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Summary

A cryogenic vacuum pump, designed to lower the base pressure from 2 x 10^{-6} Torr to 3 x 10^{-7} Torr was installed in the Bevatron in February 1972. The ~ 11,000 ft^3 vacuum volume contains > 100,000 ft^2 of outgassing surface and is pumped with twenty-four 32-in. oil diffusion pumps. Nine cryopanels (90 ft total) were distributed around the 360-ft circumference, increasing pump capacity by 400,000 l/s for condensibles at 80°K and 140,000 l/s at 20°K. Benefits include faster pumpdowns, improved beam stability, and higher intensities.

Introduction

The Bevatron is a large synchrotron at the Lawrence Berkeley Laboratory first operational in 1954. Its main ring consists of four straight sections and four curved sections. The vacuum envelope of each curved section or quadrant is approximately 3.5 ft x 8.7 ft x 75 ft long and contains the laminated magnet pole tips, a 2 ft x 3 ft crawl space and a beam space 1 ft x 4 ft. The straight sections are 10 ft x 8 ft x 20 ft long. The original pumping system had twenty-four 32-in. freon baffled oil diffusion pumps, six in each of the four straight sections. The diffusion pump speed drops from a maximum of about 150,000 l/s to about 50,000 l/s at the approach to base pressure. Typical pressures were 2 x 10^{-6} Torr in the straight sections and 3 to 4 x 10^{-6} Torr in the quadrants. These pressures were usual for normal operations but were obtained only after several weeks of pumping following a major shutdown. The slow pumpdown severely limited machine performance after shutdowns and thus, to some degree, restricted maintenance and other work within the vacuum envelope.

Design Objectives

The heavy-ion program at LBL provided the major impetus for the improved Bevatron vacuum and increased pumping speed. Lower base pressure was necessary for the production of usable beam currents of ion species heavier than alpha particles. Faster pumpdowns were also important because of the anticipated need for more frequent internal machine changes. The general requirement was to lower the base pressure by about a factor of ten.

Gas Load

The Bevatron vacuum volume contains ~11,000 ft^3 (850 lb of air), ~25,000 ft^2 of free outgassing area, and ~80,000 ft^2 of restricted outgassing area from the laminated magnet pole tips. Optimum design of a cryopumping system required an accurate knowledge of the quantity, quality and distribution of the gas load. Quantity was measured with rate-of-rise techniques and estimated from pump speed data. Quality was measured with a residual gas analyzer and trapped/untrapped ion gages. Quadrant pressure distribution was measured with a movable nude ion gage. The measured parabolic pressure distribution from beginning to end of a quadrant confirmed that the major problem was related to conductance and gas load of the curved sections.

Design Parameters

The gas load, Q, is about 0.06 Torr-l/s. Half is non-condensible at 80°K with fairly uniform peak and valley distribution around the 360-ft perimeter as dictated by machine geometry.

Desired base pressure was 2 to 3 x 10^{-7} Torr. A 20°K cryopumping surface was chosen, shielded by a liquid nitrogen cooled surface. The design for pumping air required careful consideration. Any such design would provide ample pump speed for condensibles. The pumping speed for air is given by:

$$S_{req} = \frac{Q}{P_{req}} = \frac{0.03 \text{ Torr-l/s}}{3 \times 10^{-7} \text{ Torr}} = 100,000 \text{ l/s}$$

Cryopanel Design

Two-dimensional Monte Carlo studies were made for various geometries. For the design selected the "air" pumping speed was computed as 131 l/s per linear inch of panel. Test measurements made on a 60-in. long panel confirmed this value within 5%. Nine cryopanels, each 10 ft long, were positioned around the Bevatron providing a total computed "air" speed of 140,000 l/s.

It was important to optimize the heat load of the LN_2-cooled 80°K shield in order to maintain reasonable operating costs and logistics of LN_2 handling. Therefore, six layers of 1/4-mil aluminized mylar were wrapped on the panel external surfaces. The open mouth of the 80°K exposed surface (4.72 in./in. of panel) provides a "condensible" pumping speed of 400,000 l/s. This exposed area, radiating to 310°K, is also the major heat load source. An additional floating shield could reduce the heat load by a factor of 2, but this would cut the speed. Thus, the design requires a well-chosen balance between refrigeration capacity and pumping speed.

The quadrant panels were made of stainless steel to minimize eddy-current heating from the pulsed magnetic field. This required close LN tube spacing because of poor steel thermal conductivity. Copper was used in the straight sections, and a deeper panel gives a slight increase in capture fraction.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

Conduction heat loads were minimized throughout with epoxy-fiberglas standoffs and spacers combined with poor contacts in vacuum. The plastic standoffs also provide electrical isolation for the large circuit loops within the pulsed magnetic field.

Heat load estimates were based on emissivities of 0.5 giving about 2 kW at 80°K or LN_2 consumption of 45 l/h. Heat loads at 20°K were estimated at 200 W. Transfer and conduction, as well as radiation losses, were included in the estimate.

Refrigeration and Distribution

A 3700-liter central Dewar on the shielding roof above the Bevatron supplies LN_2 to distribution boxes in the east and west straight sections. The once-through circuit is controlled with gas bulb temperature sensor thermostatic valves exhausting gas at about 85°K.

Two CTi Model 1400 helium refrigerators supply the 20°K circuits. They independently feed the east and west distribution boxes through 35-ft external vacuum-jacketed transfer lines. These external lines are insulated with 26 alternate wraps of aluminized mylar and nylon mesh.

Internal circuits are split into two paths at the distribution boxes. The internal transfer lines total 264 ft and consist of four tubes each, namely the supply and return for both the LN circuits (0.63 in. diam) and the He circuits (0.38 in. diam). Longest path length for He is 220 ft. The LN, together with aluminized mylar and nylon mesh, provides insulation for the He. Allowance was made for two-phase flow and gas removal in the LN circuit. The transfer lines accommodate up to 1.5 in. of differential expansions during the various temperature excursions.

Construction

All parts for the system were prefabricated and tested prior to installation. About 100 metal unions with nickel gaskets were used on the circuits, and individual parts were pre-tested at 250 psi gas pressure and vacuum, both hot and cold. Internal components were installed during a three-week period in February 1972. Constraints were imposed by the need to limit machine outage, the available space and access, and the residual radiation levels. External helium transfer lines were installed during a two-week shutdown in June 1972, and the helium refrigerators were connected in July. Design and pre-planning resulted in minimum interruption of normal machine operations.

Operations

LN_2 was first circulated in February 1972 following the three-week shutdown. After initial pumpdown with the diffusion pumps, good operating pressures (2 to 4 x 10^{-6} Torr and ultimately 6 x 10^{-7} Torr) were reached within a few hours after the introduction of LN_2. Previously, several weeks were needed to achieve equivalent pressures after the vacuum tank had been at air. In August the helium system was placed into operation. Helium at 18°K is circulated after a few days of precooling the panels with LN_2, and most of the heavy components are condensed on the 80°K surface. About three hours are needed to cool the He circuits after precooling. When 18°K is reached, the pressure is immediately reduced by a factor of 2. Best average base pressures have been ~2.8 x 10^{-7} Torr, with some pressures as low as 1.2 x 10^{-7} Torr. The cryopump system has proven to be very flexible, with rapid recovery of normal beam intensity after up-to-air periods. The panels are warmed up in a few hours for defrosting on normal maintenance days.

Refrigeration loads have been close to predicted values, 80 W on each of the He refrigerators, based on supply/return temperatures of 12°K/15°K. LN_2 use rate is about 60 l/h. Refrigerator output is sensitive to valve condition in the He expansion engines, and care must be taken with regard to valve icing and adjustments.

After 10 months, one cryopanel in the east straight section had portions of its aluminized mylar insulation almost completely disintegrated by radiation damage. From the trajectory and damage pattern, the source is believed to be electrons from the 70 kV inflector. The mylar insulation was removed and replaced with three layers of nylon mesh and 2 mil aluminum foil. Normally, one wouldn't attempt vacuum improvement by adding large areas of nylon mesh and mylar, but in our case it was a matter of expediency.

Beam Improvements

Whereas proton beam intensity improved only slightly, the main gains were the rapid recovery to normal operations following shutdowns and improved beam quality due to reduced multiple scattering. Heavy-ion beam intensity, on the other hand, was greatly improved. Previously such beams were severely restricted in intensity because of charge exchange with residual gas. Since only fully stripped ions can be used for acceleration in the Bevatron, the capture cross section for a k-shell electron is of importance. In describing the survival of ions, the pressure differential appears as an exponent of an exponential function. Hence the gain of intensity resulting from reduced recombination of beam ions is tenfold for every factor of 2.8 in pressure. Extracted ion beams of elements up to oxygen are now sufficiently great for the physics and bio-medical research programs.

Conclusions

Cryopumping has proved to be a very effective and efficient means of augmenting and extending the capability of the existing Bevatron pumping system. It produces clean vacuum without introducing any contaminant and achieves extremely high pumping capacities economically. In cases such as ours, where large capacities are needed in crowded, inaccessible spots, there is no other way. Design heat loads are especially critical due to their effects on refrigeration capital and operating costs.

Acknowledgments

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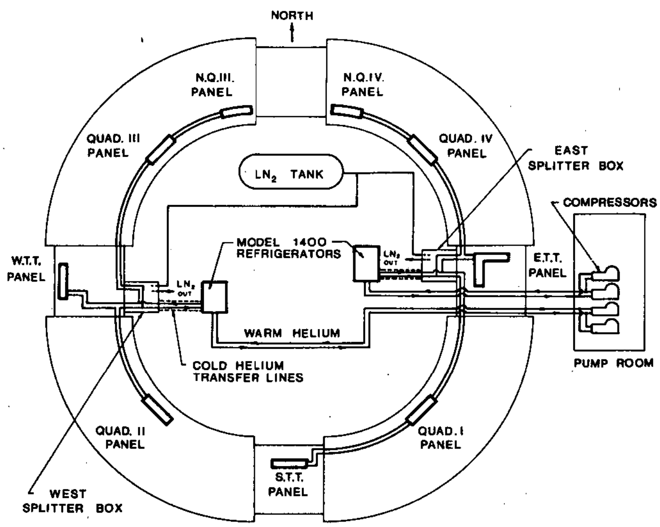
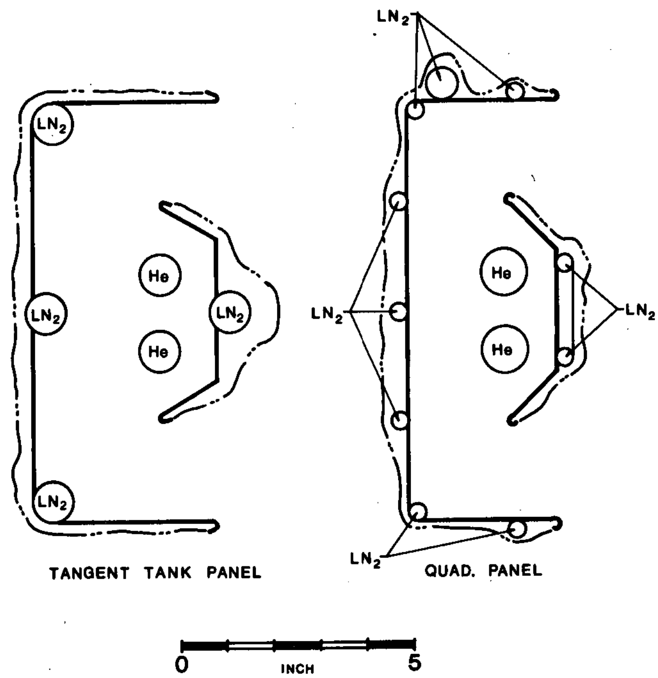
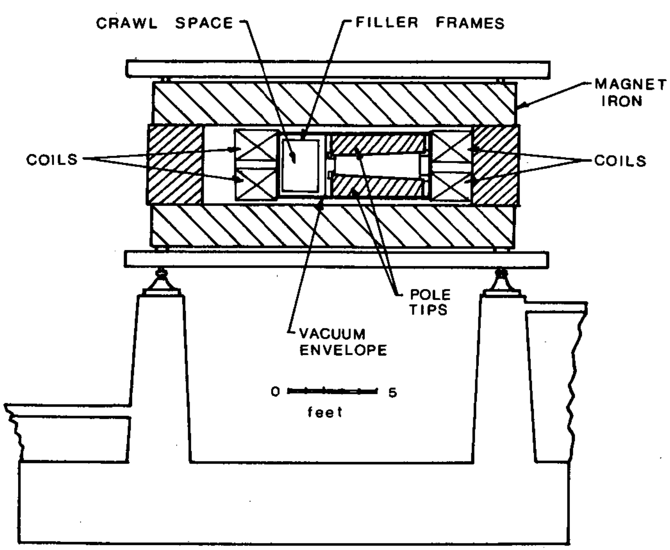


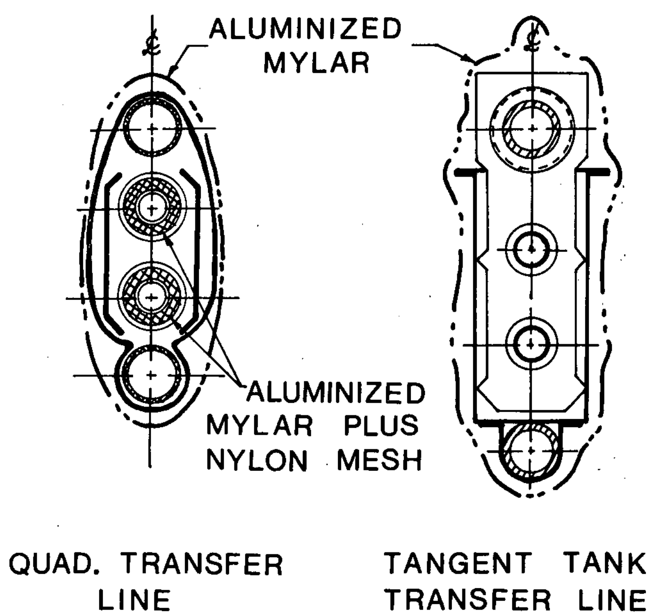
Cryopanel and gas distribution layouts.



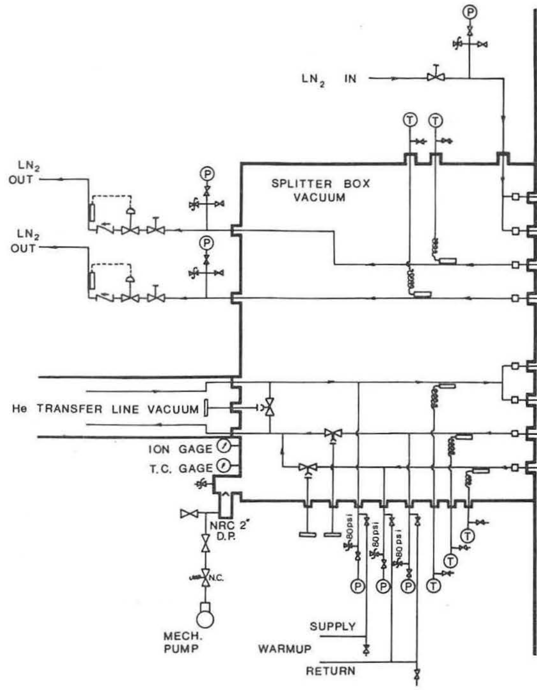
Cryopanel cross sections.



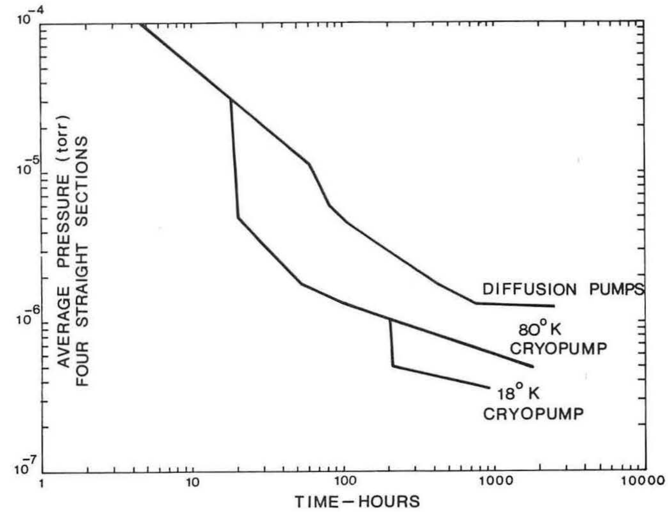
Quadrant cross section.



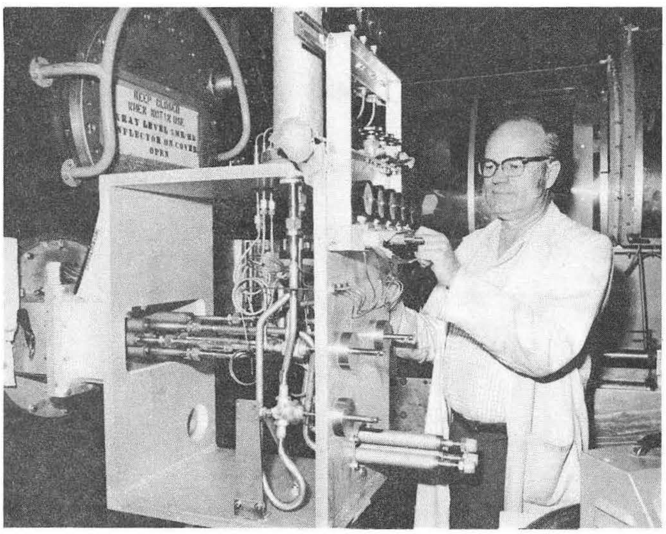
Internal transfer line cross sections.



Distribution box circuit.

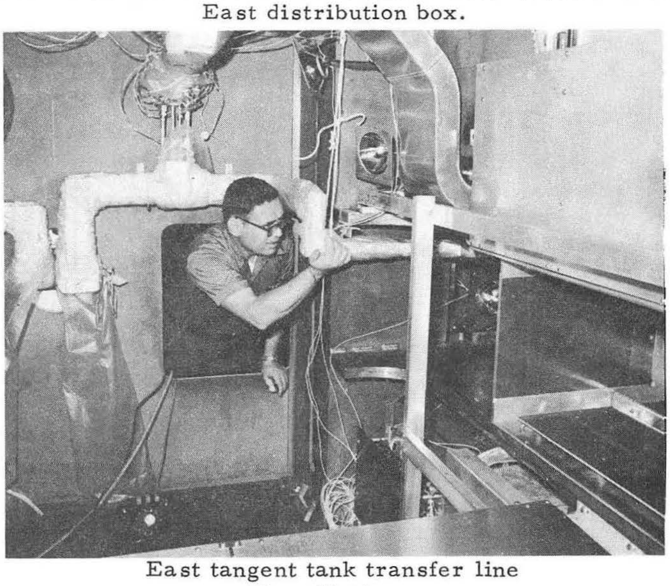


Pumpdown curves.

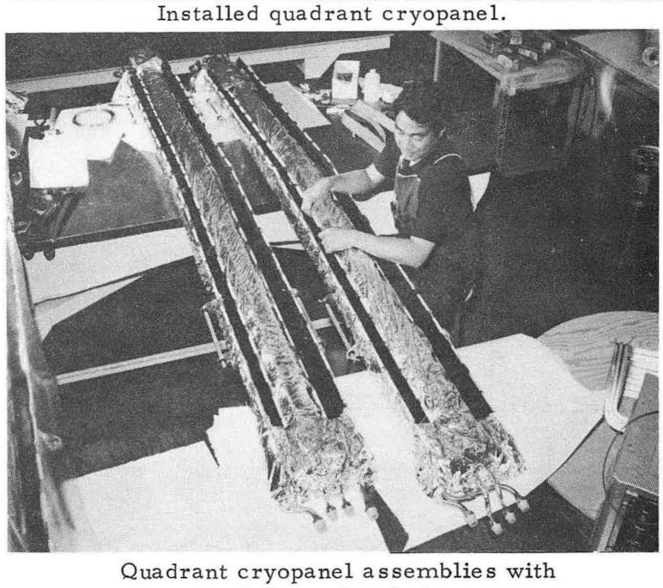


East distribution box.

Installed quadrant cryopanel.



East tangent tank transfer line installation.



Quadrant cryopanel assemblies with multilayer insulation.