SUPER-HILAC VACUUM SYSTEM*

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Abstract

The Super-Hilac Accelerator has two large rf cavities with a combined volume and surface area of 13,000 ft^3 and 9,200 ft^2. This paper describes the system whereby these cavities are vacuum pumped cryogenically to operating base pressures in the low-10^{-7} torr range.

The acceleration complex can be separated into five different areas—injector, pre-stripper tank, stripper area, post-stripper tank, and the experimental area. This report will be confined to a description of the pre-stripper tank and post-stripper tank vacuum system.

Both tanks are 124 in. i.d. The pre-stripper is 60 ft long and the post-stripper 100 ft long. The tanks have a total volume of 13,000 ft^3 and a surface area exposed to vacuum of approximately 9,200 ft^2. Four per cent of the exposed surface is steel and the remainder is copper. The pre-stripper tank is separated into two rf cavities by a diaphragm placed 20 ft from the entrance end of the tank. Cavity No. 1 contains 48 drift tubes; cavity No. 2 is 40 ft long and contains 87 drift tubes. The post-stripper tank is separated from the pre-stripper tank by 11 ft of beam line containing various magnetic and diagnostic elements. Diaphragms divide the post-stripper tank into six rf cavities. In total, 78 drift tubes are contained in the post-stripper tank. Conductance through the rf diaphragms is approximately 800 liters/sec for air. An attempt has been made to keep the number of organic seals to a minimum; however, each rf cavity contains at least ten "O" rings ranging in size from 1/2 in. diam to 12 in. diam. All rf surfaces are cooled either by water or Freon and operate at temperatures near 100°F. Maximum voltage gradient between drift tubes is 9 megavolts/meter.

Since the accelerator is divided into eight separate rf cavities with limited conductance between cavities, it is necessary to provide pumping in each of the cavities. With this in mind, coupled with the fact that we wanted a "clean vacuum," the idea of a cryopanel running the entire length of the accelerator began to look attractive when compared to a separate pumping system on each rf cavity. A number of different cryopanel geometries were investigated with the aid of a computer program utilizing Monte Carlo techniques.[1] Figure 1 shows a cross section of the cryopanel that was installed in the pre-stripper and post-stripper tanks. Three different fluids are used to cool the cryopanel: Freon 22, liquid nitrogen, and helium gas at approximately 20°K. Heat generated by rf currents flowing on the large outer shield is removed by Freon at -40°F. The rf power dissipated in this shield amounts to 35 kW. Keeping the outer shields that surround the liquid-nitrogen-cooled surfaces at -40°F rather than 90°F reduces the radiant heat load on the nitrogen

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system by a factor of 3.

Radiant heat loads on the 20°K tubes are limited to 10 to 15 W by the two nitrogen-cooled shields. These shields also provide a surface on which to pump water vapor. Two 5/8 in. o.d. tubes, maintained at 20°K by a helium refrigerator, provide the cryopumping surfaces for all the remaining gases in the tanks with the exception of helium, neon, and hydrogen. A pumping speed for water of 75 liters/sec per linear inch of panel is obtained by the nitrogen-cooled surfaces. This amounts to a total pumping speed for water of 54,000 liters/sec in the pre-stripper tank and 90,000 liters/sec in the post-stripper tank. The 20°K surfaces pump at a rate of 45 liters/sec per linear inch of panel, giving a total pumping speed of 32,000 liters/sec in the pre-stripper tank and 54,000 liters/sec in the post-stripper tank.

Figure 2 is a flow diagram of the Freon 22 system. Liquid Freon 22 is pumped through the tubes on the -40°F shields at a rate of 40 gpm in each tank. No boiling of the Freon occurs until it reaches the evaporator tank, which is external to the accelerator vacuum tank. It was necessary to circulate liquid Freon rather than use a conventional type expansion system because the resulting pressure drop in the system would have prevented us from reaching the desired temperature of -40°F. An additional heat exchanger is provided in each circulating system for fast warm-up of the -40°F system. The heat source is room-temperature "TF" Freon used in the drift-tube cooling system. By closing the suction valve on the vapor side of the Freon 22 evaporator tank and opening the "TF" Freon supply valve to the heat exchanger, the temperature of the -40°F system can be raised above the dew point in about 20 minutes. This allows the tank to be "let up to air" 20 minutes after the warm-up procedure is started without condensing large amounts of water on the cryopanel.

Figure 3 is a flow diagram of the liquid nitrogen system. A 1500-gal nitrogen dewar is located outside the Hilac building where it can be easily serviced by a transport truck. The storage dewar is also used to fill portable dewars used throughout the accelerator. A vacuum-insulated transfer line 80 ft long is used to bring the nitrogen to a distribution box located between the pre-stripper and post-stripper tanks. Manual valves inside the distribution box are operated by stem extensions which slide through vacuum seals in the distribution box. Contact between the stem extension and valve is made only during opening or closing of the valves in order to minimize heat leaks.

Nitrogen and helium enter and leave each tank through "termination boxes" as shown in Figs. 4 and 5. Since the nitrogen and helium cryolines contract approximately 4 in. in the post-stripper tank during cool-down, there is a need to provide flexing of the lines as they enter and leave the vacuum tanks. This is accomplished by the two bellows sections soldered into each line. The nitrogen and helium cryolines are fixed at the entrance end of the pre-stripper tank and at the exit end of the post-stripper tank. In Figs. 4 and 5 the outer lines contain nitrogen and the two inner lines contain helium. The helium lines were wrapped with "super insulation" prior to welding the lids on the boxes. Nitrogen gas exit temperature is controlled by the use of a standard Freon thermostatic expansion valve recharged with nitrogen. Dewar storage pressure is maintained at 40 psig which corresponds to a saturation temperature of 90°K. The expansion valve is set to maintain an exit temperature of 150°K. This temperature minimizes the amount of nitrogen used, while keeping the vapor pressure of the water trapped on the nitrogen cryopanel in the 10^{-7} torr range. Temperatures along the nitrogen system are determined by the use of vapor pressure thermometers filled with argon. The heat load on the nitrogen system has not been measured; however, it was calculated to be in the neighborhood of 700 W.

Figure 6 shows a schematic of the helium system. Refrigeration is provided by a CTI Model 1400 unit. This particular unit has been modified from their standard Model 1400. Instead of two expansion engines, our unit has just a single 3 in. diam expander and no JT valve. Expander speed is adjustable; however, the unit is normally run at 200 rpm. Without nitrogen pre-cool, the unit will deliver approximately 170 W of refrigeration with a 22^{o}K return temperature. With nitrogen pre-cool, the refrigeration capacity is increased to 230 W with a return temperature of 22^{o}K. Nitrogen pre-cool consumption is about 20 liters/hr. Superinsulated vacuum transfer lines are used between the refrigerator and a distribution box located between the pre-stripper and post-stripper tanks. From the distribution box, the 20^{o}K helium can be directed to the pre-stripper tank, the post-stripper tank, or the cryo roughing pump. The 20^{o}K cryoline in each tank consists simply of a 5/8 in. o.d. stainless steel tube which runs to the far end of the tank where it is anchored and then returns to the stripper area. Cooling of the lines results in a 4 in. change in their lengths which is provided for by bellows sections located in the termination boxes shown in Figs. 4 and 5. Temperatures at various points along the cryolines are obtained by using hydrogen filled vapor pressure thermometers.

Helium gas at a pressure of about 200 psig is supplied to the refrigerator at a rate of 60 scfm by a two-stage semi-hermetic Freon-type compressor. CTI has modified the compressor to compensate for the increase in heat of compression of helium as compared to Freon. This has been accomplished by injecting cooled oil into the suction stage of each cylinder. An oil removal system has been added to the discharge of the compressor by CTI which reduces the oil carryover to less than 1 part per million by weight. Cool-down time to 20^{o}K for the CTI 1400 working through a small mass load like the cryo roughing pump is about 3-1/2 hr.

Figure 7 is a schematic of the vacuum roughing system for the accelerator. Roughing the tanks from atmospheric pressure down to 1 torr is accomplished by three 310 cfm mechanical pumps located outside the accelerator building. A typical time for the pre-stripper tank to reach 1 torr is 90 min. When the pressure in the roughing line reaches 1 torr, a pressure switch opens a solenoid valve and bleeds in enough nitrogen gas to maintain a pressure of 1 torr in the roughing line. This is done to prevent the diffusion of any mechanical pump oil into the accelerator tank. Heaters are also used to maintain a section of the roughing line at 150^{o}F. This is done to vaporize any mechanical oil that might try to migrate along the inside surface of the roughing line. The vaporized oil is then swept back to the mechanical pumps by the 1 torr pressure that is maintained in the roughing line. At this time the tank is isolated from the mechanical pump roughing system. Tank pressure is reduced to the 10^{-3} torr range by the use of a cryo roughing pump, shown in Fig. 8. The vacuum chamber of the pump consists of a tank 2 ft in diam and 4 ft high. Inside the tank is an annular-shaped combination liquid nitrogen shield and reservoir. Suspended inside the nitrogen shield are two concentric helixes of 1/2 in. o.d. copper tubing connected in series. The total length of copper tubing is

65 ft. $20^{\circ}K$ helium gas from the refrigerator can be circulated through the copper tubing by the operation of the manual valves in the helium distribution box. Cryo roughing of the tank is started by opening a 6 in. valve between the pump and the tank. Pressure in the pre-stripper tank is reduced from 1 torr to 5×10^{-2} torr in about 10 min. If the tank is dry and tight, it will reach a pressure of 10^{-3} torr in about 30 min. During the cryo roughing of the pre-stripper tank the usual practice is to mechanically rough pump the post-stripper tank. Cryo roughing of the pre-stripper tank continues until the pressure in the post-stripper tank reaches 1 torr. At this time mechanical pumping is terminated, the pre-stripper tank is isolated, and the cryo roughing pump is put on the post-stripper tank. Cool-down of the $-40^{\circ}F$ and $80^{\circ}K$ shields in the pre-stripper can now start. When the pressure in the post-stripper reaches 10^{-2} torr, cool-down of the $-40^{\circ}F$ shields can start. Cool-down of the $80^{\circ}K$ shields starts when the tank pressure reaches the 10^{-3} torr range. Cool-down time for the $80^{\circ}K$ shields is about 20 min. When the $80^{\circ}K$ shields are cold, the cryo roughing pump is isolated from the post-stripper tank. Circulation of the $20^{\circ}K$ helium gas is now transferred from the cryo roughing pump to the cryolines in the pre-stripper and post-stripper tanks. As the cryo roughing pump warms, the boiloff gas produced is vented to atmosphere through a relief valve. Time required for the simultaneous cool-down of the $20^{\circ}K$ cryolines in both tanks is about 1 hr. As the temperature of the cryolines approaches the $20^{\circ}K$ range, the tank pressures will abruptly change from 10^{-4} torr to the 10^{-6} torr range.

Figure 7 shows the location of three titanium sublimation pumps. As mentioned earlier, the cryo pumping system operates at a temperature such that helium, hydrogen, and neon are not pumped. The titanium pumps are used to pump the hydrogen liberated during rf "bake in" operations. No provision has been made to pump helium or neon. When the tank pressures reach the 10^{-6} torr range, the titanium pumps are valved into the tank. Each pump has a pumping speed of 2500 liters/sec for hydrogen. If the tanks are leak tight, the pressures will reach the 10^{-7} torr range about 2 hr after the cryoline has reached operating temperature.

Since normal atmospheric air contains 5 ppm of helium and 18 ppm of neon, one might expect the final tank pressure would be about 2×10^{-5} torr if cryo roughing is started when the tank pressure is 1 torr. We think that most of the helium and neon is swept into the cryo roughing pump by the other gases that are cryo pumped, and that these two gases are then pumped to atmosphere by the small 15 cfm mechanical pump that operates on the cryo roughing pump during the cryo roughing.

Leak hunting is done with a standard mass-spectrometer-type leak detector. Deuterium is used as the detector gas rather than helium, since it has the same mass as helium and has the big advantage that it is pumped by the titanium pumps. The detector is also somewhat more sensitive to deuterium than helium.

Initial pump-downs of the two tanks were made during the fall of 1971. First rf "bake-in" tests were made in November of 1971. No special cleaning of the vacuum surfaces was made prior to rf baking, other than a simple wiping with alcohol. A considerable amount of hydrogen was liberated during the early bake-in stages. The rf gradients were kept to a low enough level so that the tank pressures did not exceed 10^{-5} torr. A residual gas analyzer proved to be a very useful tool during this period. Since this was our first experience with a cryo-pumped vacuum system, it was somewhat comforting to look at the various mass peaks and verify the fact that it was hydrogen and not an air leak that was keeping the pressure high. When the rf was turned off, the mass 2 peak would disappear in about 15 min, and the tank pressure would return to the 10^{-7} torr range. As the hydrogen outgassing rate diminished, the rf gradients were increased. Full gradients were achieved in most of the cavities after a few days of baking.

During these early stages of operation the tanks had to be let up to air many times to repair leaks and make modifications to the rf system. Each subsequent bake-in, however, has been easier as the hydrogen outgassing rate diminishes. The three titanium pumps use Varian Associates "Ti-Ball" assemblies. These units have a sublimation rate range of from .01 g/hr to .5 g/hr. During our initial bake-in period it was necessary to run at a sublimation rate of .3 g/hr. We now typically operate the pumps at a rate of .05 g/hr when the rf system is operating.

The vacuum system has now been in operation a total of 4000 hr, and with the exception of a few minor problems has operated well. The heat load on the 20°K refrigeration system is sensitive to the rf power level, and it may be necessary to add additional rf shielding to the cryo panel to reduce the rf heating on the 20°K lines. Calculations indicate that the rf heating can be reduced by a factor of 100 while reducing the pumping speed only 20%. At present, the system has been successfully operated at 2/3 the maximum expected rf power level. Typical operating pressures in the tanks when running beam are 2×10^{-7} torr. When the rf is off, the tank pressures are in the mid-10^{-8} torr range.

Reference:

1. Tanabe, J., Proposed Cryosystem Monte Carlo Program, Lawrence Berkeley Laboratory, Engineering Note M4338 (1970), unpublished.

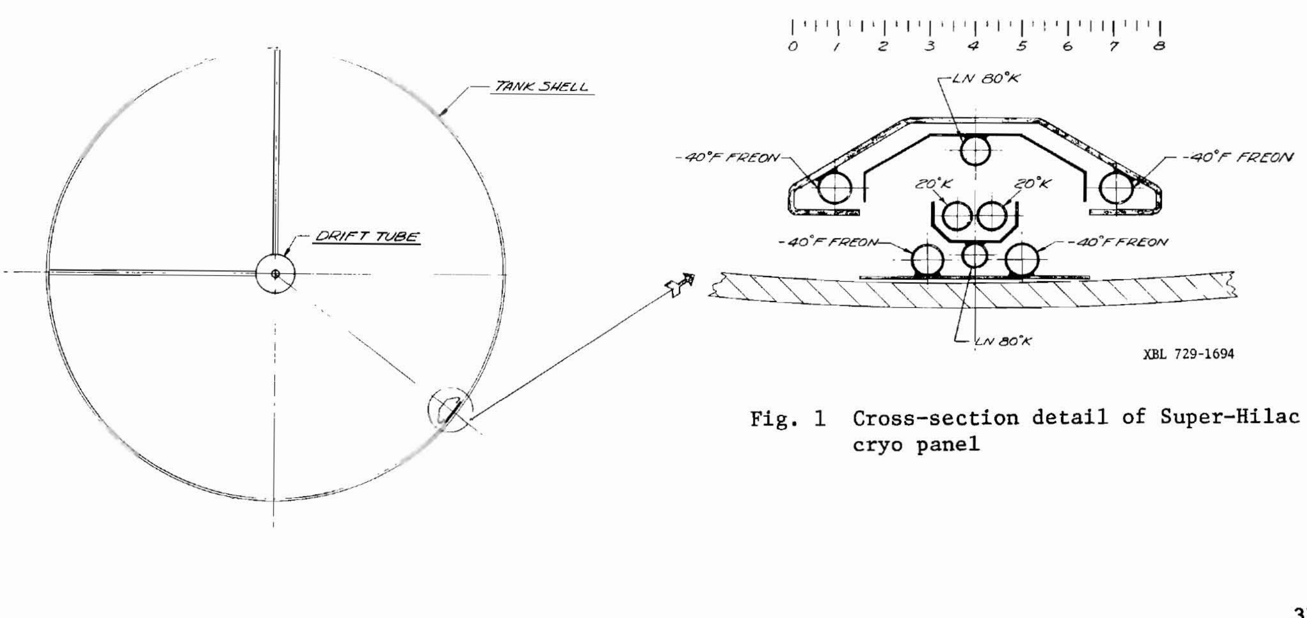

Fig. 1 Cross-section detail of Super-Hilac cryo panel

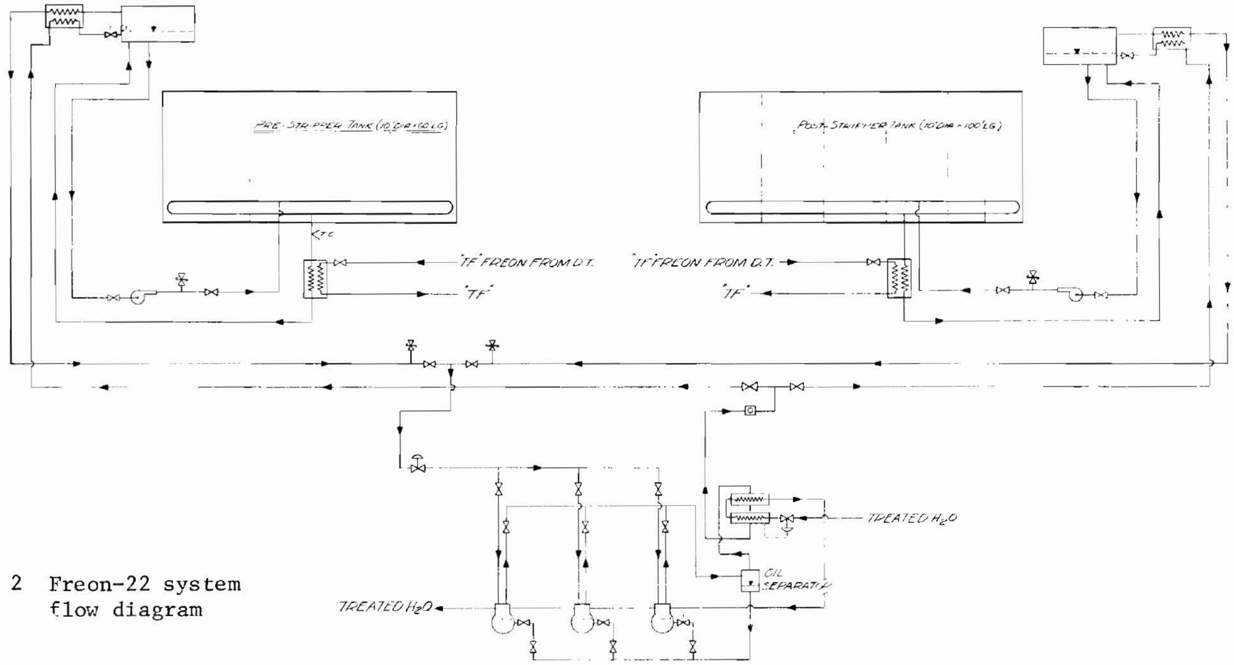

Fig. 2 Freon-22 system flow diagram

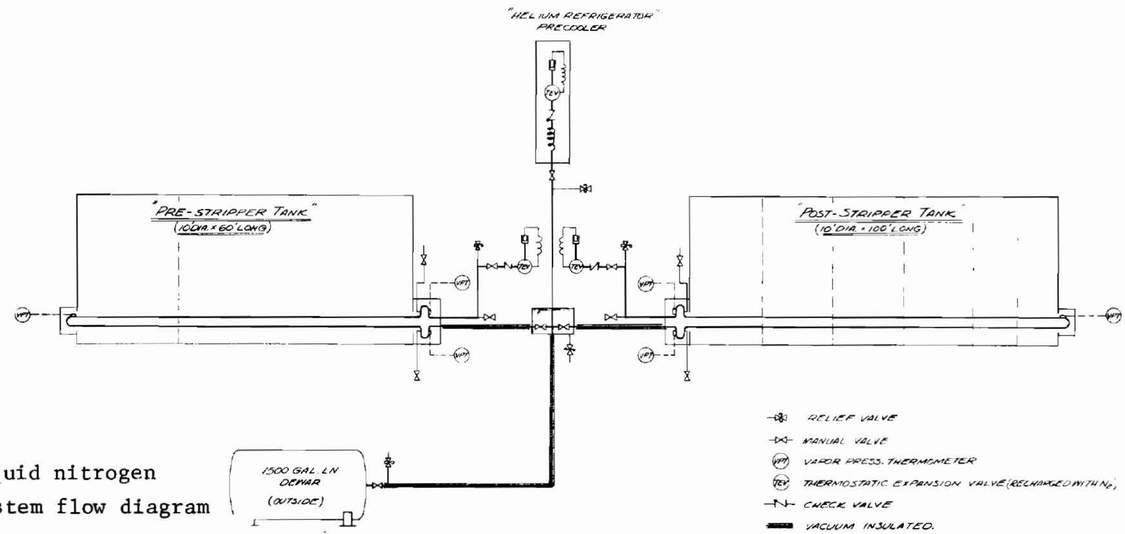

Fig. 3 Liquid nitrogen system flow diagram

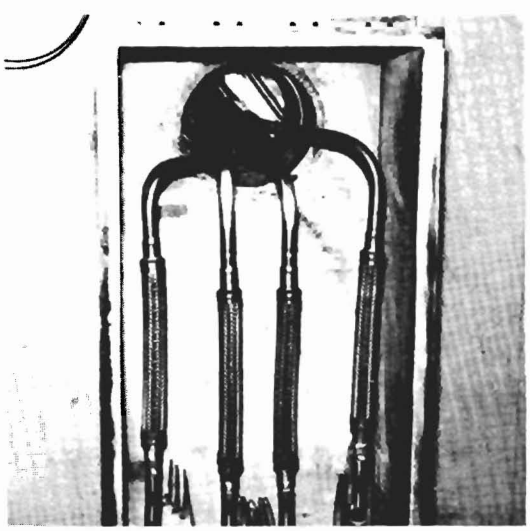

Fig. 4 Upper portion of pre-stripper termination box

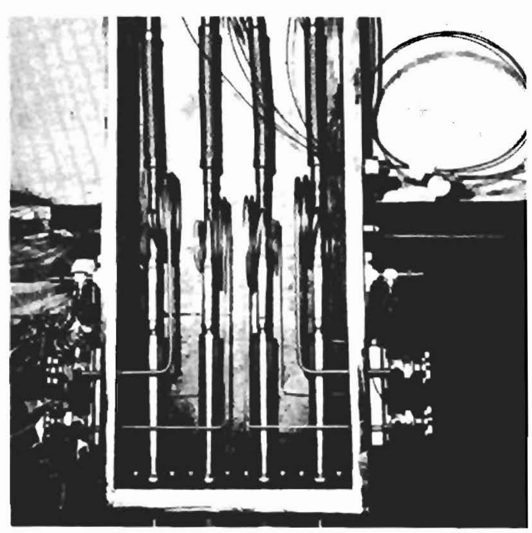

Fig. 5 Lower portion of pre-stripper termination box

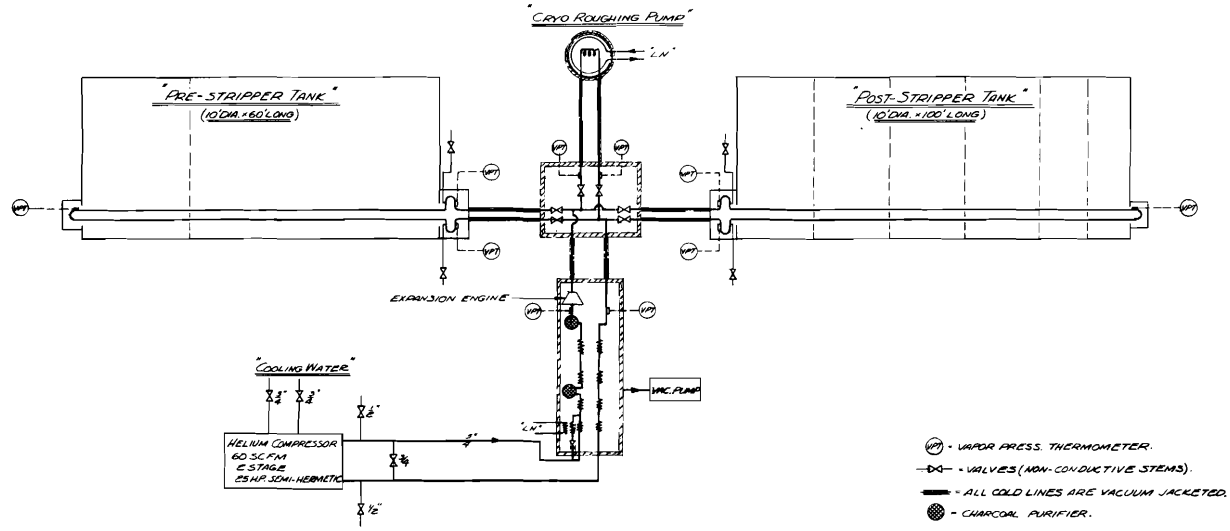

Fig. 6 Helium system flow diagram

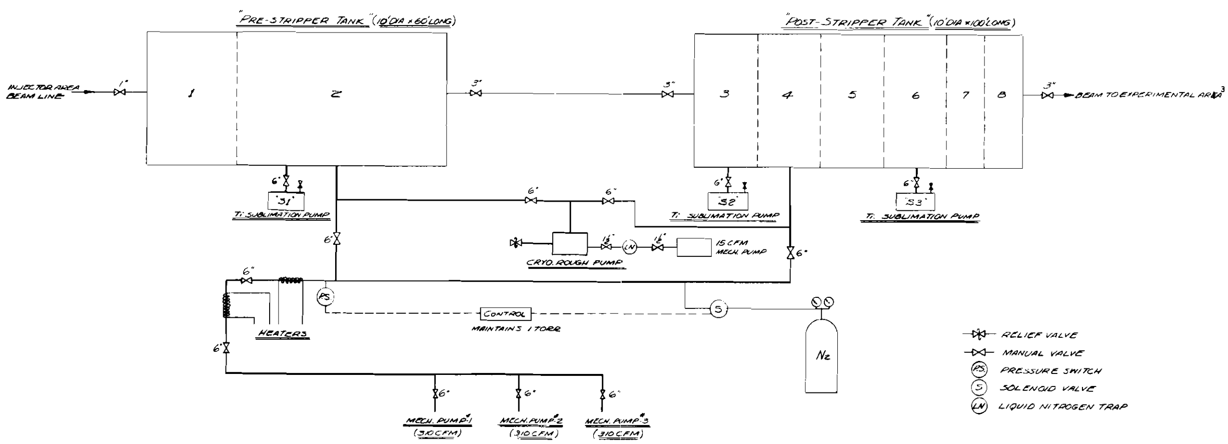

Fig. 7 Vacuum system schematic

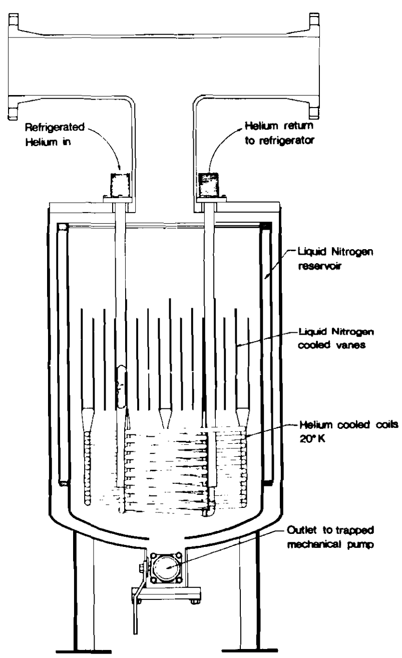

Fig. 8 Cross-section of cryogenic roughing pump