23

VACUUM SYSTEMS

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The three major vacuum systems serving the two-mile accelerator, the optical alignment system light pipe, and the beam switchyard (BSY) transport vacuum chambers are located as shown in Fig. 23-1.

The *accelerator vacuum system* must maintain a very high vacuum in the accelerator to prevent RF electrical breakdown and electron scatter. Thirty-two subsystems evacuate the accelerator to a design pressure of 5×10^{-7} torr at the center of the individual 10-ft long sections of disk-loaded waveguide that comprise the beam envelope. Separate subsystems are provided for the injector, for the positron source, and for each of the thirty sectors of the accelerator. The subsystems are interconnected only through the 2-mile length of the disk-loaded waveguide except for a normally closed cross-tie between the injector and Sector 1 subsystem piping. Mobile cryosorption pump sets evacuate the individual subsystems from atmospheric pressure to a level at which the sputter-ion pumps can take over to produce the operating vacuum.

The *alignment light pipe vacuum system* evacuates the tubular aluminum girders which support the two-mile accelerator and the central beam tube in the BSY. The design pressure of 1×10^{-2} torr prevents deflection of light rays used for optical alignment. The girders are interconnected by flexible metal bellows. A single pumping station is located at the end of Sector 30. The initial pumpdown from atmospheric pressure is accomplished using high-capacity mechanical vacuum pumps. The vacuum is maintained at the operating level by a diffusion-ejector vacuum pump backed by a mechanical pump.

The *beam switchyard vacuum system* evacuates the BSY beam transport vacuum chambers to an average design pressure of 1×10^{-4} torr to permit passage of electron and positron beams. Normally open valves are provided by which adjoining chambers can be segregated into seven independently

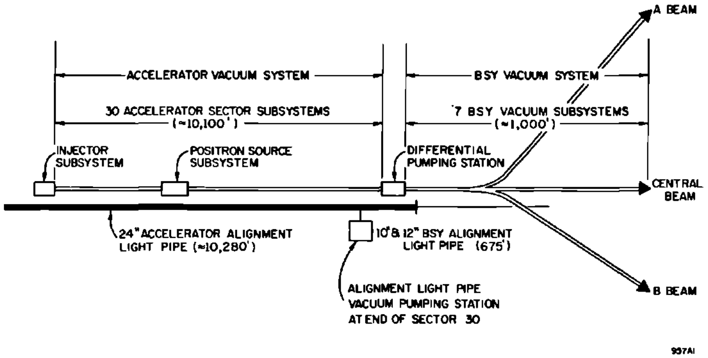

Figure 23-1 Location of vacuum systems.

pumped subsystems. The BSY high vacuum system is separated from the accelerator very high vacuum system by a refrigerated section of accelerator disk-loaded waveguide. The seven subsystems are roughed down from atmospheric pressure using mechanical vacuum pumps. The operating vacuum level is maintained by diffusion pumps.

23-1 The accelerator system

Design criteria (SRC, FFH)

Evacuation of the accelerator is required primarily to prevent electrical breakdown in the high RF fields (2856 MHz) used to accelerate the electrons and to prevent excessive scattering of the electrons by gas molecules during transit through the disk-loaded waveguide. Theoretical considerations borne out by experience on the Mark III and Mark IV accelerators at Stanford University and confirmed at SLAC indicated that a pressure of 1×10^{-6} torr or less would meet the requirement for RF breakdown. As shown by DeStaebler,[1] gas scattering is not significant below pressures of 1×10^{-5} torr. Allowing suitable safety factors, design pressures were established as 5×10^{-7} torr for accelerator sections and 5×10^{-8} torr for the vicinity of the klystron waveguide windows.

Other considerations which influenced the design were as follows. Design pumping speed at the disk-loaded waveguide input coupler was to be approximately 10 liters/sec to provide for gas bursts in the waveguides. The system was to have a design pumping speed of 20 liters/sec at the klystron window pumpout to protect against multipactoring and RF breakdown which are conditions conducive to catastrophic failure of the windows. The presence of a significant amount of hydrocarbon in the waveguides would seriously degrade the ultimate vacuum attainable; the risk of oil contamination would be great if oil diffusion pumps were used. The use of organic materials was to be minimized in the interests of cleanliness, low vapor pressure, and reliability; these materials deteriorate in the high radiation environment in the accelerator housing, and replacement could result in excessive beam downtime. Equipment requiring servicing, such as pumps, valves, and vacuum gauges, was to be located in the klystron gallery in order to be accessible to maintenance personnel while the accelerator is in operation. Reliability of equipment is extremely important. As a design objective the life of major components was to be at least 10 yr. It was to be possible to restore accelerator operation in less than 24 hours after a maximum of three subsystems had been let up to atmospheric pressure. Provisions were to be made for expansion to Stage 2 with minimum additional expense. In Stage 2 the number of klystrons is increased to 965 from 245 in Stage 1. This increases the number of rectangular waveguides connecting the klystrons with the accelerator from 16 to 32 per sector.

Pumping speeds and pressures (SRC, GIS)

To ascertain the required pumping speed, outgassing rates of RF processed copper and stainless steel were determined by test. The residual outgassing rate of copper is less than 1×10^{-11} torr-liter/sec/cm^2.[2] Over a period of time it should reduce to approximately 1×10^{-12} torr-liter/sec/cm^2 because the system is sealed and under vacuum continuously. It was found that after vacuum processing at 400°C for 24 hours, the residual outgassing rate of stainless steel is less than 1×10^{-12} torr-liter/sec/cm^2.[3] The remainder of this section gives the approximate methods used for estimating system operating parameters.

Basic vacuum system relationships are

$$Q = C \times \Delta P = d \times A = S \times P$$

where

Q = throughput in torr-liters per second
C = conductance in liters per second
ΔP = pressure difference in torr
P = pressure in torr
d = surface outgassing rate in torr-liters per second per centimeter squared
A = total internal surface area of the vacuum system in centimeters squared.
S = pumping speed in liters per second.

Calculations were based on the following assumptions:

1. The design outgassing rate of copper is 1×10^{-11} torr-liter/sec/cm^2. This is a factor of 10 times the anticipated residual rate.
2. Outgassing of stainless steel should be neglected since the outgassing rate is an order of magnitude less than the conservative design rate used for

copper. Along the accelerator, the area of copper is approximately equal to the area of stainless steel. The total copper area per sector is 1.5×10^6 cm^2 for Stage 1 and 1.95×10^6 cm^2 for Stage 2. The stainless steel area per sector is 1.5×10^6 cm^2 for both stages.

3. The point of highest pressure, or null point, in each rectangular waveguide is located halfway between the power dividers. This is because the pressures at pumpouts at each end of the rectangular waveguides are approximately equal and the waveguide conductance is very low (less than 3 liters/sec).
4. The gas load due to leaks is negligible. The maximum tolerable leak rate per joint was separately established as 1×10^{-9} atm-cm^3/second of helium. In practice, leaks were generally less than 2×10^{-10} atm-cm^3/sec even though there are some 200 flanged joints in each sector.
5. The gas load from Viton* "O" rings in valves is negligible. The total area of Viton per sector is 471 cm^2 and the outgassing rate is 2×10^{-9} torr-liter/sec/cm^2. This results in a contribution of approximately 10% of the outgassing load from copper in Stage 1. Although outgassing rates of Viton A have been reported as 1.0×10^{-8} torr-liter/sec/cm^2 after baking and subsequent exposure to air followed by 48 hours of pumping,[4] tests conducted at SLAC by E. L. Garwin and J. Jasberg showed that 2×10^{-9} torr-liter/sec/cm^2 could be attained after 96 hours of pumping.
6. Referring to Fig. 23-2, which represents a typical Stage 1 configuration, the maximum pressure in the accelerator occurs in the middle of a 10-ft section.

The conductance C_{as} of an accelerator section from the center to an end cavity was computed from the formula[5]

$$C = 12.1 \frac{D^3}{L} \alpha$$

where D = the diameter of the tube in centimeters, L = the length of the tube in centimeters, and α = the Clausing factor, dependent on the ratio L/D. The average aperture conductance (see Fig. 23-3) was calculated to be

$$C_0 = 47.8 \text{ liters/sec}$$

and the average cavity conductance was calculated as

$$C_c = 445 \text{ liters/sec}$$

It followed, then, that the conductance of the accelerator section from center to end is

$$C_{as} = \left[\frac{(47.8)(445)}{(42 \times 445) + (43)(47.8)}\right] = 1.0 \text{ liters/sec}$$

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* DuPont Company, Wilmington, Delaware.

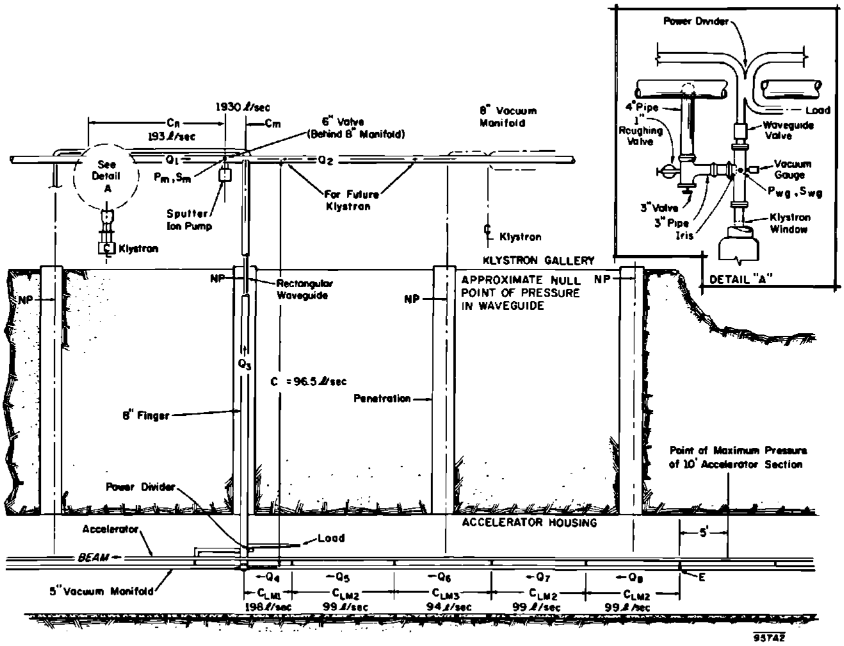


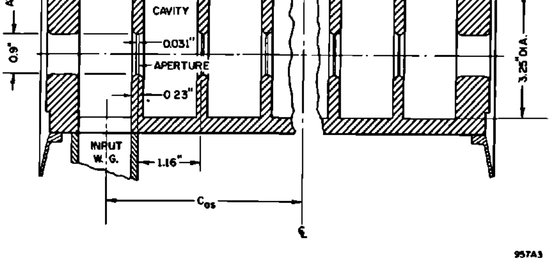
Figure 23-2 Waveguide and manifold configuration for part of a sector.

The conductance of the rectangular waveguide was calculated from the formula[5]:

$$C = 30.9 \frac{a^2 b^2}{(a + b)L} K$$

where a and b are the internal dimensions of the waveguide in centimeters, L is the length of the waveguide in centimeters, and K is a factor depending on the ratio b/a. Hence, the conductance C_{wg} of the waveguide was found to be 66.7 liters/sec for a 1-ft length.

Figure 23-3 Disk-loaded waveguide configuration.



The pressure at the pump, P_p, was computed from

$$P_p = \frac{Q_1 + Q_2 + Q_3}{S_p}$$

where Q_1, Q_2, Q_3 are the gas contributions from the various portions of rectangular waveguide and accelerator section as shown in Fig. 23-2, and S_p is the pump speed.

The pressure at the manifold, P_m, was obtained from

$$P_m = \frac{Q_1 + Q_2 + Q_3}{S_m}$$

where S_m is the effective speed at the manifold, which is given by

$$S_m = \frac{(C_{6\text{-in. valve}})(S_p)}{C_{6\text{-in. valve}} + S_p}$$

$C_{6\text{-in. valve}}$ is the conductance of the valve above the ion pump, and S_p is the speed of the ion pump.

At this point it was possible to write an expression for the pressure at the center of the accelerator section farthest away from the pump:

$$P_{as} = P_m + \left[\frac{Q_2 + Q_3}{C_m} + \frac{Q_3}{C_f} + \frac{Q_4}{C_{\text{LM1}}} + \frac{Q_5}{C_{\text{LM2}}} + \frac{Q_6}{C_{\text{LM3}}} + \frac{Q_7}{C_{\text{LM2}}} \right.$$
$$\left. + \frac{Q_8}{C_{\text{LM2}}} + \frac{Q_8}{C_{po}} + \frac{Q_{as}}{C_{5'wg}} + \frac{Q_{5'wg}}{2C_{5'wg}} + \frac{\frac{1}{2}Q_{as}}{2C_{as}}\right]$$

In this equation, Q_2, Q_3, Q_4, Q_5, Q_6, Q_7, Q_8, Q_{as}, $Q_{5'wg}$, and $\frac{1}{2}Q_{as}$ are individual gas contributions in torr-liters per second, and C_m, C_f, C_{LM1}, C_{LM2}, C_{LM3}, C_{po}, $C_{5'wg}$, $2C_{5'wg}$, and $2C_{as}$ are the corresponding conductances in liters per second as shown in Figs. 23-2 and 23-4. The latter equation was simplified by introducing the surface outgassing rate, d, yielding

$$P_{as} = d\left[\frac{368 \times 10^3}{S_p} + 20.2 \times 10^3\right]$$

so that for $d = 1 \times 10^{-11}$ torr-liter/sec/cm^2,

$$P_{as} = \frac{3.68 \times 10^{-6}}{S_p} + 2.02 \times 10^{-7}$$

This showed that the lowest pressure attainable at the center of the farthest accelerator section would be 2×10^{-7} torr using an infinitely large pump.

At the time of pump selection, nominal speeds commercially available were 400, 500, and 1000 liters/sec. The 400-liters/sec pump was ruled out because a 500-liters/sec pump cost only 15% more and used the same power supply. The 10% saved per sector by using two 1000-liters/sec pumps and power supplies instead of four 500-liters/sec pumps and power supplies was

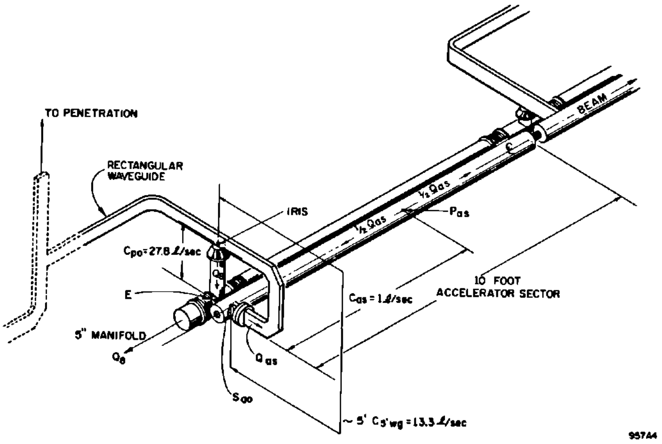


Figure 23-4 Accelerator-waveguide vacuum connection.

more than offset by the added cost of the larger stainless steel manifolds required by the 1000-liters/sec pumps. Therefore, the 500-liters/sec units were considered to be economically optimum. Setting $S_p = 500$ liters/sec, one obtains

$$P_{as} = 2.1 \times 10^{-7} \text{ torr}$$

Therefore, assuming a total copper gas load $Q = 1.5 \times 10^{6} \times 1 \times 10^{-11}$ torr-liter/sec per sector, and designing for four standard 500-liters/sec pumps per sector, the pressure at each pump was found to be

$$P_p = \frac{Q}{4S_p} = \frac{1.5 \times 10^{-5} \text{ torr liter/sec}}{4 \times 500 \text{ liters/sec}} = 7.5 \times 10^{-9} \text{ torr}$$

For stage 2 conditions with one klystron per 10-ft accelerator section, the gas load would be increased by additional rectangular waveguides. The pump pressure would increase from 7.5×10^{-9} to 9.5×10^{-9} torr. Pressure in the accelerator section should not be affected appreciably.

The effective pumping speed at the klystron waveguide window, S_{wg}, with a 500-liters/sec pump was calculated as follows:

$$\frac{1}{S_{wg}} = \frac{1}{S_p} + \frac{1}{C_{\text{6-in. valve}}} + \frac{1}{C_n} + \frac{1}{C_{\text{4-in. pipe}}} + \frac{1}{C_{\text{3-in. valve}}} + \frac{1}{C_{\text{3-in. pipe}}} + \frac{1}{C_{\text{iris}}}$$

i.e.,

$$\frac{1}{S_{wg}} = \frac{1}{500} + \frac{1}{1300} + \frac{1}{193} + \frac{1}{176} + \frac{1}{250} + \frac{1}{160} + \frac{1}{100} \text{ sec/liter}$$

or

$$S_{wg} = 29.5 \text{ liters/sec}$$

Thus, the pressure at the waveguide window pumpout is

$$P_{wg} = \frac{\text{area}_{60'wg}\, d}{S_{wg}} = \frac{60 \times 649 \times 1 \times 10^{-11}}{29.5}$$

$$P_{wg} = 1.3 \times 10^{-8} \text{ torr}$$

The effective pumping speed at the accelerator section input coupler as shown in Fig. 23-4 was calculated as follows:

$$\frac{1}{S_{ao}} = \left(\frac{1}{S_p} + \frac{1}{C_{6\text{-in. valve}}} + \frac{1}{C_m} + \frac{1}{C_f} + \frac{1}{C_{5\text{-in. manifold}}}\right)\frac{1}{2} + \frac{1}{C_{po}} + \frac{1}{C_{5'wg}}$$

$$= \left(\frac{1}{500} + \frac{1}{1300} + \frac{1}{1930} + \frac{1}{96.5} + \frac{1}{22}\right)\frac{1}{2} + \frac{1}{27.8} + \frac{1}{13.3} \text{ sec/liter}$$

$$S_{ao} = 7.1 \text{ liters/sec}$$

Although this is some 30% below the value in the design criteria, it was deemed satisfactory and has proven adequate in operation. Also it should be kept in mind that for 16 of 32 accelerator sections the length of waveguide between the vacuum system pumpout and the accelerator section input coupler is reduced from 5 ft in length to only 14 in., which approximately doubles the effective pump speed at the input coupler.

Subsystem arrangement (SRC, KGC)

The accelerator system extends over 10,084 ft including the injector and thirty sectors of accelerator, each 333 ft, 4 in. long. Each of the thirty sectors is handled as an independent subsystem. Except for the cross-tie between the injector and Sector 1, the only connection between subsystems is through the 2-mile length of disk-loaded waveguide. Sector 11 is further subdivided and a separate subsystem is provided to minimize the effect on the rest of the sector of an accident at the positron source. The injector is also served by a separate subsystem with one 500-liter/sec sputter-ion-pump connected to the rectangular waveguide in the klystron gallery and smaller pumps connected to the injector proper in the accelerator housing. To provide backup, this subsystem is also tied through an isolation valve to the Sector 1 manifold in the klystron gallery, as shown in Fig. 23-5.

A typical sector vacuum system for Stage 1 is shown in Fig. 5-19. Four sputter-ion pumps, each rated at 500 liters/sec, adequate for both Stage 1 and Stage 2, are connected by 6-in. valves to an 8-in. manifold in the klystron gallery extending the full length of the sector. A similar 5-in. manifold is located in the accelerator housing. The two manifolds are interconnected by four 8-in. vertical fingers passing through 27-in. diameter service penetrations spaced approximately 80 ft apart.

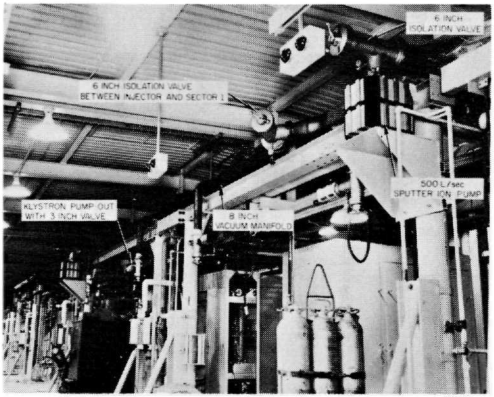


Figure 23-5 Cross-connect valve between injector and Sector 1.

Four-inch branches on approximately 40-ft centers connect the waveguide pumpouts near each klystron window to the 8-in. manifold. A 3-in. manual valve is included in each branch. Provisions are made for the future connection of twenty-four additional klystrons in each sector. In the accelerator housing, a pumpout at each of the thirty-two couplers (rectangular waveguide to disk-loaded waveguide) connects the accelerator to the 5-in. vacuum manifold.

A 5-in. finger connects the 8-in. klystron gallery manifold to the 10-ft drift section at the end of each sector in the accelerator housing. This drift section contains beam-monitoring and guidance apparatus. The drift section can be isolated from the sector vacuum subsystem by closing a 3-in. finger valve (similar to the klystron valves) in the klystron gallery and closing the beam-line valves at each end of the drift section. The upbeam valve is manually operated, but the valve at the downbeam end of the drift section is a spring-actuated fast-acting valve which closes in the order of 9 msec. These fast valves close automatically to isolate a sector in the event of accidental loss of vacuum.

Each klystron is isolated from the sector vacuum subsystem by a waveguide window, as shown in Fig. 23-2. A valve located in the rectangular waveguide approximately 2 ft above this window, used in conjunction with the 3-in. klystron valve, permits replacement of klystrons without interrupting accelerator operation.

The vacuum system in Sector 11, shown schematically in Fig. 23-6, differs from the conventional sector subsystem in the measures taken in anticipation of a water or air leak at the positron source on girder 11-3A.

The 5-in. sector manifold is interrupted and pumpout connections adjacent to girder 11-3A are eliminated to preclude the possibility of bypassing fast valves 11-2 and 11-3. The closing of valves 11-2 and 11-3 establishes a first line of defense against contamination of neighboring accelerator sections by

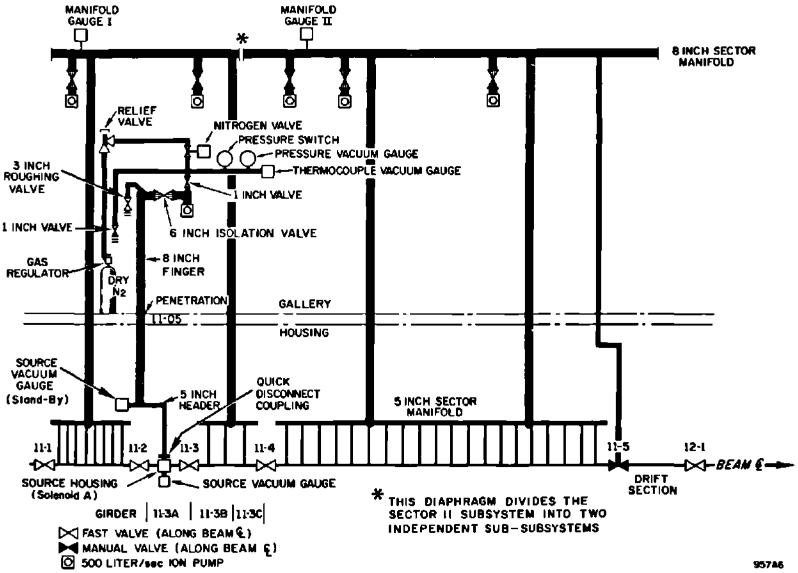


Figure 23-6 Positron source vacuum subsystem.

isolating components particularly vulnerable to leakage, such as quick-disconnect couplings and bellows, along the intervening girder 11-3A drift tube.

Double protection for accelerator sections upbeam from fast valve 11-1 and for accelerator sections downbeam from girder 11-3C is achieved by adding fast valve 11-4 and by interrupting both the 8-in. header in the klystron gallery and the 5-in. manifold in the accelerator housing. The manifold is separated at the downbeam end of girder 11-3C. The header is blocked by a metal diaphragm just downbeam from the finger serving accelerator sections 11-3B and 11-3C. Manifold gauge I monitors the vacuum and operates the interlocks in the downbeam two-thirds of the sector. Manifold gauge II monitors the vacuum and operates the interlocks in the upbeam one-third of the sector.

Pumping capacity between fast valves 11-2 and 11-3 is provided through a separate positron vacuum subsystem, which includes a 500-liters/sec sputter-ion pump, a pair of cold cathode-type ion gauges, a 3-in. roughing valve, a 6-in. pump isolation valve, a combined 8-in. header and finger, and a 5-in. header in the accelerator housing. To facilitate replacement of the radiator strongback carrying the beam line and service equipment on girder 11-3A, a 6-in. indium-sealed quick-disconnect coupling of the type used in the BSY is interposed between the end of the 5-in. header and the source housing to reduce the radiation exposure of personnel working on the joint. To minimize response time, the source vacuum gauge is located on the 5-in. header as near as possible to the points of probable leakage. The standby gauge is mounted in a region of minimum residual radioactivity where it is more readily

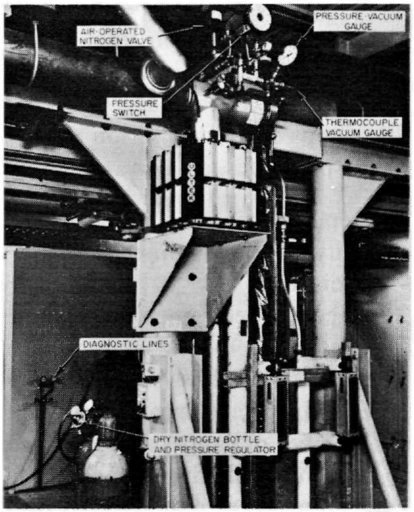


Figure 23-7 Positron source flood control.

accessible for replacement. The cable from either gauge can be plugged into the controller in the klystron gallery.

Rapid application of gas counterpressure in the event of a suspected water leak anywhere in the positron vacuum subsystem is an important feature of the so-called "flood control system." The valves, gauges, and pressure switch used to introduce and control gas flow are mounted on a manifold attached to the positron vacuum subsystem through a 1-in. valve attached to the 6-in. isolation valve body as shown in Figs. 23-6 and 23-7. When the thermocouple gauge controller in the Sector 11 instrumentation and control alcove registers a pressure rise in the subsystem to above 10^{-2} torr, an electrically controlled, air-operated nitrogen valve opens, admitting 30 psig of dry nitrogen in an attempt to stop further entry of water or air. When the gas pressure in the manifolds builds up to 5 psig, actuation of the pressure switch closes the nitrogen valve, opens the drain valve, and stops the solenoid and radiator cooling-water pump. A 1-in. valve, accessible from the klystron gallery floor, can be used for attachment of a leak detector or for introducing gas to let the subsystem up to atmospheric pressure.

Sputter-ion pumps (SRC)

Two types of pumps which appeared to be most applicable were considered during the preliminary design: sputter-ion pumps and oil-diffusion pumps baffled by molecular sieve traps with mechanical backing pumps. Liquid nitrogen baffles were ruled out due to high operating cost and complexity of operation. The cost of the diffusion pump scheme appeared to be 5% less than that of the sputter-ion pump scheme. However, the total power demand during high-vacuum operation would be 400 kW for diffusion pumps versus 12 kW for ion pumps. This represents a significant saving which, over a 10-yr period, would exceed the initial cost differential. The principal advantages of sputter-ion pumps over oil-diffusion pumps are listed below, not necessarily in order of importance:

1. Replacement of expensive diffusion pump oil is eliminated and the possibility of oil contamination of the waveguides during normal operation is avoided.
2. Once in operation, no attendance is required and the maintenance problems of mechanical equipment and associated controls and safety devices are eliminated.
3. Pump current measurement indicates pressure directly, reducing the number of gauges and gauge controllers required.
4. An inherent advantage is the fact that as vacuum improves, sputter-ion pump power requirements decrease. It was estimated that power costs for the ion pumps would be approximately 3% of that for diffusion pumps.

The applicability of diode-type sputter-ion pumps was proved by a series of tests conducted over a 6-month period at a "tree-house" test facility consisting of one 40-ft module of the accelerator. During these tests, the performance of diffusion pumps was compared with that of sputter-ion pumps. The residual gases were monitored with RF power on, and it was found that the principal gases were H_2, H_2O, CO, and CH_4, with H_2 dominating, particularly during gas bursts resulting from transient effects such as multipactoring. Because H_2 is very active, sputter-ion pumps inherently have a pumping speed for H_2 which is twice that for air. This characteristic enhanced the desirability of their use on the accelerator. Over a period of approximately 9 months at this test facility, a 400-liters/sec sputter-ion pump was repeatedly let up to gaseous nitrogen and air with no serious effect on subsequent pumping speeds or recovery times.

Sputter-ion pumps operate on the principle of the Penning* cold cathode discharge arranged to trap gas molecules in a metallic film. The pumps start at a pressure of approximately 10^{-2} torr and reach full pumping speed at a pressure of approximately 10^{-5} torr. A magnetic field is used to increase the electron path length and the probability of ionizing collisions between electrons and gas molecules. Positive ions are accelerated toward the titanium cathodes where sputtering of the titanium occurs. The gaseous ions are pumped by (1) entrapment in the sputtered material, the majority of which ends up on the anode, (2) burial in the cathode, and (3) chemical reaction with the sputtered titanium. Pumping speeds for the noble gases in diode-type pumps are much lower than for the more active gases, e.g., the speed for argon is

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* F. M. Penning, "Coating by Cathode Disintegration," U.S. Patent No. 2146025 (February 7, 1939).

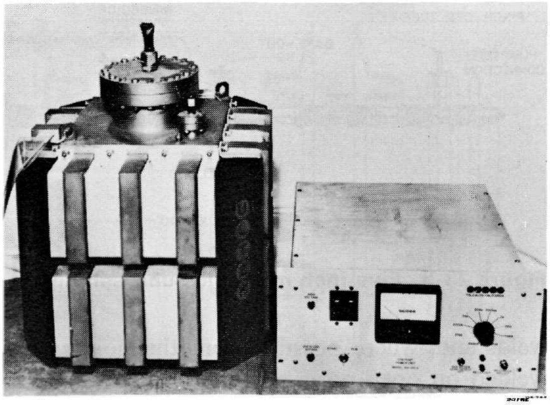

Figure 23-8 Sputter-ion pump and power supply.

approximately 1% of the speed for nitrogen and the speed for helium is about 10% that of nitrogen. Triode pumps have higher speeds for the noble gases. However, the accelerator operates as a sealed system with negligible air leaks so that the presence of noble gases is no problem. For this reason, commercially available and proven diode sputter-ion pumps were selected. The pump and power supply used are shown in Fig. 23-8.

Manifold piping (SRC)

The long pumping paths and low inherent conductances dictated that a clean system with a minimum of real and virtual leaks should be provided in order to minimize the size and related cost of pumps. System materials are (1) 304L stainless steel for piping, flanges, and valves, (2) OFHC* copper for the waveguides and waveguide flange gaskets, and (3) Viton A† "O"-ring seals in klystron gallery valve seats. To improve reliability, welded connections, rather than bolted flanges, were used where feasible. The Viton "O" rings used for valve seals were baked in a vacuum furnace at 150°C for 12 hours prior to installation in the valve. The OFHC copper rectangular and disk-loaded waveguides were chemically cleaned and processed at full RF power prior to installation.

During fabrication, manifold components were handled in pressurized clean rooms with filtered air supply. Individual parts were cut to length, degreased and cleaned, rinsed with city water, rinsed in warm deionized water, and dried in filtered warm air. Parts were then welded by the tungsten inert gas fusion process. An inert atmosphere within the subassembly was ensured by an argon gas purge. Automatic welding techniques were used for butt

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* American Metal Climax, Inc., New York, N.Y.

† DuPont Company, Wilmington, Delaware.

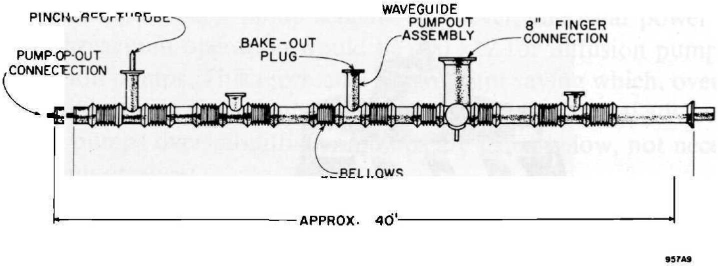
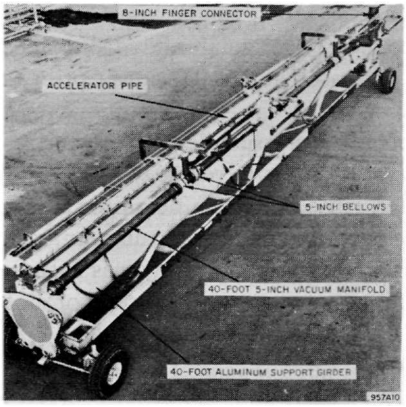


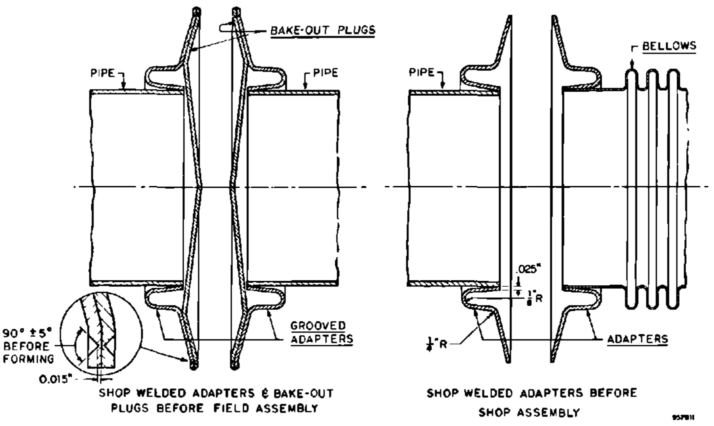
Figure 23-9 Five-inch manifold subassembly.

welds and, where possible, for other joints. Temporary bakeout plugs were welded on open ports of the subassembly. A temporary pumping port was provided for connection to vacuum processing pumps. Eight manifold subassemblies were mounted on a steel cart and connected to a liquid-nitrogen trapped, mercury diffusion pump. The eight manifolds were baked out simultaneously in a special furnace with the temperature maintained at 400° to 425°C for a period of 24 hours. After bakeout, the subassemblies were checked by the rate-of-pressure rise technique for compliance with the specified maximum outgassing rate of 1×10^{-12} torr-liter/sec/cm^2. They were then let up to dry nitrogen through pinch-off tubes on the end opposite the pump connections. The nitrogen purge was maintained while the pumped end was separated from the pumping manifold and a cap welded on. The let-up connection was then pinched off and the subassembly was crated for shipment. A completed 40-ft long, 5-in. manifold subassembly is shown in Fig. 23-9.

Forty-foot long, 8-in. and 5-in. manifold subassemblies were sealed, backfilled with dry nitrogen in the manner described above, and delivered to the field. The 5-in. manifold subassemblies were installed on the 24-in. support girders and connected to the waveguides in the SLAC shops. The completed

Figure 23-10 Forty-foot girder ready for installation.





SHOP WELDED ADAPTERS & BAKE-OUT PLUGS BEFORE FIELD ASSEMBLY

SHOP WELDED ADAPTERS BEFORE SHOP ASSEMBLY

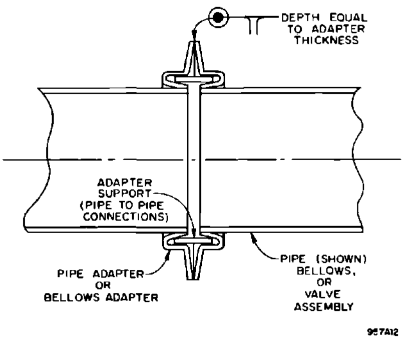
Figure 23-11 Weld joint adapters.

girder assembly ready for installation in the accelerator housing is shown in Fig. 23-10. During field installation, a positive pressure of dry nitrogen was maintained inside the piping.

The special adapters used to connect pipe to bellows and for joints made in the field are shown in Fig. 23-11. In the latter application, both the adapter and the temporary bakeout plug installed in the shop have a 90° V-groove, $\frac{1}{8}$ in. from their outer edges. The bakeout plug is welded to the outer edge of the adapter beyond the groove. In the field, the area between the apex of the groove and the outer edge is peeled off and the field weld connecting the adapters made at the new edge as shown in Fig. 23-12.

Bellows are provided to (1) allow for thermal expansion, (2) prevent excessive loading of the accelerator structure, particularly during accelerator alignment procedures, and (3) to facilitate installation. There is a total of ninety 8-in. bellows and 1920 5-in. manifold bellows in the complete accelerator vacuum system installation.

Figure 23-12 Adapter field weld.



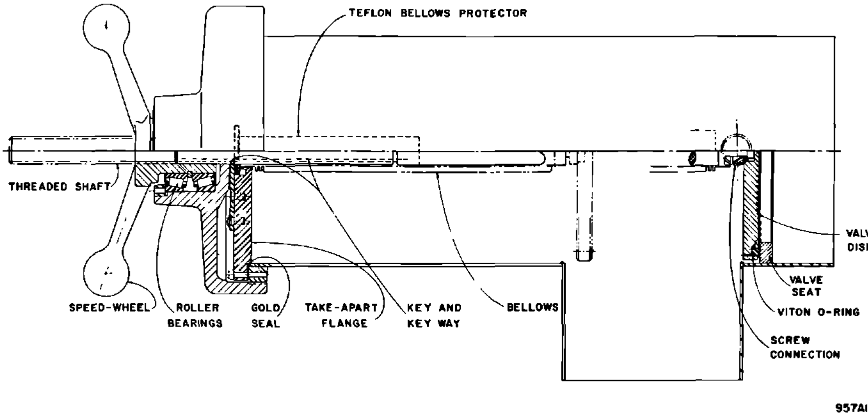


Figure 23-13 Cross section of 6-in. valve.

Klystron gallery valves (SRC)

Valves located in the klystron gallery are used to isolate sputter-ion pumps, klystrons, and drift sections. In addition, a 1-in. roughing valve is attached to each isolating valve. The roughing and isolation valves are of the angle type with a bellows-sealed stem. Inasmuch as there are 150 6-in. valves and 270 3-in. valves, cost considerations precluded the use of all-metal stainless steel valves and led to the selection of Viton A "O" rings for seals at valve seats. Other valve material exposed to vacuum is 304L stainless steel.

A cross section of the 6-in. valve is shown in Fig. 23-13. The 3-in. valves are similar. Flanges with gold-wire seals are used to separate the valve interior from the atmosphere. An unusual feature of this valve is the detachable valve disk held to the stem by means of a screwed connection. This allows the bellows and valve operator, which are the least reliable components, to be replaced with vacuum maintained in the system.

For isolation of the vacuum gauges mounted on the thirty 8-in. manifolds, a bakeable, all-metal, commercially available valve was used, since the pressence of an elastomer at the gauge could give erroneous readings. It was also felt that it would be necessary to bake the cold cathode gauges periodically to 400°C. Therefore elastomers are not suitable for this application. A 12-in. long, $\frac{1}{4}$-in. diameter, pinch-off tube is provided to allow roughing of the gauge volume when replacement is necessary.

Beam-line fast-acting valves (ALE)

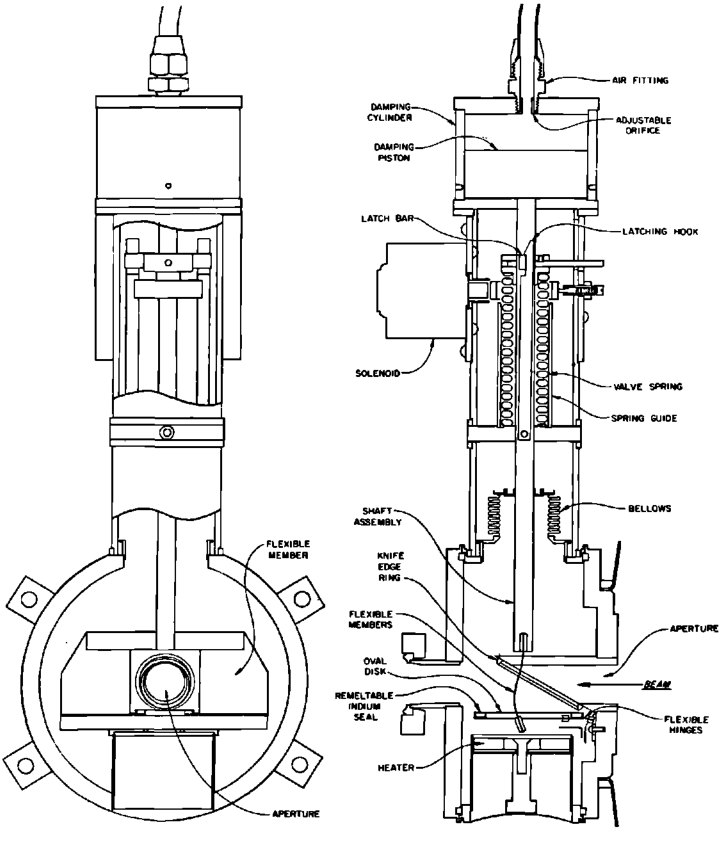
A fast-acting vacuum valve[6] for applications along the electron beam axis was developed and installed at the downbeam end of each 333-ft, 4-in. sector. The valve closes in 9 msec, affording substantial protection for the disk-loaded waveguides against vacuum failure anywhere in the system. The valve is automatically actuated when the pressure rises to a predetermined value.

The actuating signal is provided by the manifold gauge controller described below. The same signal turns off the electron beam. Thus, an individual sector is isolated by the closure of its fast valve and the fast valve at the downbeam end of the preceding sector.

A cross-sectional view of the fast valve is shown in Fig. 23-14. The valve has a 13/16-in. aperture for the electron beam. The oval disk of the valve has a groove in which a remeltable indium seal is located. When the valve is closed, the knife edge ring on the beam aperture tube indents the indium to effect the seal. After each set of 20 to 30 closure cycles, the indium is remelted under high vacuum while the valve is open.

Good reliability of the valve is achieved by virtue of the fact that no sliding or rolling metal-to-metal contacts are necessary in vacuum for the valve to be closed or opened. The cycling is accomplished by flexible metal hinges that are attached to the oval disk. The actuating force is from the stored energy in the compressed spring. The actuation of the valve is initiated by tripping the solenoid which releases the latch hook, allowing the spring to

Figure 23-14 Cross section of beam-line fast valve.



extend and hence move the shaft assembly upward. This action pulls the oval disk closed against the beam aperture seat.

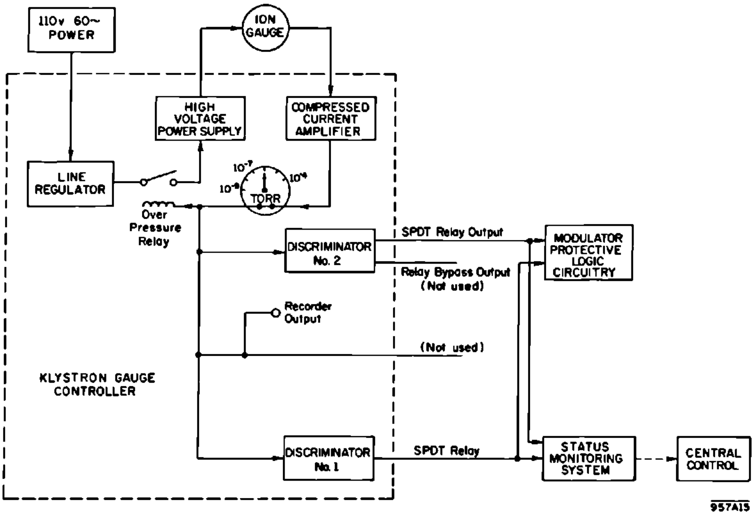
The shaft assembly travels in two bearings and is lubricated by molybdenum disulfide, a permanent lubricant that is relatively unaffected by the radiation environment. The bellows permits the shaft assembly to operate in air at its upper end and in vacuum within the valve body. Molybdenum disulfide is also used as a permanent lubricant for the piston which operates within the cylinder without seals. The air holes in the side of the cylinder provide release of vacuum damping under the piston during the valve closing and also prevent pressure buildup under the piston when it is forced downward to open the valve. An adjustable restriction located in the air fitting at the top of the valve regulates the air escape to achieve the desired damping during valve closure.

Accelerations of 200 to 300 *g* occur during the operation of the valve, requiring the air damping cylinder to cushion the motion at the instant the oval disk seats against the beam aperture. The air cylinder is also used to reset the valve. The air piston is forced down by compressed air until the latch hook re-engages. Actuation and resetting of the valve are readily accomplished remotely. The parts of the valve needing maintenance, such as the spring, solenoid, and damping cylinder assembly, are all outside the vacuum system, so that repairs can be made without disturbing the vacuum side of the valve.

Gauges and controllers (WBP)

There are approximately 280 vacuum gauges required for accelerator operation. A gauge is located at each of the 245 klystrons. The primary function of these gauges is to protect the klystron and klystron window from damage

Figure 23-15 Klystron gauge logic diagram.



due to operation with a poor vacuum. The gauge senses any degradation in vacuum and the klystron gauge controller opens an interlock chain which takes the klystron modulator and hence the klystron out of operation. As shown in Fig. 23-15, the status of the gauge is also available at central control via the status monitoring system.

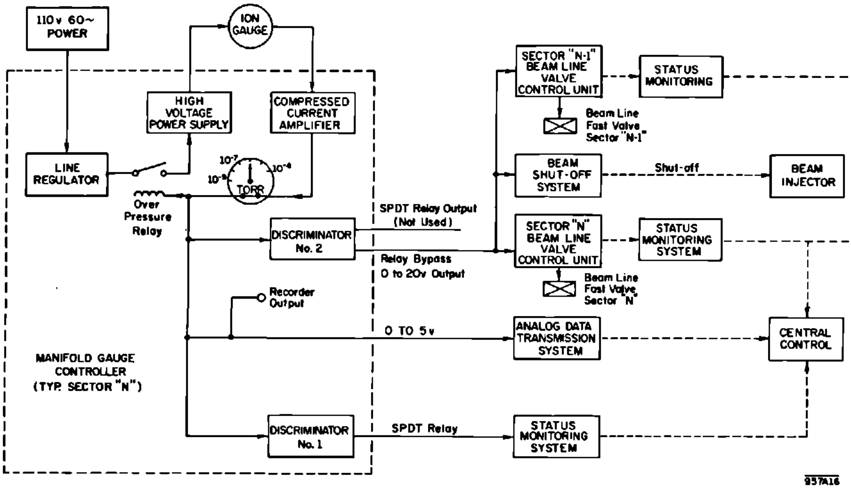
A gauge is located in the klystron gallery near the center of each of the thirty sector manifolds. Five gauges are located in the accelerator housing at the positron source and beam-analyzing stations. These thirty-five manifold gauges have two primary functions: to give a representative sector vacuum indication and to sense a vacuum failure and cause the manifold gauge controller to generate a fast response signal closing the beam-line fast valves at each end of the sector. A schematic of the manifold gauge controller appears in Fig. 23-16.

The vacuum gauges selected for the accelerator are of the cold cathode discharge type. These were selected over the more widely used hot filament type because they have greater sensitivity by a factor of 10 to 20, they require simpler electronics because of the higher sensitivity and elimination of the hot filament, construction is more rugged because of the metal envelope, and they have a longer life.

Criteria set for the gauge performance were as follows:

1. Operation should be stable from 10^{-4} to 10^{-9} torr
2. Their sensitivity for nitrogen should be within ±50% of the nominal specified value
3. The maximum sensitivity variation for each individual gauge should be stable within ±25%
4. The maximum start-up time at 10^{-8} torr should be 30 seconds
5. All-metal construction bakeable to 400°C should be used
6. The maximum operating voltage should not exceed 4000 V dc.

Figure 23-16 Manifold gauge logic diagram.



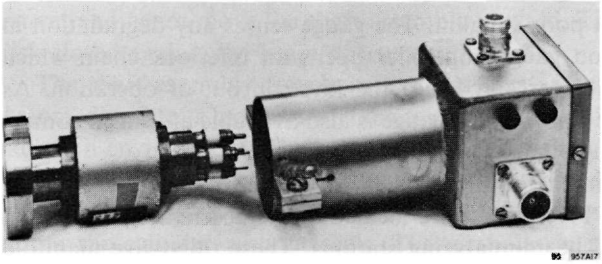


Figure 23-17 Vacuum gauge and guard.

The performances of cold cathode-type discharge gauges supplied by several manufacturers were checked on a test dome and on the previously mentioned "tree house," a 40-ft accelerator hot test facility. The test dome was capable of handling as many as eight gauges simultaneously. The gauge ion current was measured on a calibrated micromicroammeter and compared with the pressure in the test chamber. Pressure measurements in the chamber were obtained by comparison with a gauge calibrated by an independent laboratory and by a "known pumping speed–known volume of gas" method.

Calibration curves compared fairly well over the desired pressure range. Other problems, however, developed with gauges of two different designs. One problem, common to both designs, was instability. This was due to the existence of two different modes of operation which resulted in a change of sensitivity and pressure indication by as much as a factor of 3. Also, gauges of one design frequently extinguished and would not restart at pressures below 10^{-7} torr. After exhaustive tests, the General Electric* all-metal, cold cathode gauge with a permanent magnet and a starting filament was selected as most nearly in conformance with SLAC specifications. This gauge is shown in Fig. 23-17.

Specifications for vacuum gauge controllers were written with the intention of purchasing the controllers from a commercial supplier. Fifteen units were purchased from each of two different manufacturers. After considerable testing and evaluation, it was determined that neither model would satisfy all requirements. As a consequence, an in-house project was initiated to design an acceptable unit.

The design philosophy was to use the best components available and, if at all possible, to use only silicon semiconductors within the controller. The ambient operating temperature for the controllers varies from 0° to 60°C. The relative humidity can be as high as 100%.

The cold cathode gauge chosen for use on the accelerator requires 2500 V and a separate starting filament voltage. The sensitivity of the gauge is approximately 2.5 A/torr. The operating range is from 10^{-9} to 10^{-4} torr, with currents of 2.5×10^{-9} to 2.5×10^{-4} A available for display and control. It

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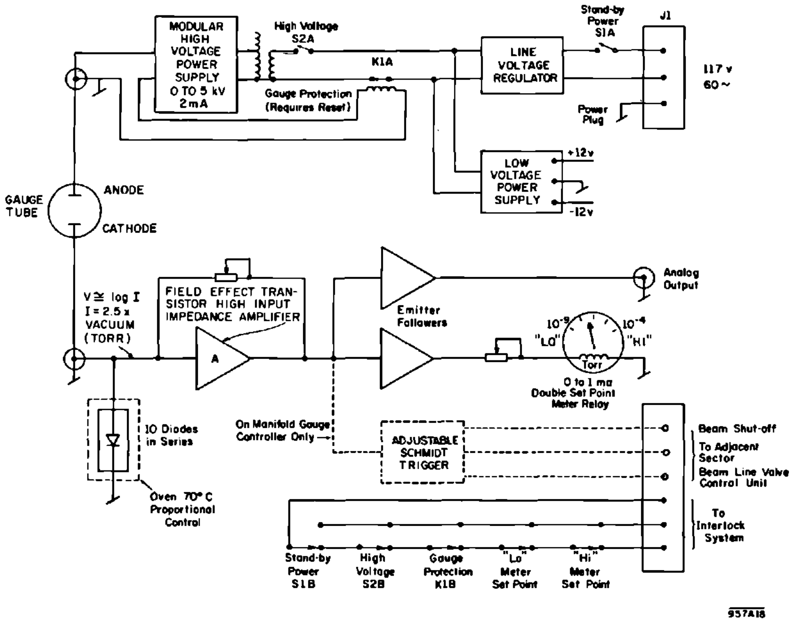
* General Electric Company, Vacuum Products Operation, Schenectady, New York.

was decided that the five-decade range of current should be covered on a single logarithmic meter scale with no range switching.

To meet the interlock requirements, it was necessary that all 280 controllers used with both klystron and manifold gauges be fail-safe and initiate protective action for the system when the vacuum deteriorates below a preset adjustable level. In addition, a fast response output was required from the thirty-five controllers used with the manifold gauges, in order to close the beam-line valves in time to preserve the vacuum in the adjacent sectors. Total closing time from fault-sense to valve closure is less than 12 msec; 9 msec are required for valve closure alone.

As shown schematically in Fig. 23-18, the controller contains a modular, high-voltage power supply. Adjustment over the range of 0 to 5 kV is accomplished by a small adjustable autotransformer across the input. An overcurrent relay protects the unit from destruction due to gauge shorting. To present the five decades of current which will be passed by the gauge as the vacuum varies over the five decades of pressure, a scale compression, or log amplifier, is required. A voltage proportional to the log of the current is obtained by passing the current through a silicon diode and observing the voltage. Ten diodes were placed in series to increase the voltage output level; this also served to reduce the effects of variation in diode characteristics. The series diodes were placed in a proportional control-type oven to maintain a constant temperature and thus keep amplifier drift, measured at the amplifier output, within the required specification of less than 0.25 V, or 5%, over the ambient

Figure 23-18 **Schematic of vacuum gauge controller.**



temperature range of 0° to 60°C. The amplifier that follows the diodes is a high-current gain amplifier with considerable voltage feedback. Since very low currents are measured at the input, a high impedance device is necessary. A low leakage field-effect transistor was used with very satisfactory results. The output of the amplifier corresponding to the 10^{-9}–10^{-4} torr range is 0–5 V. This analog output is available for remote indication. Klystron protection is obtained from relay contacts on a front panel meter driven from the 0–5-V analog signal.

Rapid response to vacuum failure is required of the manifold gauge controller. The fast output used to close the valves isolating the sector is a pulse of 2 msec duration and 20 V amplitude derived from a Schmidt trigger-type circuit.

Cryosorption roughing pump sets (GIS)

Roughing pumps are required to reduce the pressure in the accelerator vacuum system to below 10^{-2} torr before the main sputter-ion pumps can be started. This is done by a mobile, three-stage cryosorption pump utilizing molecular sieve material cooled by liquid nitrogen.

The volume of each sector subsystem is approximately 9000 liters and each is roughed separately. A permanent roughing system was originally proposed for each sector. As planning progressed, it became obvious that a reliable vacuum could be maintained with relatively infrequent letups to atmospheric pressure. Sector isolation by fast valves so that not more than three sectors would be affected in the event of a major leak was also a factor in the decision to use portable roughing equipment.

The use of high vacuum equipment such as diffusion and turbomolecular pumps was initially considered for roughing service, since it was felt that sputter-ion pump life and performance could be substantially extended if the starting pressure were limited to a maximum of 1×10^{-6} torr. Tests conducted on the " tree house " facility indicated that sputter-ion pumps operated adequately when repeatedly started at pressures of 10^{-2} to 10^{-3} torr. Consequently, the types of pumps offered for final consideration were multistage cryosorption pumps, liquid nitrogen-trapped mechanical pumps, and Roots blower with liquid nitrogen trap and mechanical pump.

Cryosorption roughing as originally proposed[7] included a combination of mechanical and cryosorption pumps. Tests were conducted with systems utilizing a mechanical pump and a two-stage cryosorption pump. It was found that a pressure of 2×10^{-4} torr was reached in 1½ hours.[8] In this series of tests, 2×10^{-4} torr was reached in 3½ hours using a prototype, three-stage, cryosorption unit without a mechanical pump. After reviewing the design of the large cryosorption pumps with the manufacturer, it was concluded that by incorporating some minor modifications and using a different molecular sieve material (Linde 5AX),* pressures of 2×10^{-4} torr could be reached

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* Union Carbide Corporation, Linde Division, New York, New York.

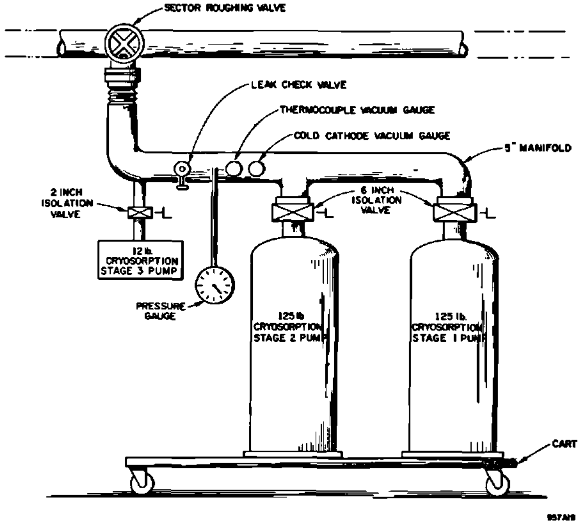
without the mechanical pump in less than 2 hours, including the time required to cool the cryopumps down to operating temperature.

In order to eliminate the possibility that oil from the mechanical pump might contaminate the waveguides, it was finally decided to rely exclusively on molecular sieve cryosorption pumps.

Two identical cryosorption pump sets were procured, each consisting of two large and one small cryopump. The large Stages 1 and 2 pumps contained 125 lb of Linde 5AX molecular sieve material. The small Stage 3 pump contained 12 lb of the same material.

The complete cryosorption pump set is mounted on a mobile frame, including vacuum and liquid nitrogen valves, manometer, thermocouple and cold discharge gauges, and temperature-sensing devices. A schematic of the pump set is shown in Fig. 23-19 and actual equipment is shown in Fig. 23-20. Molecular sieve material in the large pumps is reactivated by compressed air electrically preheated to 315°C. Because the small pump absorbs relatively little gas when used in the third and last stage of the roughing cycle, it is reactivated at ambient temperature. After the sieve material is reactivated and with the sector roughing valve still closed, valves above each pump are opened and the large Stage 1 pump is chilled with liquid nitrogen. When the pressure in the 5-in. roughing manifold reaches approximately 10^{-2} torr, the 2-in. valve above the small Stage 3 pump and the 6-in. valve above the large uncooled Stage 2 pump are closed. These preliminary operations require approximately 25 min. Roughing then begins when the sector roughing valve is opened. While Stage 1 is pumping the other two stages are being chilled.

Figure 23-19 Schematic of sector roughing pump set.



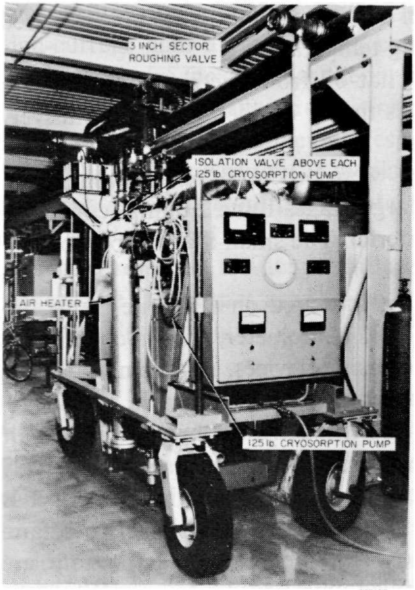


Figure 23-20 Sector roughing pump set.

Stage 1 is valved off when the pressure reaches approximately 200 torr after 50 min of pumping and Stage 2 is valved in. From the curve in Fig. 23-21, it is seen that a pressure of 10^{-3} torr can be reached in about 75 min using two of the three stages. By closing off Stage 2 and valving in the small Stage 3 pump, a further reduction in pressure to 3×10^{-4} torr can be achieved in another 15 min or so.

Liquid nitrogen consumption for a complete pumpdown is 350–400 liters. Each large pump requires about 100 liters for cooldown and 75 liters for pumpdown. The small pump consumes about 40 liters total for cooldown and pumpdown.

Because the useful life of each of the 245 klystrons in Stage 1 is limited to several thousand hours, one or more klystrons may have to be replaced every day. In order to accomplish this without disrupting the vacuum system, two valves were incorporated in the klystron-waveguide system. One is a 3-in. stainless steel valve with a Viton "O" ring seal. It is located in the klystron window pump-out connection. The other is an all-metal, remeltable indium-sealed valve built into the copper waveguide and further described in Chapter 11. The 3-in. valve has a 1-in. roughing valve on the klystron side. A typical arrangement is shown in Fig. 23-22. After klystron replacement, a small portable roughing system is used to evacuate the volume of approximately 9 liters between the 3-in. valve and the waveguide valve. The system consists of a pair of liquid nitrogen-cooled cyropumps, each filled with 2 lb of Linde

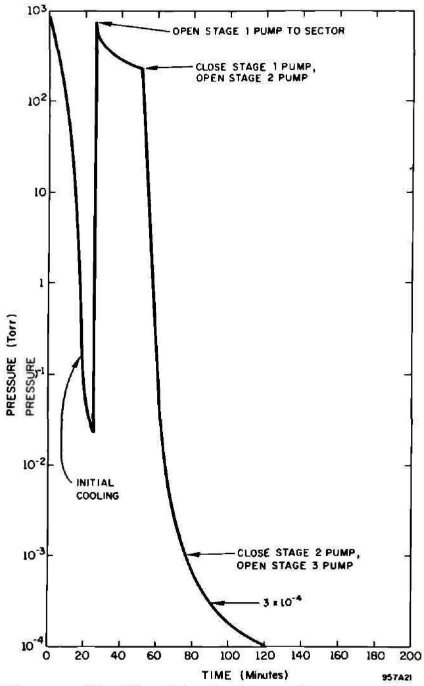
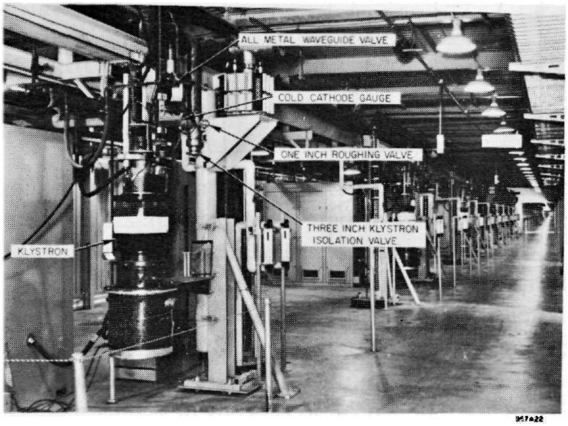


Figure 23-21 Typical sector rough-down cycle.

5A sieve material. Starting at atmospheric pressure, it takes about 5 min to reach 5×10^{-4} torr, assuming letup to dry nitrogen before the previous klystron was removed. At that pressure, the 3-in. valve and the waveguide valve are opened. The momentary rise in subsystem pressure, measured at the window of the nearest klystron, is about two decades.

Figure 23-22 Klystron vacuum arrangement.



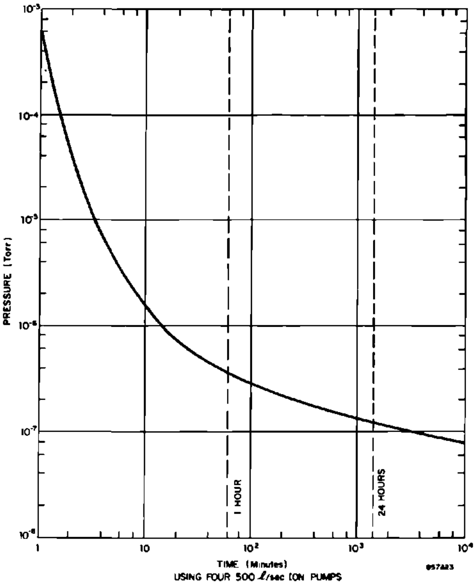
Operating experience (MEB)

The accelerator vacuum system has performed essentially as predicted. The base pressure has continued to improve with time and now is approximately 8×10^{-9} torr at the sputter-ion pumps and 3×10^{-8} at the klystron windows with no RF on. With RF and beam on, these pressures increase by a factor of about 2. As shown in Fig. 23-21, a cryosorption pump set is capable of roughing a typical sector from dry nitrogen at atmospheric pressure to 3×10^{-4} torr in approximately $1\frac{1}{2}$ hours, including the time required for cooldown of the pumps. The additional time required for the four sputter-ion pumps to bring the sector down to operating pressure is shown in Fig. 23-23.

The 500-liters/sec sputter-ion pumps have been trouble-free with one exception. The original high-voltage cable connectors supplied with the pumps were poorly insulated and required replacement with a new type. The old connectors exhibited corona, and the resulting high ozone concentration led to corrosion of the metal end of the power feedthroughs. As a result of this corrosion, a deposit was formed on the ceramic insulators. Cracks then developed in the insulators, causing serious leakage. After many months of continuous operation with the new connectors, no failures of this nature have occurred.

The large cryosorption pump sets have proven extremely useful and reliable. No degradation in their performance has been noticed since the original acceptance tests. During a sector pumpdown, the liquid nitrogen required to cool the cryopumps is supplied from a 600-liter mobile tank. The same tank

Figure 23-23 Sector pumpdown.



is used for letting a sector up to nitrogen. Letup from high vacuum to 1 psig requires approximately 45 min.

No major problems have been encountered with the "O" ring-sealed 1-in., 3-in., and 6-in. valves or with the indium-sealed waveguide valves. The ion pump power supplies, gauge power supplies, and gauge tubes have also performed as expected with only filter and indicator light replacement being necessary.

Leak detection has not presented any serious problems thus far. Probably the primary reason is that there have been very few problem leaks since installation. In most cases, the location is obviously where a new component or drift section has just been installed. Except for very large leaks, a helium mass spectrometer-type leak detector is used. Large leaks can usually be found by spraying with acetone and noting the response of a thermocouple gauge or by use of an ultrasonic leak detector or, in some instances, by the unaided ear. A differential amplifier connected to the recorder output of a sputter-ion pump or vacuum gauge power supply is also occasionally used for leak detection. The suspected area is sprayed with oxygen and argon, and entry of the gas through the leak results in a current change in the gauge or pump. Argon increases the current and deflects the amplifier meter to the right, whereas oxygen reduces the current and causes a left deflection. This method has been successful when the leak is very close to the gauge or pump being used as the sensing element. It does not work well at distances of over 10 or 15 ft or when large volumes are involved. It is difficult to make a general statement concerning response and cleanup times when the helium leak detector is used. A typical situation involves probing a leak in a drift section between sectors in the accelerator housing with the detector connected to a valve in the klystron gallery. In this instance, the response time is of the order of 5 sec for a subsystem pressure in or below the 10^{-5} torr range. If a very small amount of helium is introduced, cleanup time is 5–10 min. If the leak is sprayed heavily with helium, it can take as long as several hours, due primarily to the sputter-ion pump's low pumping speed for helium.

23-2 The alignment light pipe vacuum system

Design criteria (SRC, FFH)

The 24-in. o.d. aluminum support girder in the accelerator housing supports the disk-loaded waveguide and its appurtenances and serves as an evacuated light pipe for the laser alignment system.

The alignment system light pipe extends from a point 178 ft west of the start of Sector 1 to a point in the BSY 102 ft downbeam from the end of Sector 30, a total of approximately 10,280 ft. A 24-in. pumping finger, approximately 50 ft long, extends from the accelerator housing to the pumping station located in the klystron gallery at the end of Sector 30. Extending into the BSY and connected to the 24-in. pipe is about 675 ft of 10- and 12-in. o.d., schedule-40, aluminum pipe. The total volume of this light pipe system is approximately 31,000 ft^3 including an allowance for additional volume in the area of the nine bellows per sector used to connect adjacent girders and for the three target boxes for alignment monuments at Sectors 16, 27, and 30. As outlined in Chapter 22, the vacuum requirement for this system was established at 10^{-2} torr. At this pressure, displacement of the laser beam caused by a 1°C/ft average temperature gradient from top to bottom of the aluminium light pipe will be less than 0.001 in.

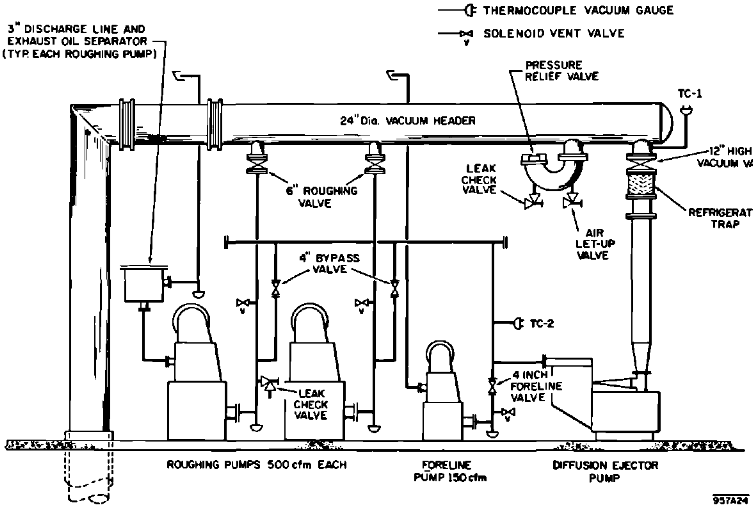
A maximum of 16 hours was proposed for evacuation of the light pipe, thus permitting overnight pumpdown.

System description (SRC)

For roughing down the system, two 500-ft^3/min mechanical pumps were selected. For continuous pumping of the system, an oil diffusion-ejector pump with a speed of 2000 liters/sec was chosen. A refrigerated baffle operating at -30°C was used to minimize contamination of the alignment light pipe. A 150-ft^3/min mechanical forepump was selected to back the diffusion-ejector pump. The exhaust to outdoors from the three pumps was equipped with oil separators to minimize the oil mist which occurs when roughing from atmospheric pressure.

Calculations indicated that a pumping system using this equipment would reach design pressure of 10^{-2} torr after approximately 10 hours pumpdown time[9]. The outgassing rate for the steam-cleaned, unbaked 24-in. girders was found to be approximately 10^{-7} torr-liter/sec/cm^2.

Figure 23-24 Schematic of light pipe vacuum pumping station.



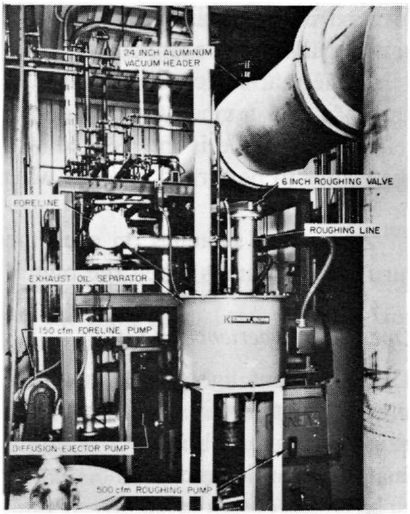


Figure 23-25 Light pipe vacuum pumping station.

All vacuum valves, except for the manual letup and leak test valve, are air operated and controlled as described below.

The arrangement of the pumping station is shown schematically in Fig. 23-24. Figure 23-25 shows the final installation. Provisions have been made for future installation of an additional diffusion-ejector pump and its backing pump, and of an additional 500-ft^3/min roughing pump if leak rates of the system are found to be higher than expected.

Valves are arranged to permit using either one of the roughing pumps to back the diffusion-ejector pump and also to allow roughing with one 500-ft^3/min mechanical pump with the other backing the diffusion-ejector pump.

The motor control center contains all the electrical controls, plus the cooling water, compressed air, vacuum readouts, and relays that are required for operation of the pumping station.

Instrumentation and control (GIS)

The pumping station equipment for the alignment pipe system is protected by pressure, temperature, and shaft speed sensing devices.

Thermocouple vacuum gauges are located so that the pressure on each side of any vacuum valve can be checked before the valve is opened. Referring to Fig. 23-24, gauge TC-1 is on the high vacuum side. Its gauge controller closes the 12-in. valve above the diffusion-ejector pump if the pressure is above a predetermined level. Gauge TC-2 is on the roughing line. Its gauge controller closes the 4-in. foreline valve if the pressure is above a predetermined level. In turn, the diffusion-ejector pump heater is shut off and the 12-in. valve is closed.

A thermal switch on the diffusion-ejector pump heater de-energizes the heater if the temperature exceeds 150°C. Another thermal switch on the refrigerated baffle is interlocked with the diffusion pump heater and allows the heater to be turned on only when the temperature at the baffle is $-20°$C or below.

Zero-speed switches on each mechanical pump shaft are interlocked to turn off the pumps when the pump shaft speed falls below 80% of normal.

Operating experience (KGC)

The alignment light pipe vacuum system has been operating satisfactorily since its installation. An overnight pumpdown brings the system to the required vacuum. Although the rate of pressure rise with pumps turned off is faster than anticipated, it has been possible to maintain an operating pressure close to the design level.

23-3 The beam switchyard system

Design criteria (SRC)

The BSY contains a large number of bending magnets, quadrupoles, and various protection and monitoring devices extending over a length of approximately 1000 ft along three major branches. Associated with these devices are extensive, relatively large volume, vacuum chambers. The high level radiation environment results in severe operation and maintenance problems and imposes the necessity for remote handling of components. For these reasons, it was not economically feasible to design for a pressure as low as the accelerator (10^{-6} to 10^{-7} torr). Fortunately, because high RF fields do not exist in the BSY, vacuum requirements are not as rigorous and a design pressure of 1×10^{-4} torr was used.

The general criteria resulting from the above considerations are described in the preliminary design study.[10] No organics were to be used in those parts of the vacuum system located in the BSY housing. The average pressure was to be less than 1×10^{-4} torr. Time to reach operating pressure after letups to atmospheric pressure was to be less than 6 hours. Remote disconnect-type couplings were to be supplied at each end of every magnet, slit, collimator, and other instruments to facilitate their removal and replacement. Provisions were to be made to protect sections of the vacuum chambers containing delicate instruments from accidental ruptures and letups. The vacuum envelope was to be nonmagnetic. It was to be possible to let any section of the BSY between isolating valves up to air without disturbing the other sections.

The optimum pumping system was found to be the oil diffusion type. The use of these pumps obviated the necessity of providing "windows" to separate the BSY vacuum system from the diffusion-pumped target area vacuum systems. However, it imposed the necessity for an effective means of protecting the "clean" very high vacuum of the accelerator from degradation due to its connection with the "dirty" high vacuum of the BSY. This led to the development of the differential pumping station described in a subsequent section.

Subsystem arrangement (GIS)

Figure 23-26 shows the layout of the BSY. Single or multiple beams enter from the left or west side and exit toward the right or east side along any one or all three of the beam paths.

In order to permit maintenance or replacement of the various instruments without letting the entire switchyard up to air, all-metal isolation valves separate the system into seven distinct volumes, evacuated by eight pumping stations. The stations are located approximately at the center of the separate volumes so as to equalize the gas load and the pressure at the beam line.

To protect delicate instruments from shock waves and flying debris if a vacuum window should break, all-metal fast valves requiring a maximum of 25 msec to close have been located as shown in Fig. 23-26.

Table 23-1 lists approximate areas and volumes pumped by the individual pumping stations, less the areas and volumes of the "fingers" connecting the stations with their respective vacuum chambers in the lower housing of the BSY.

Outgassing rates were assumed to be 10^{-9} torr-liter/sec/cm^2 for unbaked stainless steel and 10^{-8} torr-liter/sec/cm^2 for unbaked aluminum. The average effective pumping speed at the vacuum finger connection to the beam was calculated to be approximately 150 liters/sec.

Figure 23-26 Schematic of beam switchyard vacuum system.

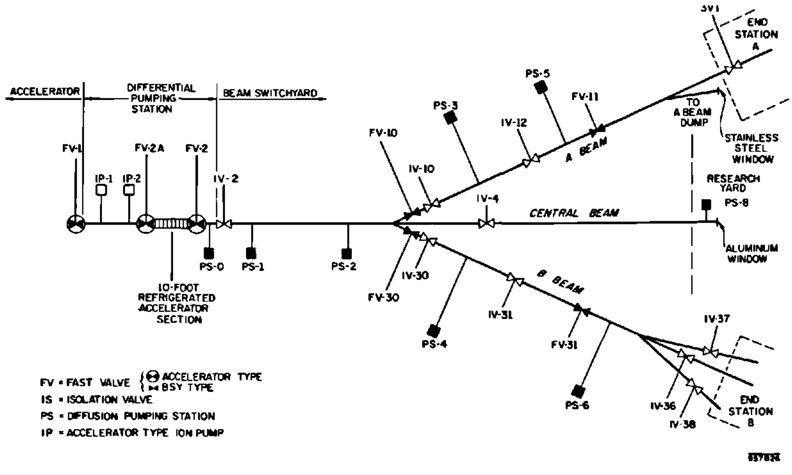


Table 23-1 Surface area and volume of chambers evacuated by beam switchyard vacuum pumping stations

Pumping station	*Area[a] in cm²*	*Volume[a] in liters*
PS-0	45,000	64
PS-1 and PS-2	3,490,000	67,460 (includes divergent chamber)
PS-3	1,420,000	12,600
PS-4	600,000	4,800
PS-5	720,000	1,150
PS-6	720,000	3,700
PS-8	720,000	1,200

[a] Areas and volumes of connecting "fingers" not included.

Taking the divergent chamber as the worst case and assuming pumpdown by PS-2 alone, the pressure at the chamber was calculated as follows:

Q = total gas load (torr-liter/second)
A = internal surface area (2.26×10^6 cm²) of the divergent chamber
q = outgassing rate (10^{-8} torr-liters/sec/cm² for clean unbaked aluminum)
P_1 = pressure at the chamber connection
S_1 = effective pumping speed at the chamber (150 liters/sec)

then

$$Q = A \times q = 2.26 \times 10^6 \text{ cm}^2 \times 10^{-8} \text{ torr-liter/sec/cm}^2$$
$$= 2.26 \times 10^{-2} \text{ torr-liter/sec}$$

and

$$P_1 = \frac{Q}{S_1} = \frac{2.26 \times 10^{-2} \text{ torr-liter/sec}}{150 \text{ liters/sec}} = 1.5 \times 10^{-4} \text{ torr}$$

Diffusion pumping stations (GIS)

Vacuum in the BSY is maintained by eight diffusion pumping stations, seven located at grade about 60 ft above the beam line and one in the research yard at the end of the central beam. The seven stations at grade each consist of a water-cooled 6-in. oil diffusion pump, a 6-in. baffle refrigerated to −25°C, a 65-ft³/min mechanical pump, and pneumatically operated valves in high vacuum, roughing, and forelines. A photograph of a typical system is shown in Fig. 23-27. The station in the research yard is essentially similar but incorporates a water-cooled baffle and a 15-ft³/min pump. Pressure is measured by a Bourdon gauge, a thermocouple gauge, and a cold cathode gauge on the

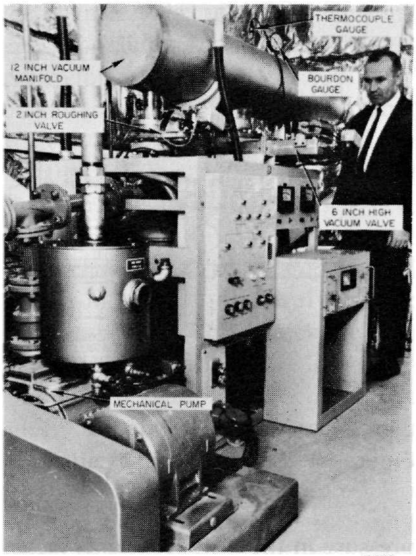


Figure 23-27 Beam switchyard vacuum pumping station.

high vacuum side and a thermocouple gauge on the foreline. Each station is interlocked in such a manner that if the mechanical pump stops, all valves will be closed and the diffusion pump will be shut off. The mechanical pump is interlocked with a cooling-water low-flow switch and a zero-speed switch. High pressure on the high vacuum side will close the 6-in. valve. An air reservoir with a check valve is provided at each station to operate the vacuum valves in the case of failure of the main air supply. Controls and switches for the pumps and valves are all locally mounted. However, the status of the pumps and valves and the indication from each cold cathode gauge is transmitted to the Data Assembly Building control room.

Differential pumping station (GIS)

The problem of connecting the "dirty" BSY system to the "clean" accelerator system and bridging the difference between 1×10^{-4} torr in the BSY and 5×10^{-7} torr in the accelerator was solved by using a differential pumping station. As shown in Fig. 23-28, this consists of a low conductance tube, a diffusion pumping station, a 10-ft accelerator section refrigerated to −30°C which serves as a high impedance oil trap, and a sputter-ion pump. A second sputter-ion pump is located about 100 ft upbeam. Accelerator-type beam-line fast valves FV-2A and FV-2 are located on either end of the refrigerated accelerator section. These valves close when pressure in the BSY rises to 10^{-2} torr, when refrigeration temperature rises above −10°C, or when

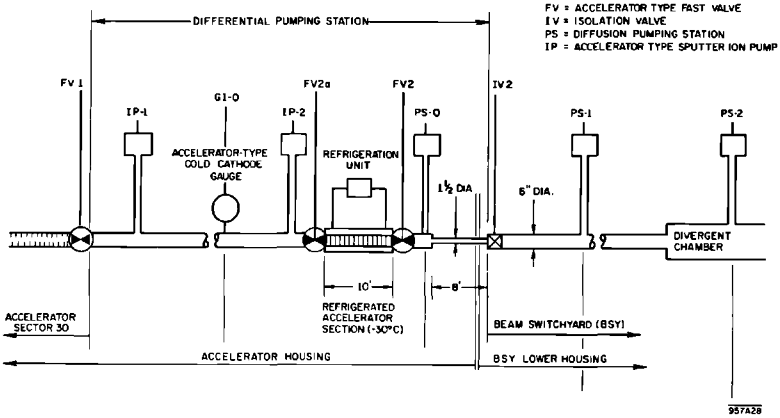


Figure 23-28 Schematic of differential pumping station.

pressure in the drift section as measured on gauge G1-0 rises to about 10^{-5} torr. Valve FV-1 at the end of Sector 30 is tripped simultaneously with FV-2A and FV-2. The refrigerated accelerator section is cooled by triethyl phosphate which is chilled by a conventional mechanical refrigeration system. Triethyl phosphate was selected for use in the BSY lower housing because it is resistant to radiation breakdown.

Tests showed that a pressure differential of five orders of magnitude is possible over the length of the station. The normal pressure differential at the present time is much smaller due to the absence of leaks in the BSY. Typical pressures are as follows:

Drift section between Sector 30 and BSY: 2×10^{-8} torr
First diffusion pumping station, PS-0: 2×10^{-7} torr
Second diffusion pumping station, PS-1: 5×10^{-7} torr

However, when the pressure at the next station downbeam (PS-2) rises due to an occasional leak in the BSY, a differential as great as three decades has been observed between the drift section and PS-1.

Calculations made from laboratory tests indicate that it will take about 20 yr to cover the last 10-ft section of the two-mile accelerator with a single layer of hydrocarbon molecules.[11]

Divergent chambers (FFH)

The divergent chamber is located at the downbeam end of a series of magnets which can be pulsed to switch a single or multiple beam received from the accelerator to one or more of the three beam paths shown in Fig. 23-26. The beams enter the 3-ft diameter chamber as the overall spread along the diverging paths approaches the capacity of the 12-in. upbeam pipe. After they have traveled the 220-ft length of the chamber, the adjacent beams are far enough apart to accommodate the pipes, couplings, and other equipment necessary to establish a separate vacuum envelope for each.

A 12-in. quick-disconnect coupling joins the upbeam pipe with the chamber. About halfway down the chamber, the cylindrical wall is offset in the direction of the A-beam and a separate 10-in. pipe is added to carry the B-beam. At the downbeam end of the chamber two 10-in. quick-disconnect couplings are provided, one for the A-beam and one for the B-beam, together with a 6-in. coupling for the central beam. The chamber is secured and aligned by two sets of adjustable jacks. One set is floor-mounted for vertical support; the other set is wall-mounted for horizontal restraint. The fourteen jacks in each set are mounted in pairs, one jack on each side of the center line.

Aluminum was selected for the chamber walls because it was believed less likely to fail from overheating than stainless steel should the electron beam accidentally be steered into the wall. The quick-disconnect half-couplings welded to the chamber at each end were also made out of aluminum.

The chamber was manufactured from 20-ft wide, $\frac{1}{2}$-in. thick, 5083 aluminum plates rolled into 20-ft long cylinders. Pairs of cylinders were welded into 40-ft sections which were checked for straightness and leaks before shipping to SLAC. The 40-ft sections were aligned in place at SLAC and preheated at the weld area prior to welding. The tungsten inert-gas process was used in making the five leak-tight circumferential field welds. The root pass was made from the inside. After x-ray examination and repair, subsequent passes were made from the outside. The completed welds were again x-rayed and necessary repairs were made.

Provisions were made to drain the chamber if a vacuum–water interface window at a beam dump should fail. The drain pipes were welded shut but can be cut open in the event of such an accident.

A second smaller divergent chamber was also installed in the B-leg of the BSY. It was fabricated of stainless steel in a manner similar to the vacuum piping described below.

Piping and bellows assemblies (GIS)

The vacuum piping which serves as the beam transport envelope in the BSY generally consists of 6-in., 10-in., and 12-in., schedule-five Type-304L stainless steel pipe. The one exception is the aluminum divergent chamber described in the previous section. Direct current magnet, quadrupole, and instrument chambers were made from Types-304L and -316L stainless steels, chosen for low magnetic permeability. Pulse magnet chambers were ceramic to prevent induction heating.

The three different sizes of pipes for the beam vacuum chambers were chosen to accommodate the various beam profiles. Type-304L stainless steel was chosen for the vacuum piping because it is essentially nonmagnetic, it could be readily welded or brazed to all initially planned BSY vacuum chambers except the aluminum divergent chamber, it is resistant to all corrosives in the contemplated environment, and its strength is adequate.

Sections of pipes were cut and chemically cleaned at the vendor's facility. Quick-disconnect half-couplings were welded to the pipe sections used to connect the magnets, slits, instrument stands, valves, and other removable beam-line equipment. The subassemblies were then leak-checked. After leak-checking, the ends were covered with plastic protectors and the complete lengths of pipe were wrapped in polyethylene sheet for shipment to SLAC.

Needless to say, the above-mentioned quick-disconnect couplings were quite expensive and for this reason the minimum possible number were used. Pipe sections not fitted with quick-disconnect half-couplings were assembled in the BSY lower housing and welded together. The tungsten inert-gas welding process was used to join stainless steel piping throughout the BSY vacuum system. Filler rod was used only on pipes with wall thicknesses over $\frac{1}{8}$ in.

Water cooling was provided for the chambers of the four bending magnets and the length of vacuum pipe leading into the A-Beam dump. This is an area where appreciable amounts of beam power can be absorbed on the chamber surfaces.

Due to the various sizes of pipes, certain sections had unequal axial loads. These loads were taken up by restraints extended from instrument or magnet stands.

To facilitate the replacement of beam-line equipment, the connection to the vacuum pipe at each end was through a stainless steel bellows fitted with mating quick-disconnect half-couplings. To remove the equipment, the bellows assemblies are first uncoupled and taken out. The equipment can then be unbolted and lifted off its mounting rails.

Connections between the beam chambers and piping in the BSY lower housing and the pumping stations on the top of the fill, some 60 ft above, were made of 20-in. schedule-10 Type-304L stainless steel pipes. These connections are called "vacuum fingers." All-metal $1\frac{1}{2}$ in. angle valves are provided in the upper housing for leak checking each finger.

Ten-inch double stainless steel bellows were used to connect the vacuum fingers in the lower housing to the beam line. These bellows were designed to accommodate a 3-in. radial displacement of the beam line. Because the two sputter-ion pump fingers at IP-1 and IP-2 and the first diffusion pump station finger at PS-0 are offset within the lower housing, the pair of bellows at the foot of each of these three fingers were gimballed to preclude damage to the drift piping due to relative movement of the vertical fingers.

Quick-disconnect couplings (ALE)

The ability to remove and replace vacuum equipment without undue exposure of personnel to a high radiation environment is an essential feature of accelerator design if beam off-time is to be minimized. To meet this

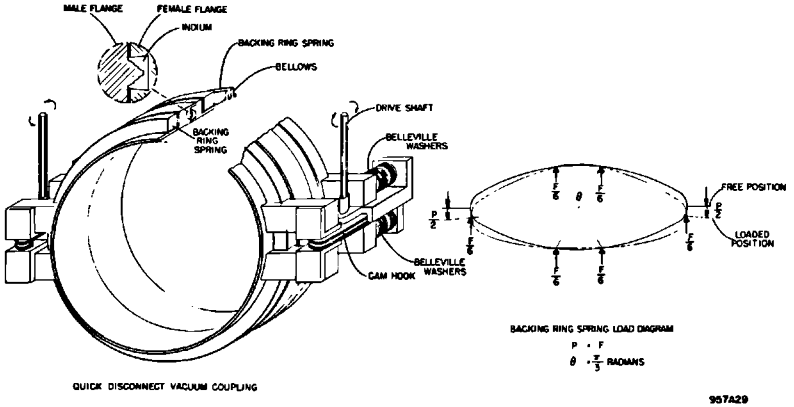


Figure 23-29 Quick-disconnect coupling.

requirement, vacuum equipment such as magnet vacuum chambers, beam analysis instruments, and drift pipes located in the BSY were equipped with quick-disconnect couplings.[6]

The couplings were built in 6-, 10-, and 12-in. pipe sizes. Figure 23-29 illustrates a typical coupling. The design is essentially the same for all three pipe sizes with the exception that the material cross section is changed to keep stresses constant. The couplings consist of two flanges, one containing an annular groove filled with indium. The other mating flange has a circular knife edge of a stepped, triangular cross section protruding from a flat face. The two flanges are pulled together, forcing the knife edge into the indium to make the seal.

The flanges are forced together by two rings which bear against the backs of the flanges at six places equally spaced about the rings. These rings are pulled together by two cam hooks which are operated simultaneously by rotating shafts extending vertically from the cam hooks. As the rings deflect, they distribute the load to the flanges at the six points of contact as shown in Fig. 23-29. The cam hooks are further spring-loaded by Belleville washers to compensate for the cold flow of the indium and to maintain a nominal loading of 100 lb/in. of seal.

To compensate for the lateral and angular misalignment of adjacent pieces of apparatus, the couplings are used in pairs, separated by a bellows as shown in Fig. 23-30. This arrangement accomplishes several things such as providing an allowance for a 3/16-in. lateral misalignment, 3° angular misalignment and a $\frac{1}{4}$-in. variation in the axial location of apparatus.

All pieces of equipment have a male coupling half on each end of their vacuum chambers. The bellows are welded between two female coupling halves. This allows for maximum flexibility in the placement of equipment and also permits remote inspection of the female flange halves of all joints that are uncoupled.

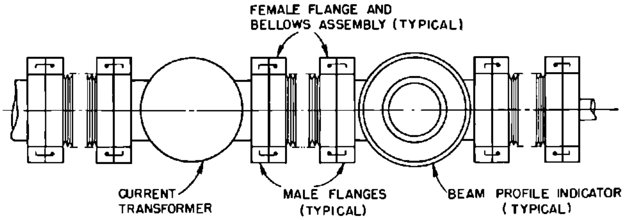


Figure 23-30 Typical coupling installation.

Beam-line isolation valves (GIS, SRC)

Pneumatic, cylinder-operated, all-metal valves are required in the BSY vacuum system to provide a means of automatically isolating an individual subsystem in the event of a sudden pressure rise and of manually isolating an individual subsystem for maintenance, repairs, equipment changes, and leak-checking.

The following criteria were established for the isolation valves. The valves were to be of all-metal, in-line construction. The minimum opening was to be 4 in. in diameter except for the valve which was initially installed immediately upstream of the A-beam dump and which required a 6-in. opening. Leakage across the seat against atmospheric pressure was to be less than 1×10^{-6} atm-cm^3/sec. The valve was to be remotely operable. A minimum service life of 500 cycles was required.

The valves were purchased to SLAC specifications and consist of a stainless steel welded body in which a carriage moves on roller bearings, carrying a seal plate. The seal consists of a copper sealing disk bearing against a stainless steel seat. Actuation is by means of an air cylinder. Two external microswitches are mounted on the air cylinder for remote indication of the gate position. The seals in the air cylinder are of graphite-filled asbestos. A photograph of a 4-in. valve is shown in Fig. 23-31.

The vacuum seals on the top plate and on the valve ports are of the Batzer[12] type, utilizing aluminum foil for the gaskets. Nine 4-in. valves are now installed in the BSY.

Beam-line fast-acting valves (GIS, SRC)

Fast valves are required downbeam of the differential pumping station to interrupt shock waves and flying debris resulting from sudden ruptures of beam-line windows. The criteria for the fast valves were as follows. They were to be of all-metal construction. The minimum opening was to be 4-in. in diameter. Closure time was to be 20–30 msec, but the valve need not be vacuum-tight. The valves were to be remotely operable. A minimum service life of 500 cycles was required.

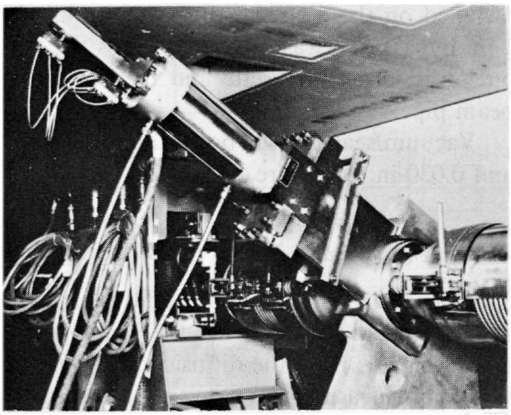
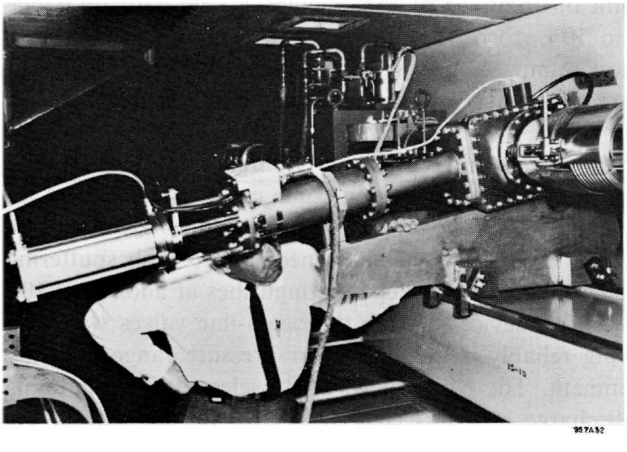


Figure 23-31 Beam switchyard isolation valve.

A photograph of the valve, which was procured commercially, is shown in Fig. 23-32. The valve body is a stainless-steel casting in which a machined aluminum plate, guided by two side rails, slides across the port. The aluminum plate is held in the open position, against the force of a compression spring, by a specially designed solenoid coil and an armature plate. Approximately 400 mA at less than 0.5 V dc is required to hold the gate open. When the current through the solenoid is suddenly interrupted, the compression spring forces the gate to close at a high velocity. Tests indicated a closure time of 22 to 28 msec. The energy of the moving masses is absorbed by Belleville washers. An air cylinder retracts the gate and recocks the spring. The "standard" valve was modified. An additional microswitch was installed in the body to indicate "gate closed." An actuating arm and microswitch were

Figure 23-32 Beam switchyard fast valve.



installed on the air recocking shaft to allow automatic recycling. Finally, a $\frac{1}{2}$-in. bypass line was provided across the valve gate to equalize the pressure on both sides of the gate and to eliminate any "trapped" volumes in the beam pipe.

Vacuum seals on the body and flanges of the valve are made from 0.020- and 0.030-in. gold wire.

Instrumentation and control (GIS, WBP)

The vacuum instrumentation and controls in the BSY interlock the valves and the beam and provide the Data Assembly Building with digital and analog signals from the diffusion pumping stations. Pressure at the pumping stations is measured by conventional gauges as described below. Due to the difficulty of maintenance in the high radiation environment, vacuum-sensing devices along the beam line are limited to the switches required to trip the fast and isolation valves.

Accidental letup to atmospheric pressure because of beam-line window rupture or puncture of the vacuum envelopes due to a missteered beam could generate shock waves within the vacuum piping. Under certain conditions, velocities of Mach 6 could be reached in the pipe and cause damage to delicate instruments and foils.[13] As described above, fast valves were, therefore, located at strategic places to protect these instruments.

All beam-line valves are interlocked with the beam permissive system so that the beam cannot be turned on until the valves are all fully open. If a valve gate starts moving toward its closed position, the beam is interrupted.

At the diffusion pumping stations, three sensors measure pressures ranging from 760 torr at the beginning of the roughing cycle to 10^{-7} torr during normal operation. A Bourdon gauge measures from 760 to 1 torr. A thermocouple gauge then measures from 1 to the 10^{-3} torr range. This thermocouple gauge is interlocked with the 6-in. valve on the high vacuum side of the diffusion pump so that the valve closes when the pressure exceeds the set point of about 10^{-2} torr. Finally, a cold cathode gauge measures from 10^{-4} to 10^{-7} torr. This gauge is located on the high vacuum side of the diffusion pump. A special control unit transmits an analog signal of this pressure to a meter with logarithmic readout in the Data Assembly Building control room.

The pressures in the BSY can be three or four orders of magnitude higher than in the accelerator and, in some cases, could extend into the 10^{-2} torr range where conventional hot cathode gauges are not suitable and the life of cold cathode gauges is shortened due to high sputtering rates. The discharge in cold cathode gauges extinguishes at about 2×10^{-2} torr.

A sensing device to close the beam-line valves was required, capable of operating reliably in the 10^{-2} torr pressure range and in a high radiation environment. The McClure switch[14] selected for this application utilizes a cold discharge and an electrostatic field for ionization. The device, shown

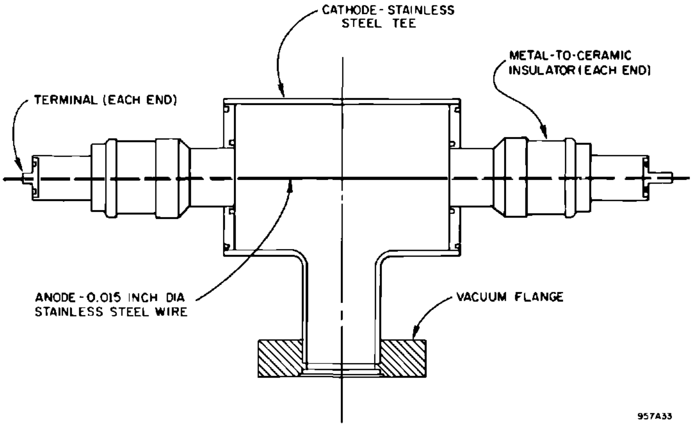


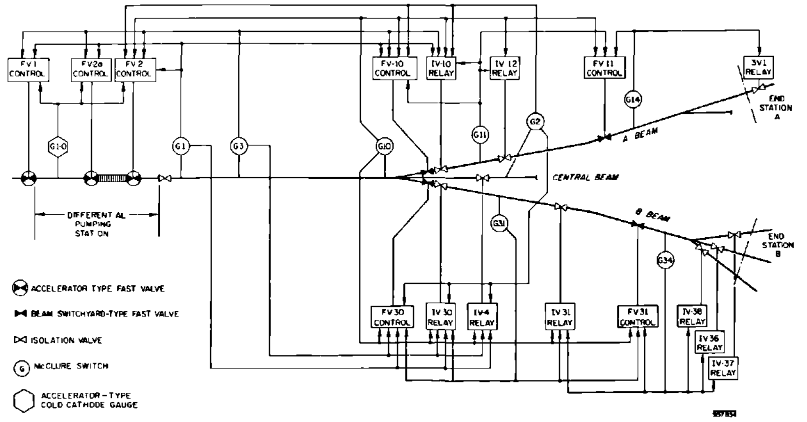
Figure 23-33 McClure switch.

in Fig. 23-33, is set to trip at 1 to 2 × 10^{-2} torr. It operates as a true "switch" with no readout capability.

In order to provide maximum protection for the BSY instruments, the McClure switches were installed at Cerenkov cells and other places particularly vulnerable to window rupture. The fast valves were located far enough away so that there would be time for them to close ahead of the shock waves. In general, each McClure switch closes whatever beam-line valves may be required to contain the pressure rise within a single subsystem. A diagram of the valve interlock chains is shown in Fig. 23-34.

Several interlocks are incorporated in the diffusion pumping stations. The foreline and high vacuum valves close if the pressure in the high vacuum manifold and in the foreline exceeds the set point of about 10^{-1} torr in the

Figure 23-34 McClure switch—valve interlocks.



foreline, and 10^{-2} torr in the high vacuum manifold. Temperature and water interlocks also protect the pump. All operations such as starting the pumps and opening the valves are done manually at the pumping stations. Remote indications are provided at the Data Assembly Building control room to indicate whether the mechanical pump is on or off, whether the diffusion pump is on or off, whether the high vacuum valve is closed, open, or moving, and whether the roughing valve is closed, open, or moving. A remote indication is also provided of the pressure at the cold cathode gauge on the high vacuum side of the diffusion pump.

All controls for the beam-line valves and the McClure switches are located in the Data Assembly Building control room. The isolation valves close on a trip signal from the McClure switches. They can also be closed by pressing a pushbutton on the panel. The fast valves close only from a trip signal.

An analog panel with meter readouts indicates pressure at each pumping station and also at the drift section between Sector 30 and the BSY. If the vacuum exceeds the set point, a flashing yellow light warns the operator of a pressure rise. This warning indication is also connected to the scanning system which prints out the fault data.

A temperature readout from the differential pumping station is also located at the Data Assembly Building control room. A relay on this meter closes the two fast valves on either side of the refrigerated accelerator section if the temperature exceeds the preset point of about $-10°$C.

The McClure switch controller contains a 0–2000 V variable high-voltage power supply and the electronics necessary to detect the switch closing. When a switch closure is detected, the controller generates a 25-V amplitude, 10-msec minimum width pulse used to close the fast valves. Each controller has parallel outputs for closing up to six fast valves. The controller also energizes a relay for 3 sec which is used to close the isolation valves. Each controller can close seven isolation valves at once. Once the switch has fired, the high voltage is removed from the switch until the controller is manually reset.

The controller incorporates four electronic components. A 2000-V power supply module with a variac on the input was obtained commercially. Electronic circuits detect the vacuum switch current and trigger a silicon-controlled rectifier used to generate the fast valve pulse and start the 3-sec relay closure. A reed-type relay is used with the interlock system to turn off the beam within 50 μsec of the switch firing. A meter on the front panel indicates the voltage on the switch, which determines the vacuum level at which the switch fires. The meter is of the meter relay type with the lower set point acting as an interlock, affording protection against operation with no high voltage on the switch.

The controllers for the fast valves are completely transistorized units powered from ± 24-V battery power supplies. A schematic diagram of the controller appears in Fig. 23-35.

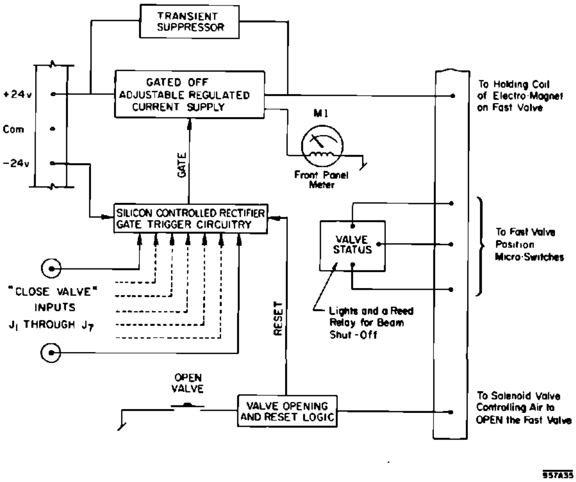


Figure 23-35 Beam switchyard fast valve controller.

The 400-mA current required to hold the valve open is supplied from a variable two-stage transistor constant current power supply. To close the valve, the holding current is reduced to zero in as small as possible time interval. This produces large transients across the solenoid coil and hence across the pass transistors. Two 75-V Zener diodes shunt the solenoid for voltage spike suppression. A 20-V Zener diode is required to permit a voltage drop to develop across the solenoid in the forward direction.

The control has a total of seven inputs and requires a 5-V, 2-μsec pulse. The holding current is reduced to zero by firing the silicon-controlled rectifier and back-biasing the first stage of the constant current power supply.

The front panel meter indicates the solenoid holding current. There are indicating lights showing valve position, open or closed, and ±24-V power on. Also located on the front panel is a "valve open" pushbutton switch which resets the electronics and energizes the necessary air solenoid for opening the valve. Because inadvertent closure of valves is to be avoided insofar as possible, there are no switches on the front panel for closing the valves or turning off the power supplies.

Operating experience (MEB, GIS)

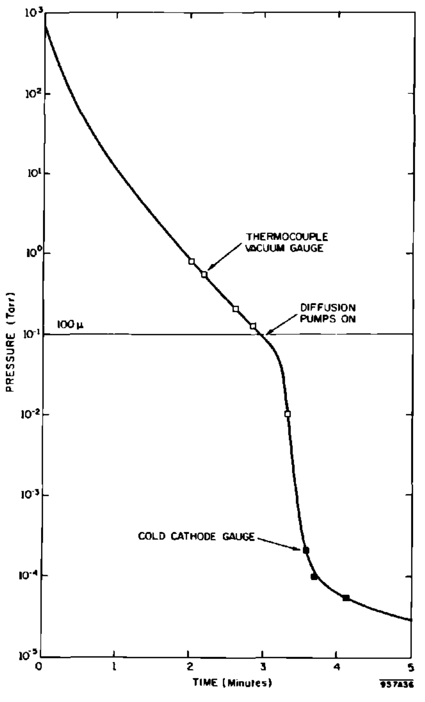
The operating experience acquired since initial startup of the subsystems indicates that all design criteria have been met or exceeded. The diffusion pump stations, using silicon oil and elastomer seals, produce base pressures of approximately 1.5×10^{-7} torr with the 6-in. gate valves closed. When operating with the valves open and with no detectable leaks, the pressures measured at the pump stations range from 2×10^{-7} to 1×10^{-6} torr. The variation is due to differences in the areas, volumes, and conductances.

The pumpdown times for the seven subsystems of the BSY also vary due to the differences in volume. Maintenance or repair work on a beamline component normally requires shutdown of only one, or in certain cases, two pump stations and the isolation of the corresponding subsystem in the lower housing. The time required to pump any one of these subsystems from atmospheric pressure down to an acceptable operating vacuum of, say, 5×10^{-4} torr is approximately 90 min. Pump stations PS-1 and PS-2, which serve the collimator, pulse magnet chambers, and the large divergent chamber, cannot be isolated from each other in the housing. Using these two pump stations only, the pumpdown time for the combined subsystem is approximately 3½ hours, as shown in Fig. 23-36.

The fast valves, isolation valves and vacuum switches installed in the beam line have generally been trouble free. During the first 7 months of operation, there was one fast valve failure due to seizing of internal parts and one isolation valve malfunction caused by a part displaced during shipment or installation. Although no record of closures has been kept, it is estimated that a typical valve might be cycled approximately 250 times per year.

The indium-sealed quick-disconnect couplings used throughout the BSY have proven to be extremely reliable. There have been instances when these

Figure 23-36
Beam switchyard pumpdown.



couplings leaked, but in almost all cases the leaks were caused by improper makeup, interference of the male or female pilots, or foreign material embedded in the indium. In some instances, joints have been made up leak-tight and remade as many as 3 or 4 times using the same indium. However, this is not a recommended procedure, particularly for 10- and 12-in. couplings, which leak approximately 50% of the time when the old indium is retained. The best practice is to replace the indium each time a joint is uncoupled. The experience to date has been that over 90% of the quick-disconnect joints made in the BSY are made up tight the first try.

Leak detection in the BSY has proven to be much easier than anticipated. One of the major reasons is that the quick-disconnect couplings either seal completely or leak quite badly. Most leak detection is done with the helium mass spectrometer leak detector connected to a 1½-inch all-metal valve on each vertical finger in the BSY upper housing. A valve has been provided at each pump station enabling the leak detector to be connected to the diffusion pump foreline. The connection in the housing proved to be the most useful simply because the person operating the helium probe can hear the audio response of the leak detector. It is also easier to move the leak detector by means of the overhead crane in the housing than to transport it from one pump station enclosure to another. The time from introduction of helium until a response is noted on the leak indication meter is typically about 5 sec. The time required for the indicator to return to its original or background level is from 1 to 5 min. These times are representative when leak-checking joints in a 6-in. pipe approximately 100 ft from the leak detector.

Acknowledgments

In addition to the authors noted under the chapter heading, many other people made significant contributions to the vacuum design. N. Carter worked on initial studies of vacuum system requirements. K. Trigger consulted on basic vacuum calculations and pump selection. E. L. Garwin was principal advisor on design details and equipment selection. R. B. Neal, H. DeStaebler, A. L. Eldredge, J. V. Lebacqz, and J. Jasberg were invaluable in furnishing design criteria for the accelerator vacuum system. W. Herrmannsfeldt developed design criteria for the alignment light pipe vacuum system. L. Schwarcz, P. Thingstad, and H. Weidner helped prepare beam switchyard vacuum system design criteria. U. K. Cummings conducted the tests for determining outgassing rates of RF processed OFHC copper as well as monitoring fabrication of components and assemblies. E. Hoyt conducted the tests on the "tree house" test facility and studies of outgassing rates for stainless steel. C. Hale was very helpful in preparing specifications for pumps and vacuum system fabrication and installation so that schedules could be maintained. G. Egg was extremely helpful in monitoring fabrication of klystron gallery 3- and 6-in. valves as well as the field installation of the accelerator vacuum system. A. Burch developed the basic design of the gallery

3- and 6-in. valves and was very helpful in working out details of adaptors and restraints for piping and bellows, as well as design of the beam switchyard divergent chamber. D. Cheng designed the refrigeration system for the beam switchyard differential pumping station. M. Heinz developed the basic design for the accelerator beam-line fast acting valves. R. Allyn developed the basic design for the beam switchyard quick-disconnect vacuum couplings. R. Callin is responsible for operation and maintenance of the accelerator vacuum system and K. Welch conducts engineering investigations of its operational problems.

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