stops the TMP from rotating and reduces the chances of damaging the pump.

5.5.5. Power requirements. Each TMP is powered from the service building by a frequency converter unit which requires 10A at 208V, 3 ϕ. Each rotary-vane pump uses 20A at 208 V, 3 ϕ; its contacts are controlled from the service buildings.

References

[1] Pressure Measurements in a Cryogenic Environment, D. Edwards, Jr., and P. Limon; Journal of Vacuum Science and Technology, 15 (3), May/June 1978.

[2] A Vacuum Cold Bore Test Section at the CERN ISR, C. Benvenuti, R. Calder, N. Hilleret; CERN ISR-VA/77-19.

[3] Ion Desorption of Condensed Gases, N. Hilleret and R. Calder; CERN ISR-VA/77-33.