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THE STANFORD TWO-MILE LINEAR ACCELERATOR VACUUM SYSTEM*

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Summary

The vacuum system of the Stanford two-mile linear accelerator has been designed as nominally a "very high" vacuum system operating in the 10^{-6} to 10^{-8} torr region. Main vacuum pumps are of the getter-ion type; the pumps are connected to an all-metal system fabricated of stainless steel except for viton "O" rings in the valve seats.

The accelerator structure evacuated by this system consists of OFHC copper rectangular and disk-loaded waveguides with stainless steel flanges connecting the various portions of the structure.

For completeness, a brief description of the vacuum system for the beam switchyard at the end of the accelerator is included because it is an integral part of the overall system. Conventional diffusion pumps are used to maintain pressures of 10^{-4} to 10^{-5} torr, i.e., nominally "high" vacuum.

General Description

The accelerator consists of disk-loaded waveguide connected to standard S-band waveguide; radiofrequency power for the accelerator is supplied by 240 klystron amplifier tubes. The disk-loaded waveguide, or accelerator pipe, is located in the underground accelerator housing which is separated by 25 feet of earth shielding from the parallel, above-ground klystron gallery. The gallery contains 240 klystrons, 240 modulators, 120 vacuum pumps, vacuum gauges, and other electronic, electrical, and mechanical equipment associated with the accelerator.

The rectangular waveguide has an internal cross section of 1.34 inches × 2.84 inches. The accelerator pipes have an internal diameter of approximately 3-1/2 inches; each 10-foot section contains 84 equally spaced disks with approximately 3/4-inch-diameter holes in the center of each disk.

Sector Subsystem

The accelerator is divided into thirty 333-1/3-foot long sectors. Each sector contains thirty-two 10-foot-long sections of accelerator pipe plus a 9-1/3-foot long drift section. Four 10-foot-long sections are mounted on a single 40-foot-long, 24-inch-diameter aluminum girder which is the main support for the accelerator as well as the alignment system sight tube. The 24-inch support girders are connected together by bellows and the articulated volume will be evacuated to 10^{-2} torr for alignment purposes.

A typical vacuum subsystem for a 333-1/3-foot sector is shown in Fig. 1. Each subsystem is independent, and the only vacuum connections between sectors are via the continuous accelerator pipe. Four getter-ion pumps, each rated at 500 liters/second, are connected by 6-inch valves to a longitudinal 8-inch manifold in the klystron gallery, extending the full length of the sector. A longitudinal 5-inch manifold is located in the accelerator housing. The 8-inch and 5-inch manifolds are interconnected by four 8-inch fingers spaced approximately 80 feet apart, passing through 27-inch i.d. service shafts.

Four-inch branches with 3-inch valves connect the klystron window pumpouts to the 8-inch manifold on approximately 40-foot centers. Provisions are made for 24 future klystron connections in each sector. Accelerator pipe pumpouts located at each of the 32 input couplers of rectangular waveguide to accelerator pipe are connected to the 5-inch sector manifold.

A five-inch "finger" connects the 8-inch manifold to a 10-foot-long drift section in the accelerator housing. This drift section contains beam monitoring and guidance apparatus. The drift section can be isolated from the main vacuum system by closing a 3-inch "finger" valve (similar to the klystron valves) and the valves in line with the accelerator at both ends of the drift section. The upstream in-line valve is a manual valve and the downstream valve at the end of the drift section is a fast acting valve which closes in 10 msec.[1] The fast acting valves close automatically to isolate a sector from the rest of the machine in the event of accidental loss of vacuum in that sector.

Each klystron is evacuated separately and isolated from the main vacuum system by waveguide windows. A waveguide valve[1] located in the rectangular waveguide approximately two feet above this window permits replacement of klystrons without interrupting accelerator operations.

Accelerator Vacuum Requirements

Design Pressures

Evacuation of the accelerator is required primarily for two reasons:

1. To prevent electrical breakdown in the high (2856 Mc/sec) radiofrequency fields used to accelerate the electrons.
2. To prevent excessive scattering of the electrons by residual gas molecules in transit through the disk-loaded waveguide.

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Theoretical considerations borne out by practical experience show that a pressure of 10^{-6} torr or less will provide reliable operation and prevent rf breakdown. A pressure of less than 1×10^{-5} torr is adequate to prevent electron scattering. For the purposes of design, the objective is a pressure of 5×10^{-7} torr in the center of the accelerator pipe.

The accelerator proper is inherently conductance limited, having a conductance of approximately one liter per second from the center of a 10-foot accelerator section to the pumpout location. To provide adequate pumping speed for gas bursts, the vacuum piping was designed to provide a minimum of 10 liters per second pumping speed at each accelerator pipe pumpout. For the critical region of the klystron window a pumping speed of approximately 20 liters per second has been provided. With the final configuration of the system, pressure distribution is:

Center of accelerator pipe	5×10^{-7} torr
Waveguide at klystron window	5×10^{-8} torr
Getter-ion pumps	1×10^{-8} torr

Other System Requirements

Other limitations imposed on the design were:

1. No organic materials were to be located in the accelerator housing.
2. An all-metal system was to be used, if possible, in order to minimize maintenance.
3. The system must be virtually oil free.
4. Life of major components had to be greater than 10 years.
5. Equipment requiring servicing was to be located in the klystron gallery due to the high radiation environment in the accelerator housing.

Vacuum System Components

System Materials and Assembly

The long pumping paths and low inherent conductances dictated that a clean system with a minimum of real and virtual leaks must be provided in order to minimize the size and related cost of pumps. The main vacuum pumps are of the getter-ion type. System materials are: (1) 304L stainless steel for piping, flanges and valves; (2) OFHC copper for the waveguides and flange gaskets; and (3) viton "O" ring seat seals in valves. Welded connections, rather than bolted flanges, are used where possible for reliability. The stainless steel components are chemically cleaned and baked out as 40-foot manifold assemblies at 400°C under vacuum prior to installation. The viton "O" rings used for valve seat seals are baked in a vacuum furnace. The OFHC copper rectangular and disk-loaded waveguides are chemically cleaned and processed at full rf power prior to installation.

During fabrication, components are handled in pressurized clean rooms with filtered air supply. Forty-foot long, 8-inch and 5-inch manifold assemblies are delivered to the field sealed and backfilled with dry nitrogen. The 5-inch manifold assemblies are installed on the 24-inch support girders and connected to the waveguides in the SLAC shops. During field installation, a positive pressure of dry nitrogen is maintained on the interior.

Shown in Fig. 2 are the special adapters used to connect pipe to bellows and for joints made in the field. The adapters used for the latter purpose are attached to the bakeout plugs and have a 90-degree V groove 1/8-inch from the outer edge. 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 is made at the new edge.

Bellows are provided to: (1) allow for thermal expansion; (2) prevent excessive loading of the accelerator structure, particularly during alignment; and (3) to facilitate installation. There are a total of 90 eight-inch bellows and1920 five-inch bellows in the stainless steel manifolds. Located between 40-foot accelerator pipe increments are one-inch bellows.

A photograph of a typical 5-inch manifold installed on a 40-foot module, which consists of the accelerator pipe, 24-inch support girder, and 5-inch manifold, is shown in Fig. 3.

High Vacuum Pumps

Two types of pumps which appeared to be most applicable were considered during the preliminary design, i.e., getter-ion pumps and oil diffusion pumps baffled by molecular sieve traps with mechanical backing pumps. The cost of the diffusion pump scheme appeared to be 5% less than for the getter-ion pump scheme. However, the total power demand during high vacuum operation was 400 kW for diffusion pumps versus 12 kW for ion pumps, which constituted a significant cost savings over a 10-year period. This, coupled with the obvious advantages of getter-ion pumps, such as elimination of contamination due to diffusion pump oil from normal operation and accidents, minimum attendance, and simplified operation, formed the basis for the selection of getter-ion pumps.

Applicability of getter-ion pumps was proved to be sound based on tests conducted over a six-month period on a test facility consisting of one 40-foot module of the accelerator. During these tests, 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 getter-ion pumps inherently have a pumping speed for H_2 twice that for air, the desirability of their use on the accelerator was enhanced.

Pumping speeds were predicated on a total gas load per sector of 4.8×10^{-6} torr liter/sec from the copper waveguide and 1.5×10^{-6} torr liter/sec from the stainless steel piping. Measurements made at SLAC showed that an outgassing rate of less than 4×10^{-12} torr liter/sec/cm^2 for the copper system could be expected when the system was maintained at its normal operating temperature of 45°C and after a reasonable period of rf operation. Residual outgassing rates of stainless steel baked initially at 400°C for 24 hours are less than 1×10^{-12} torr liter/sec/cm^2 as measured at SLAC and reported elsewhere in the literature.

The area exposed to vacuum per sector is 1.2×10^6 cm^2 for copper and 1.5×10^6 cm^2 for stainless steel. (Total for the machine is 36×10^6 cm^2 for copper and 45×10^6 cm^2 for stainless steel.) Leaks are not significant because the majority of joints are welded, and leaks above 1×10^{-9} std cc/sec for a 40-foot increment are not tolerated. A total gas handling capacity of 2×10^{-5} torr liter/sec at 1×10^{-8} torr pump pressure is provided per sector to accommodate the ultimate equilibrium gas load from the copper, stainless steel, and viton valve seats, with a factor of two allowed for intangibles.

Stainless Steel Valves

To isolate getter-ion pumps and for sector roughing, approximately 150 six-inch valves are required. In addition, approximately 270 three-inch valves are used to isolate klystrons and for isolation of drift sections. Each of these valves is equipped with a one-inch roughing valve. All valves are angle type. Cost considerations precluded the use of all-metal stainless steel valves and led to the selection of viton A "O" rings for seat seals. All other valve material exposed to vacuum is 304L stainless steel. Flanges with gold "O" rings and bellows-sealed valve stems isolate the valve interior from atmosphere.

Vacuum Gauges

Some 270 gauges are required to monitor pressure along the accelerator. In view of this great number of units and because accurate measurement of vacuum is not required, reliability and stability have been stressed rather than accuracy. Cold cathode gauges were selected because they are, in principle, longer lived and more rugged than hot filament ionization gauges. Also, the sensitivity of the cold cathode gauge is an order of magnitude higher than for the hot cathode gauge. This factor, in conjunction with the elimination of the hot filament, simplifies the electronics of the control unit and results in higher reliability.

Gauges are located at each klystron window pumpout and on each sector manifold. The manifold pressure reading is transmitted to central control. Special control units are being built to SLAC specifications. The current amplifier is a compressed scale type which allows presentation of the vacuum range from 10^{-9} to 10^{-4} torr on the meter face without switching scales. Discriminator are provided for the following functions:

1. To prevent klystron operation in the event of gauge failure.
2. To prevent klystron operation if pressure exceeds a locally adjustable level ($\approx 1 \times 10^{-6}$ torr).
3. To inhibit the electron beam and to close fast acting accelerator valves in case of a catastrophic vacuum failure.
4. To protect the gauge tube from overpressure (above 1×10^{-4} torr) by removing the high voltage from the gauge.

Functions (2) and (3) have been combined into one discriminator circuit with two outputs. One output operates a form C relay for klystron protection The other output bypasses the relay and has a maximum response time of 2 milliseconds for actuation of the accelerator fast acting valves. The control units are interchangeable between klystron and sector manifold gauges.

Main Roughing Pumps

Each sector has a volume of approximately 9,000 liters and is roughed individually with portable units. Each unit consists of a combination of a 50-cfm mechanical pump operating from atmosphere to 50 torr and two 150-pound cryosorption pumps from 50 torr to below 1×10^{-3} torr. If there are no gross leaks, a pressure of 2×10^{-4} torr can be attained in approximately 90 minutes, at which point the getter-ion pumps are turned on. A prototype cryosorption pumping system, less the mechanical pump, is shown in Fig. 4.

Klystron Replacement

There are 240 klystrons, each having an anticipated life of 2,000 hours, so that three to four klystrons per standard eight-hout working day will require replacement. To remove a klystron, the 3-inch valve connecting to the 8-inch manifold and the waveguide valve are closed. When the new klystron has been installed, the five-liter volume confined by the 3-inch and waveguide valves and the klystron windows is roughed through the one-inch roughing valve to approximately 5×10^{-4} torr by means of two 2-pound cryosorption pumps operated in sequence. This pumpdown procedure takes approximately two to five minutes when the region has been purged with dry nitrogen and the sorbent material has been reactivated.

Beam Switchyard

The beam switchyard vacuum system located beyond the accelerator is shown schematically in Fig. 5. The beam switchyard array is very complex, involving many magnet chambers, protection and monitoring devices, collimators, slits, and beam dumps. With the complexity of the system and the limitations imposed by the requirement for remote handling due to the high radiation environment, it is improbable that cleanliness and complete vacuum integrity can be maintained as well as is possible in the accelerator. Fortunately, vacuum requirements are not as rigorous in this area so that a pressure of approximately 1×10^{-4} torr is adequate.

Vacuum pressure will be maintained by seven conventional oil diffusion pump systems located at grade about 50 feet above the electron beam centerline. Each system consists of a 6-inch diffusion pump, refrigerated trap in the high vacuum line, 30 liter/second mechanical pump and pneumatically operated valves in both high vacuum lines and forelines. Twenty-inch stainless steel pipes connect to the aluminum and stainless steel switchyard beam tube system.

A differential pumping system is located between the beam switchyard and the accelerator and consists of two getter-ion pumps and two oil diffusion pumps separated by tubes having low conductances. A standard 10-foot accelerator section refrigerated to -30°C provides the low conductance path for the second stage of the differential pumping station and also traps diffusion pump oil.[2]

Fast acting valves[3] capable of closing in approximately 10 milliseconds are located such that they can isolate strategic sections of the switchyard and can protect critical equipment from catastrophes caused by window rupture at beam dumps or penetration of the vacuum envelope by a missteered electron beam. The valves are operated from both piezo-electric crystal detectors and McClure switches. The former are capable of sensing sudden rises in pressure from shock wave effects. The latter sense slower rises in pressure and act as a back-up for the piezo-electric detectors. Remotely operated all-metal valves are also provided in order to isolate sections of the switchyard for maintenance purposes.

List of References

1. R. J. Allyn, A. J. Keicher, "Microwave and Fast-Acting Valves and Vacuum Couplings for Accelerators", Paper G-8, IEEE Particle Accelerator Conference, Washington, D.C., March 10-12, 1965.

2. E. W. Hoyt and E. L. Garwin, "Accelerator Vacuum Problems: Beam Switchyard Differential Pumping and Oil Trapping Tests," Paper GG-20, IEEE Particle Accelerator Conference, Washington, D.C., March 10-12, 1965.

3. J. Boyd, "Fast All-Metal Six-Inch Valve," Paper GG-21, IEEE Particle Accelerator Conference, Washington, D.C., March 10-12, 1965.

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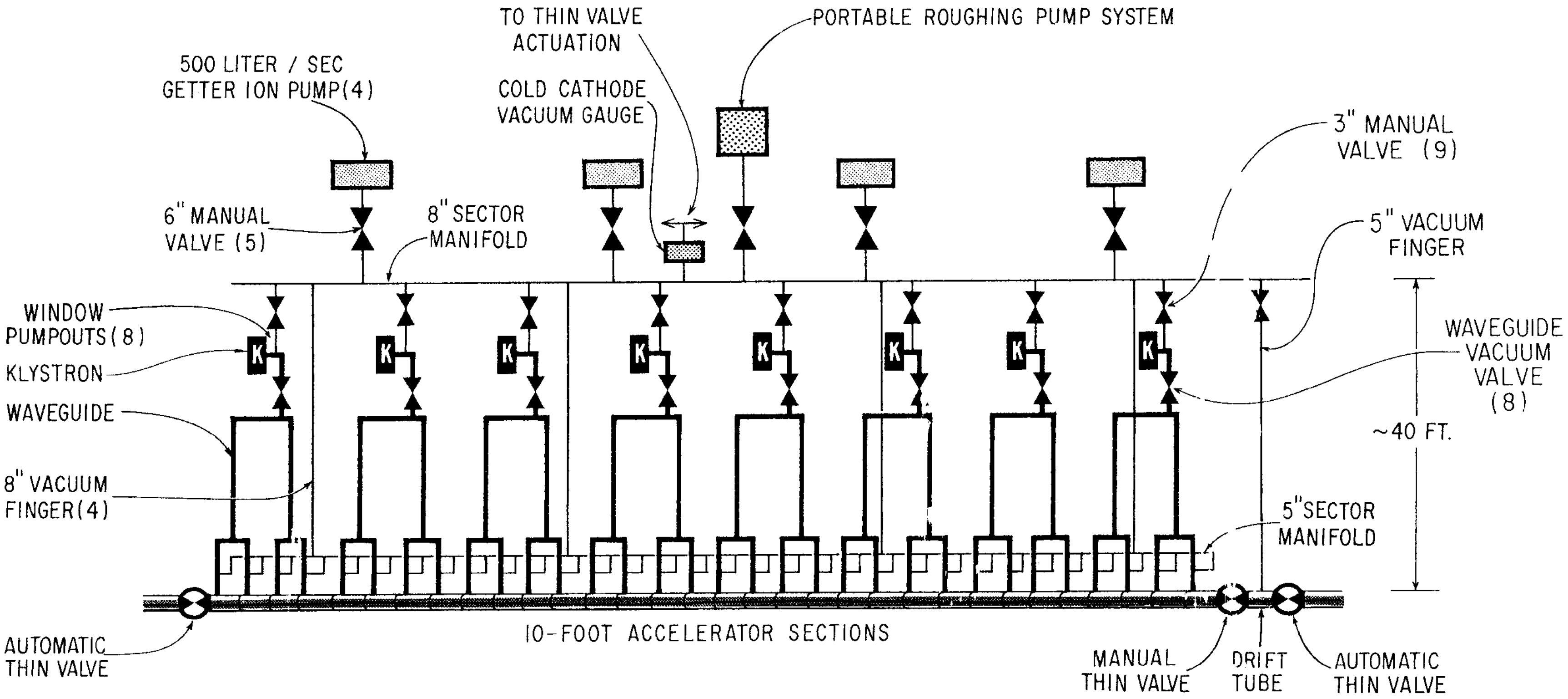

VACUUM SYSTEM SCHEMATIC FOR ONE 333-FT SECTOR

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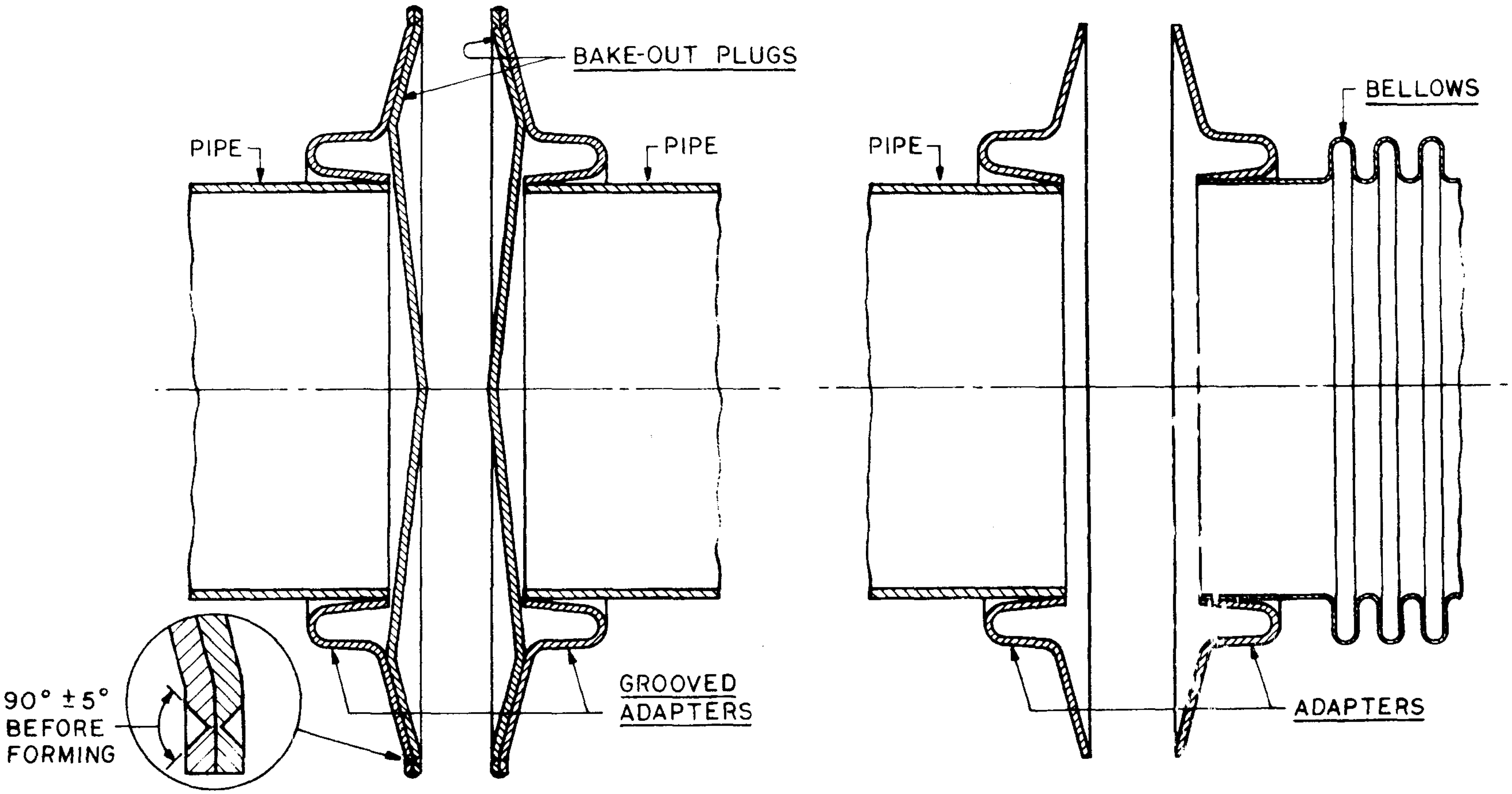
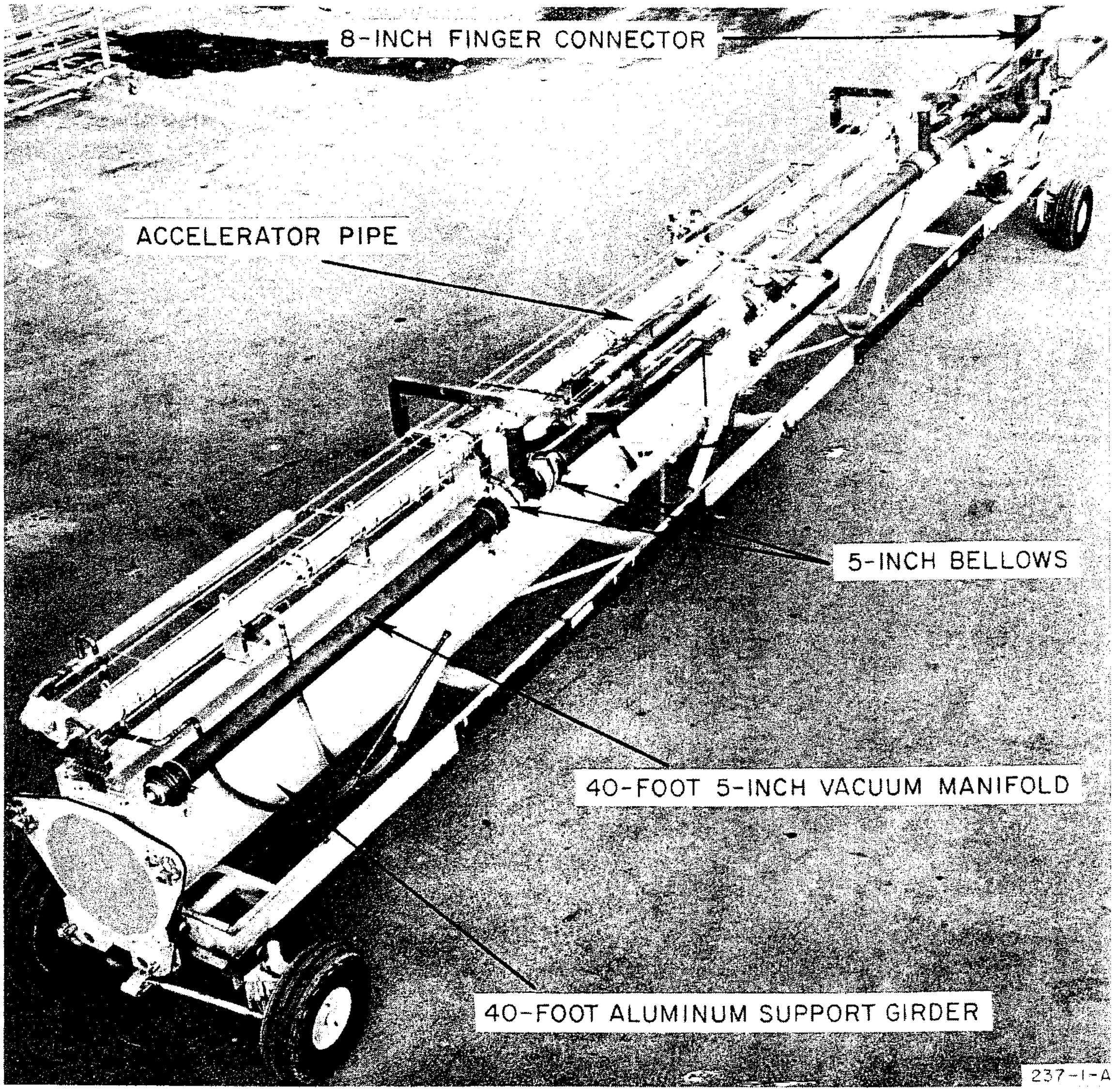
Fig. 1



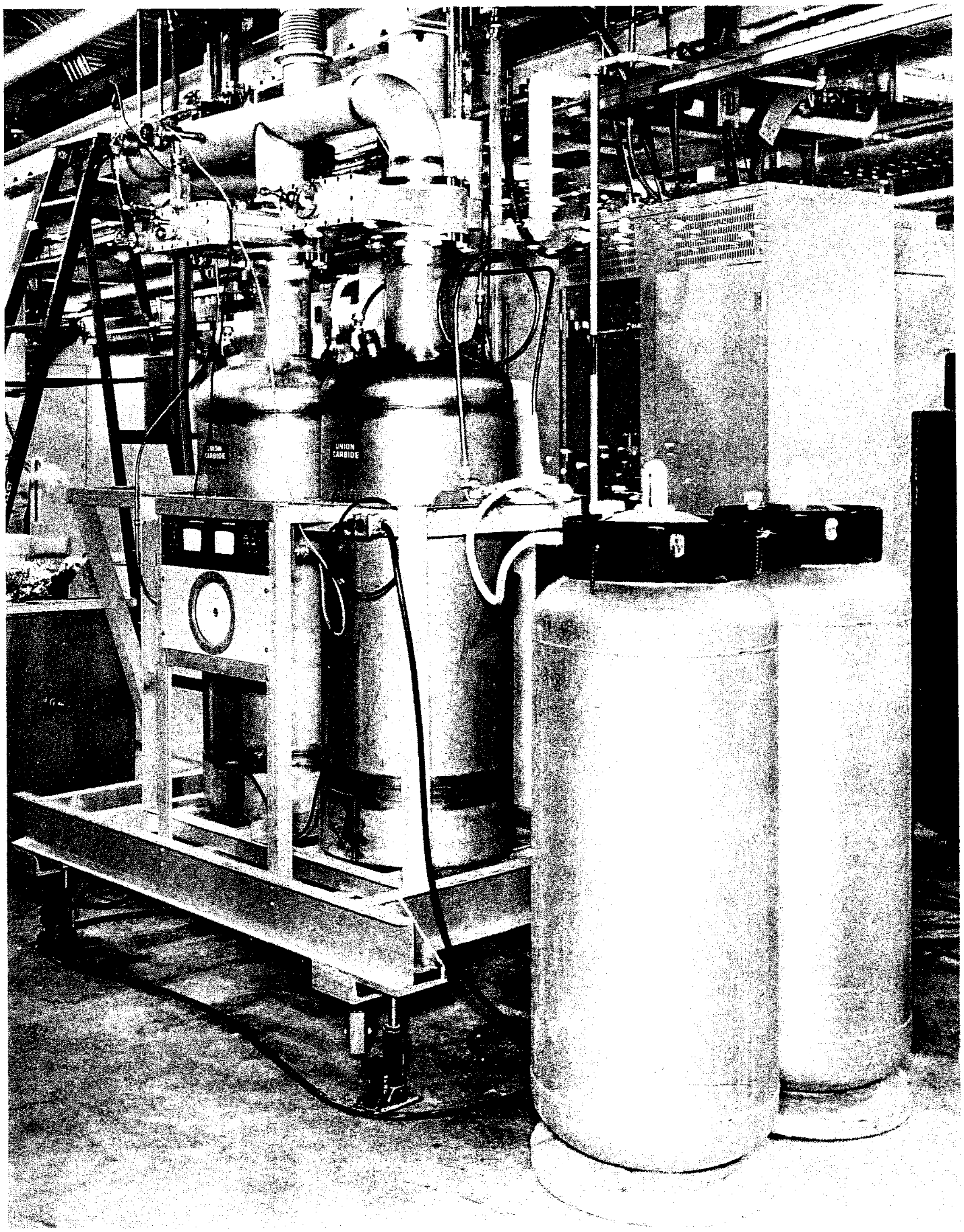
SHOP WELDED ADAPTERS & BAKE-OUT PLUGS BEFORE FIELD ASSEMBLY

SHOP WELDED ADAPTERS BEFORE SHOP ASSEMBLY

FIG. 2



3. Photograph of typical 5-inch vacuum manifold installed on 40-foot accelerator module.



4. Prototype cryosorption pumping system (not shown: mechanical pump).

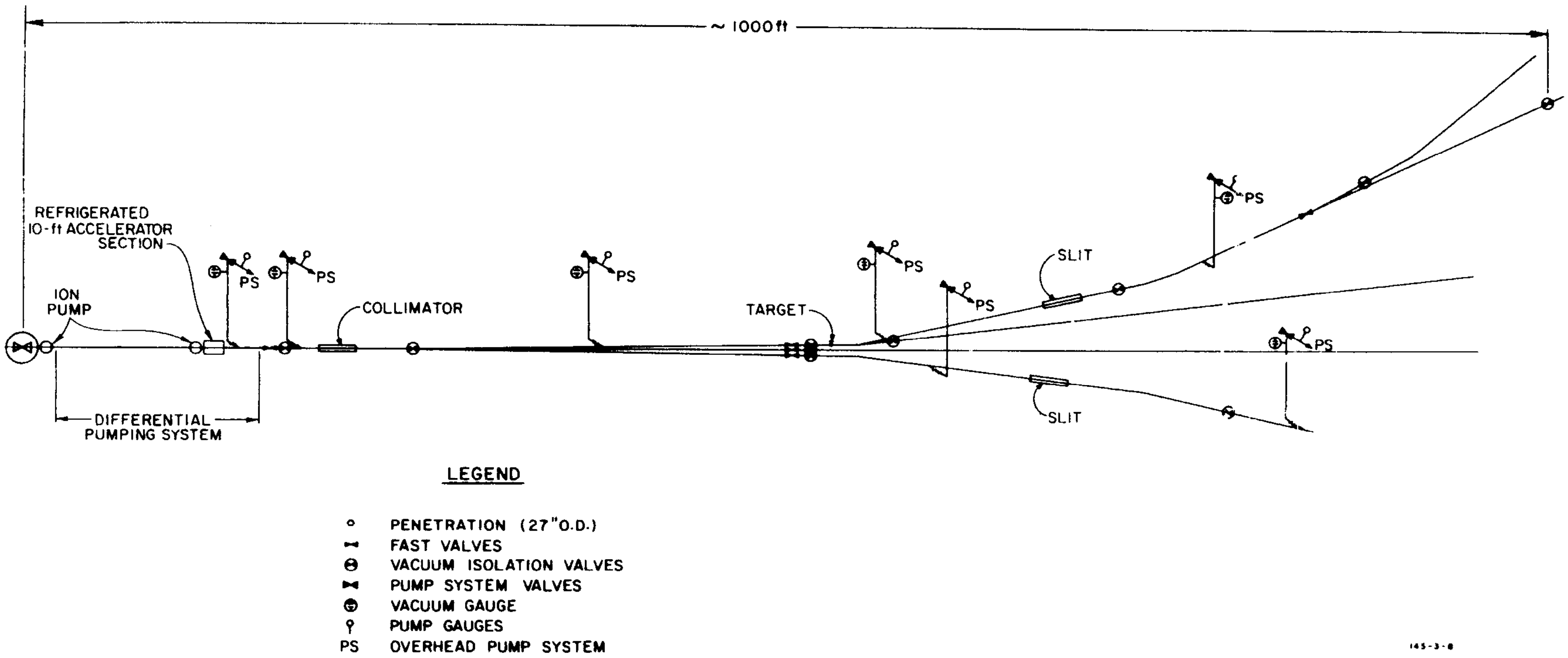


FIG. 5 - B.S.Y. VACUUM SYSTEM SCHEMATIC